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Good, bad or 'necessary evil'? Reinterpreting the colonial burning experiments in the savanna landscapes of West Africa

PAUL LARIS* AND DAVID ANDREW WARDELL†‡

**Department of Geography, California State University, Long Beach, 1250 Bellflower Blvd, Long Beach, CA 90840, USA*

E-mail: plaris@csulb.edu

†Institute of Geography, University of Copenhagen, Øster Voldgade 10, DK 1350 Copenhagen K, Denmark

‡Centre for World Environmental History, University of Sussex

E-mail: daw@geogr.ku.dk

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A simple ecological model underlies contemporary fire policy in many West African countries. The model holds that the timing (or seasonality) of annual savanna fires is a principal determinant of vegetation cover. The model's origin can be traced to the ideas held by influential colonial scientists who viewed anthropogenic fire as a prime force of regional environmental degradation. The main evidence in support of the model derives from the results of a series of long-term burning experiments carried out during last century. The experimental results have been repeatedly mapped onto fire policy often taking the form of a three-tiered model in which fire exclusion is considered the ultimate management objective, late dry-season fire is discouraged and early dry-season fire is allowed but only under specific, often state-controlled circumstances. This paper provides a critique of contemporary fire policy in the region and the fire ecology model on which it is based. Through an analysis of burn scars for the 2002–3 fire season generated from ETM+ imagery, the study documents the spatiotemporal pattern of burning for an area in southern Mali. It argues that current policy, which is informed by an a-spatial model, cannot adequately account for the critical pattern of burning that is characteristic of the region. A reinterpretation of the burning experiments is presented in light of four factors: empirical data; recent developments in patch-mosaic theory; historical evidence on the effects of fire suppression; and data on indigenous burning strategies, all of which suggest a need to reconsider current fire policy.

KEY WORDS: Mali, West Africa, savanna, fire policy, colonial science, remote sensing

Introduction

Fire policy in West Africa has been the source of longstanding and sometimes violent conflict between rural populations and government agencies. Since the colonial era, governments have striven to reduce the amount of savanna and woodlands burned by setting policies that restrict fire use (Fairhead and Leach 1996; Pyne 1997; Laris 2004; Wardell *et al.* 2004). Rural inhabitants have often reacted to suppression policies by resisting restrictions and continuing to set fires, sometimes covertly (Pyne 1997; Kull 2004; Laris 2004). Throughout West Africa, a century-long effort to promote anti-fire legislation, to impose sanctions, and to conduct educational awareness campaigns has failed to result in significant changes in indigenous burning practices or in a reduction in the annual area burned. Not surprisingly, the effort has increased the tension and conflict between the rural population and the forest service just as it has elsewhere (e.g. Pyne 1997; Kull 2004). Yet, the fire policies in many West African countries remain resolutely anti-fire

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(Fairhead and Leach 1995; Schmitz *et al.* 1996; Bassett and Zuéli 2000; Goldammer and de Ronde 2004; Wardell *et al.* 2004; Republic du Mali undated).

Since the middle of the last century, fire policy in the region has been guided by a simple yet influential savanna fire ecology model – the effects of fire on vegetation can be determined largely by the timing (seasonality) of fire, especially when burning is an annual or biannual event. The model – hereafter referred to as the 'fire triad' – has a three-tiered structure which is derived from the results of several long-term empirical studies of different fire treatments – total fire protection, early burning and late burning. The experiments, which were largely conducted during the early and mid-twentieth century, have demonstrated that over the long term a regime of late dry season (LDS) fires creates a landscape with a low tree/grass ratio; fire suppression creates a landscape with a high ratio while a regime of early dry season (EDS) fires creates a landscape with a moderate ratio. The results of these experiments are especially important because they provide the only quantitative long-term (decadal-scale) data on the impact of different fire regimes on vegetation structure.

Savanna fires, often referred to as bush fires or *feux de brousse*, are ground fires that operate on the landscape scale. They primarily consume dead and dying grasses, tree litter, shrubs, and small trees. They are set for a variety of purposes, but should not be confused with fires set to burn plots for slash and burn agriculture. Savanna fires are distinguished from agricultural fires in that they are broadcast fires that primarily burn standing (un-cut) vegetation[1]. It is widely recognized that periodic fires, which regularly burn through much of the world's savannas, are the major disturbance regime in these environments and that disturbances are critical determinants of vegetation structure (Menault and Cesar 1982; Cole 1986; van Wilgen *et al.* 1997; Scholes and Archer 1997; Mistry 2000, Wiegand *et al.* 2006).

The perceived fire problem in West African savannas has historically been defined in terms of fire's negative impact on tree cover because woodlands were highly valued by colonial governments and deemed by influential colonial botanists to be the natural vegetation cover for the region (Chipp 1922; Bégué 1937; Aubréville 1947; Fairhead and Leach 1996). Indigenous fire use has generally been viewed as careless and damaging, especially to woodland cover. Indeed, several influential colonial scientists considered indigenous use of fire an 'evil' practice that was steadily converting woodlands into degraded savanna grasslands (e.g. Stebbing 1937; Aubréville 1947).

The rationale behind contemporary fire policies in numerous countries is built on this anti-fire view and bolstered by the findings of the burning experiments. As such, policy often takes a hierarchical form in which fire exclusion is considered the ultimate management objective; late fire is actively discouraged and often illegal; and early fire is acceptable as a 'necessary evil', but only under specific, controlled circumstances. For example, the Malian fire code allows early burning as long as appropriate fire control measures are taken and a permit is acquired, but it prohibits late fires (Republic du Mali undated). Similar policies regulate fire in numerous other West African countries (e.g. Fairhead and Leach 1995; Bassett and Zuéli 2000; Wardell *et al.* 2004).

There is no doubt that frequent burning has deeply influenced the biogeography of the region. Archaeological evidence dates the introduction of wide-scale firing of the African savanna at 400 000 years ago (Bird and Cali 1998). Many questions remain, however, particularly regarding the nature of indigenous burning regimes, their underlying logic and the role of social institutions governing the customary use of fire, their benefits and costs to society, and their long-term biogeographical consequences.

One emerging ecological paradigm in particular raises questions about the appropriateness of contemporary fire policy in West Africa and the continued use of the fire triad model to guide policy. This new perspective argues that landscape heterogeneity rather than homogeneity is a key source of biodiversity and ecosystem resilience (Pickett *et al.* 1997). As such, disturbances such as fire, which produce spatial and temporal heterogeneity on the landscape, are recognized as critical for ecosystem health (White and Picket 1985; Turner 1989). According to the 'patch-mosaic' paradigm, the spatiotemporal pattern of burning (and not simply fire timing) affects ecosystem function and can result in different vegetation outcomes. For example, a regime of small, fragmented, patch-mosaic fires, which divides the landscape into patches of burned and unburned vegetation, produces different vegetation formations than that of a regime of large, contiguous fires. Such mosaic burning regimes are thought to have at least two ecological effects that are considered beneficial: first, they reduce potential for a large, destructive, uncontrolled fire later in the season; and second, they create edges – boundaries of ecological areas – that tend to increase ecosystem biodiversity (Russell-Smith *et al.* 1997b; Parr and Brockett 1999; Brockett *et al.* 2001). Indeed, mosaic burning has been deemed so critical to ecosystem management that land managers in several savanna environments are working to reintroduce it (Brockett *et al.* 2001; Trollope and Trollope 2004). Surprisingly, this shift in thinking and policy has been largely overlooked by West African policy-makers despite the growing body of evidence documenting mosaic burning patterns in the region (Mbow *et al.* 2000; Bucini and Lambin 2002; Laris 2002).

There is clearly a need to rethink fire policies (and the ecological model that supports them) in West Africa in light of the failure of past policies, new data on the spatiotemporal patterns of fires generated from remotely sensed imagery, and the emergence of new biogeographical theory on the role of mosaic fire regimes. The objectives of this paper are as follows:

1 to provide a critical review of the burning experiments by tracing their intellectual origins, evaluating published experimental results, exploring how findings were translated into policy, and examining the impacts of the resultant fire policies;
2 to reinterpret the experimental results based on patch-mosaic theory and new empirical data on the spatiotemporal pattern of indigenous burning regimes using a case study from southern Mali; and
3 to suggest changes in fire policy. The paper argues that the fire triad model is problematic in two ways. First, the a-spatial nature of the model ignores a critical aspect of the indigenous fire regime – the importance of early burning for creating a landscape mosaic with many uses for multiple user groups. Second, the model is based on the notion that tree preservation should be the main objective of fire regulation in savannas – an ideal that is rooted in colonial views and which reflects colonial values rather than indigenous ones.

The burning experiments

> Now that the curse which has been plaguing Africa has been identified, it is imperative that measures be taken to counteract the evil . . . Restrictions must be imposed to limit indiscriminant burning
>
> Aubréville 1947, 11

Origins of colonial fire policy

Fire policy in West Africa has its origins in colonial forestry. Colonial forestry departments were created to oversee the establishment of national networks of forest reserves often on the pretext of climatic stabilization or micro-climatic regulation, the enhancement of timber production in higher rainfall zones, the control of fuelwood production in the Sudano-Sahelian zones, and the introduction of scientific methods to regulate the use and impacts of fire. A key issue was the elimination of all human and natural hazards, including the perceived threat of fire-induced vegetation change to local climate, hydrology, land productivity, and the downstream flows of major river basins such as the Niger and the Volta. These concerns underpinned the construction of West African colonial discourses on forest degradation from the late 1800s (Moloney 1887; Kemball 1905; Vuillet 1907). The threat posed by savanna fires implicated in the processes of 'savannization', the formation of 'derived savannas' and the supposed desiccation of the region preoccupied French and English forestry administrations throughout the colonial era (Chevalier 1928; Chipp 1923 1927; Bégué 1937; Stebbing 1937; Aubréville 1938 1949; Jones 1938; Moor 1939; Marshall 1945; Anglo-French Forestry Commission 1973). These fears underscored the arguments for greater state control over forest resources, and often reinforced convictions about the inherent destructiveness of African resource and land use practices. The customary uses of fire in agricultural, livestock, forestry and other livelihood activities were, in particular, vilified by many during the colonial era (Stebbing 1937; Stewart 1944; Aubréville 1947).

From the perspective of Aubréville, the French botanist and forester who was perhaps the most influential colonial scientist in the region, the principle drivers of savannization were slash and burn agriculture combined with frequent and widespread burning of the savanna (Aubréville 1947 1949 1953). Aubréville's ideas took the form of a regional degradation model that incorporated elements of desiccation and savannization (Fairhead and Leach 1996 2000; Bassett and Zuéli 2000). He theorized that the annual burning practices of Africans were contributing to land degradation (desertification) on two fronts. On the southern front, forests and dense woodlands are subject to savannization as woodlands are cleared for farming and then repeatedly burned until ultimately replaced by grasses[2]. On the northern front, the savanna and deciduous forests are being degraded into more grass-dominated savannas as a result of shifting cultivation followed by persistent annual burning. Yet Aubréville, who was a skilled field scientist as well as a theoretician, did not translate his degradation theory directly into policy. Rather, he took time to test his ideas carefully through a number of long-term burning experiments, the results of which were eventually codified into fire suppression policy.

The burning experiments

In 1936 Aubréville set up an experiment to study the impacts of fire on savanna vegetation in the

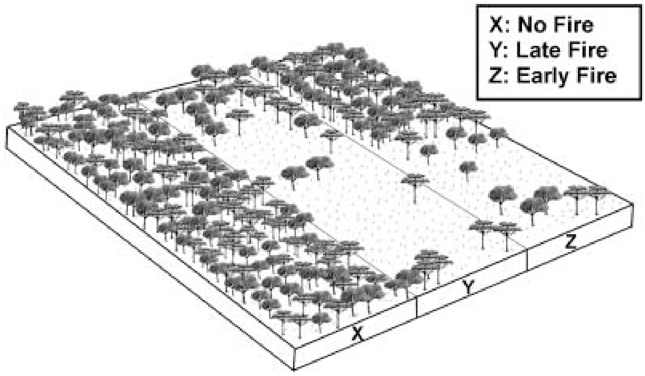

Figure 1 Layout for Aubréville's burning experiment showing the impact of different burning regimes on vegetation cover over the long term
Source: Louppe *et al.* (1995a)

northern Ivory Coast (Aubréville 1953; Louppe *et al.* 1995a 1995b). He was convinced that vast tracks of savanna in West Africa were of anthropogenic origin, derived from tropical dry forests which he had theorized were the natural vegetation climax for the region[3]. The experiment was designed to corroborate his conviction that anthropogenic fire, not soil conditions, was the decisive factor in the regression of these forests to grass-dominated savanna (Aubréville 1947 1949 1953).

Although Aubréville's fire experiment was not the first of its kind, it proved to be extremely influential[4]. During subsequent decades, experiments using a similar design were established in numerous African savannas (Charter and Keay 1960; Jouvanceau 1962; Ramsay and Rose-Innes 1963; Onochie 1964; Rose-Innes 1971). The accumulated data from these fire studies were interpreted as providing quantitative evidence in support of Aubréville's theories of regional savannization (Aubréville 1947 1953). The findings became the foundation for a nascent savanna fire ecology model and they remain the principal source of data derived from temporally based, quantitative studies on the effects of different fire regimes on savanna vegetation.

Aubréville selected a study site for his experiment in the savanna of the northwest Ivory Coast that he believed to have been humanly derived from tropical dry forest. His experimental design divided the study site into three plots. Care was taken to create a laboratory-like setting by clearing surrounding vegetation so that the vegetation on the plots could be subjected to specific fire treatments. Every year three different treatments were applied, one to each plot: plot one was totally protected from fire; plot two was burned 'early' at the beginning of the dry season on 15 December; and plot three was burned 'late' at the end of the dry season in May. The treatments were repeated annually for decades (Aubréville 1953; Louppe *et al.* 1995a) (see Figure 1).

The burning experiments were replicated at numerous sites in French and British controlled West Africa. In each case the same, or very similar, treatments were carried out (Figure 1)[5]. As testament to his continuing influence in the field of savanna ecology, Aubréville's study plots in the Ivory Coast remain the longest running burning experiment; the findings based on 60 years of the continuing experiment were recently published (Louppe *et al.* 1995a).

The results of Aubréville's burning experiment are generally in agreement with the published findings of numerous other studies (e.g. Charter and Keay 1960; Ramsay and Rose-Innes 1963; Rose-Innes 1971; Afolayan and Ajayi 1979; Brookman-Amissah *et al.* 1980; Carson and Abbiw 1990; Swaine *et al.* 1992; Chidumayo 1997). Following decades of fire treatment there are marked differences in the vegetation cover on the three plots as follows:

- Trees cover the protected site and in some cases the canopy is completely closed, making fire impossible.
- Grasses dominate the vegetation on the late burning site.
- The early burned site is somewhere in between the other two. It is similar to the protected site but with fewer trees and more grass cover. The trees are proportionately different in size (lower density but higher girth) from the protected site.

In addition to the documented changes in vegetation structure, the experiments demonstrate that burning also affects species – fire intolerant tree and shrub species are eliminated from the burned plots.

Some experiments also tracked changes in herbaceous species as a result of different burning regimes. Although the results vary, Ramsay and Rose-Innes (1963) conclude that a regime of early fire increases the percent cover of *Andropogon gayanus* – one of the most valuable forage species in the zone. A regime of late fire, on the other hand, produces a cover dominated by coarse, unpalatable grass species.

In sum, the findings from the burning experiments established a basic principle of savanna ecology – fire regime can determine vegetation cover. The findings have been widely cited in the savanna ecology literature (e.g. Bourliere 1983; Cole 1986; Scholes and Walker 1993) and contemporary fire codes in many West African countries remain deeply influenced by them.

Limitations of the burning experiments

Despite and/or because of efforts to conduct the burning experiments under controlled conditions, the studies have been subject to a variety of critiques. Three key limitations discussed here are attributed to the laboratory-like design of the experiments which serve to limit their applicability to actual conditions in West Africa. First, experimental controls and documentation of the initial conditions of the plots were far from ideal. Second, it does not appear that the burn timing dates employed in the studies are representative of actual indigenous practices. Third, the a-spatial nature of the experiments limits their application to what is a highly heterogeneous environment. As such, it is difficult to translate the results of the experiments into policy because, until very recently, there have been few data on the total area and forms of vegetation affected by each type of fire studied.

Ramsay and Rose-Innes (1963) reviewed numerous studies and argued that the role of fire in shaping the structure of African vegetation has been subject to a great deal of observation and deduction, but little quantitative study – only a few of the experiments from West Africa are capable of yielding reliable data. The authors criticized several experiments for their lack of methodological rigour. In particular, they note that little consideration is made of the context of the study sites. Specifically, the composition of the surrounding vegetation, the main seed source for re-vegetation, is not recorded and the experiments were not controlled for variations in edaphic conditions which are known to have a strong impact on vegetation cover (Cole 1986; Stott 1991).

Interestingly, the results of the experiments themselves can be quite revealing in regard to the latter. For example, the Aubréville plot subjected to early burning demonstrates a marked difference in tree density from the up-slope end of the plot to the down-slope end, suggesting that fire and soils have a combined effect on tree establishment. As noted by Louppe and colleagues (1995a), the tree canopy on the more fertile upper slope is virtually closed. Wooded savanna covers the infertile ground in the lower area where the stand is very open and invaded by grasses (see Figure 1). The late burned plot showed a similar marked difference in vegetation cover on the upper and lower slopes (Louppe *et al.* 1995b, 290). Ramsay and Rose-Innes (1963, 45) also note the influence of soils on early and late burned plots in their study, 'The canopy on better soils has closed, herbaceous vegetation is in some places too sparse to support fire, and new species have appeared. Vegetation on the poorer lower slope has not advanced so well'. As these findings suggest, soil and fire interact on the landscape to influence vegetation structure. The finding is critical, given that African land and resource users place high value on specific soil–vegetation formations compared to others. In particular, lowland areas with higher rates of moisture retention are often more valued than the uplands in semi-arid zones of the savanna.

The initial conditions and site history of the study plots were rarely reported. The experiments were conducted on controlled plots, usually at research stations that did not necessarily reflect the actual conditions of farming, fallowing, and burning in Africa. The history of land use is important because, as Nyerges (1989) has shown, the number of consecutive years a plot is held in agriculture, and whether they were farmed using hand-held hoes or animal traction, can influence subsequent vegetation cover. Data on the initial vegetative cover of the experimental plots are uncertain. In a few cases, the researchers documented that prior to the experiments some plots were covered by secondary growth, while in others they were covered with a mixture of trees and grasses of unknown history. In most cases, the plots were cleared of all trees prior to the experiments, in part because it was thought that the existing vegetation cover might bias the results (Ramsay and Rose-Innes 1963), but also because it was thought this practice mimicked slash and burn agriculture. This is unfortunate because it is common practice throughout West Africa to leave particular tree species standing in farmed plots, which serve as an important source of seeds for natural regeneration. More importantly, in dry and wooded savannas, regeneration from coppice is the most common form of tree regeneration as very few seedlings survive (Nyerges 1989), and it is not clear from the written record whether the study sites were de-stumped (thereby preventing coppice) before the experiments began.

Moss (1982) critiques the experiments on different grounds. He argues that the experiments do not reflect the reality of burning practices in Africa because the dates of experimental burning do not coincide with the actual burn timing in the areas studied. For example, areas surrounding the Lampto research site in Ivory Coast usually burn in mid season (January or February), yet the study only tests the impact of early (December) or very late (May) fires. Aubréville and others probably selected the very late burn date because it was understood that later fires were more damaging and scientists were seeking proof that fire could cause savannization.

It is also critical to recognize that fires – early or late – do not have the same impact on trees in different stages of growth, since normally only young trees are killed by fire and primarily by late dry-season fires. Mature woodlands are much less affected by fire, particularly when burning occurs early in the dry season. Thus, the results of the burning experiments tell us little about the effects of repeated burning on existing stands of mature trees. Other studies have found that mature savanna trees can withstand intense fires, although, if burned late when diseased or drought stressed (for multiple years), fire can kill even large trees (Swaine 1992; Menault *et al.* 1995).

Finally, the experiments were not designed to account for the influence of the spatiotemporal patterns of fire. Moreover, the experiments were conducted at a time when it was not possible to quantify the temporal patterns or area burned by fires over large areas, the implications of which are addressed below.

In sum, the colonial burning experiments were somewhat effective at isolating one important variable – fire timing – and documenting its impacts on vegetation over time. According to most contemporary savanna ecological models, however, savanna vegetation structure is understood to be a function of numerous interacting factors including site history (especially disturbance history), soil moisture and nutrient content, topography, and the spatial relationships between these factors (Cole 1986; Scholes and Archer 1997; Mistry 2000; Weigand *et al.* 2006). Moreover, many scientists agree that the savanna does not represent a stable mixture of trees and grasses, but an inherently unstable mixture which persists owing to disturbance events such as fire, herbivory, and fluctuating rainfall (Jeltcsh *et al.* 2000; Sankaran *et al.* 2005). From this perspective, humans are an important disturbance factor, but not the only one.

Yet, despite their limitations, the experiments provide a rare long-term view into the impacts of fire timing on vegetation cover and are useful when reconsidered within the context of contemporary savanna ecology and in conjunction with quantitative data on the spatiotemporal patterns of fire. Initially, the experimental results appeared to confirm the convictions of Aubréville and others that the savannas were of anthropogenic origin and that fire suppression was required to halt savannization. But it is important to note that, although the experiments provide evidence for a mechanism by which regular burning could cause savannization, there is little empirical evidence to support the claim that indigenous burning is a primary cause of the expansion of the savanna. Indeed, recent studies have documented cases where forest and woodland areas have expanded despite continued regular burning (Fairhead and Leach 1996; Bassett and Zuéli 2000; Amanor 2001; Wardell *et al.* 2003).

Fire policy and the burning experiments

By the time the first results of the burning experiments became available in the late 1940s, numerous colonial states had already attempted campaigns to ban burning (Wardell *et al.* 2004). Fears that fires were also causing increased soil erosion, and thus, threatening agricultural production – perceptions inspired by the Dustbowl experience in the United States (Stebbing 1938; Stewart 1944; Grove and Anderson 1987) – further fuelled the anti-fire movement. Although the results of the burning experiments seemed to support existing calls for fire suppression, forestry departments did not immediately impose strict bans on burning. Efforts to implement fire restrictions were tempered by the views of forestry agents with field experience and were mediated by a number of pragmatic concerns, such as a general lack of funding for forestry personnel and equipment, as well as resistance by rural inhabitants to fire suppression. Together, these factors instigated a period of pragmatism during the late colonial period (1940–1960), in which early fires were often accepted and occasionally promoted as a necessary evil – the effects of which needed to be minimized, rather than eliminated. These lessons were largely forgotten or ignored shortly after independence, as numerous countries adopted vigorous anti-fire policies. Most recently, governments have (again) begun to relax restrictions on the use of fire although official doctrine most often still considers fire a threat to the savanna environment (Laris 2004; Wardell *et al.* 2004).

Already by the 1930s a few experienced forestry and agricultural officials had recognized that complete fire suppression was both impractical and undesirable (Moor 1935; Vigne 1935; Lynn 1937). Forestry agents had long laboured to prevent fire especially in and around forest reserves. By the 1950s field agents and some administrators of forestry departments working in rural areas had undoubtedly observed indigenous burning practices, and thus realized the futility of total fire protection as well as the benefits of early burning. These agents were quite aware that the indigenous population would resist fire suppression by continuing to set fires. Their experiences, probably in combination with the observed beneficial aspects of indigenous early burning practices, led some to conclude that complete fire suppression was not possible and perhaps not even desirable in the established reserve areas. Fires in forest reserves were common because fires fanned by January Harmattan winds could jump across fire breaks. Moreover, forestry departments had small budgets and lacked sufficient personnel to police the rural areas adequately. In northern Ghana, colonial officers failed in their attempts to use customary chiefs to limit the use of fire. The pragmatic solution was to accept or even promote an early burning regime.

The results of the burning experiments made it clear that early fires were less damaging, and thus, if complete suppression was not realistic, then a programme of early burning was the next best thing (Letourneux 1957). The concept of fire as a necessary evil worked its way up to the upper levels of the government. In 1955 the governor of French Sudan (Mali and Senegal) issued a decree reversing an existing ban on fire and promoting early burning:

> Early fires are a goal in themselves when it comes to assure minor damage to the forest . . . Early fires are primarily a means to protect agriculture lands and fallow against big blazes by constitution of a barrier distant from combustible materials
>
> Ortoli 1955, 7–11

Following this change, the forest service instituted a widespread campaign to ring important areas, including young fallow lands, with a band of early burning. In so doing, it drew upon the participation and knowledge of the rural population in this effort:

> When early fires were set in the past, teams of guards [foresters], and sometimes laborers, were in charge of setting the fires following itineraries. That is no longer possible. The choice of lands, their burning or their protection is the responsibility of the inhabitants . . . Our role is to guide and to support but not to carry out
>
> Ortoli 1955, 13

A similar conclusion was reached several years later in northern Ghana:

> There can be no doubt that at the present time a policy of burning early in the dry season not only satisfies the diversity of interests most closely connected with the human situation, but is also the only practical solution to our problems
>
> Ramsay and Rose-Innes 1963, 63

In Burkina Faso, two decrees were passed in the 1950s authorizing the use of fire in specified vegetation zones, for clearing farmland and for the regeneration of pasture (GGAOF 1954 1955).

In sum, the policies established in the 1950s reflected the influence of the burning experiments as well as the growing field experiences of forest agents. The continued use of fire in customary land and resource management practices, the collaboration between forestry technicians and local resource users in using fire to define the limits of protected areas, and the preliminary results of bushfire experiments probably all contributed to the *de facto* acceptance of early burning as a necessary evil and the institutionalization of the fire triad model during the late colonial period.

The shift from promoting anti-bushfire prescriptions to recognizing the benefits of early burning occurred against a dynamic backdrop of conflicting opinions, tensions between technical and political officers, and disagreements amongst forest officers and other technical line departments (Jeffreys 1945; Nash 1944; Wardell forthcoming). This divergence of opinion and some scientific uncertainty may have left an opening for the resurrection of anti-fire sentiment after independence. Indeed, the pragmatic approach to fire management proved to be very short lived. By the early 1980s, several nations had reintroduced strict fire suppression policies. Mali, Burkina Faso, and Guinea all passed laws forbidding any form of savanna fire (Traoré 1980; Government of Haute Volta 1981; Fairhead and Leach 1995). The laws often carried harsh penalties[6]. The initial resurgence of interest in suppressing fires was probably triggered by the effects of the Sahelian drought which had instigated a resurrection of the desertification hypothesis. The 'crisis narrative' of the African Sahel of the 1980s (Swift 1996) fuelled a move to criminalize indigenous behaviours such as burning and fuelwood cutting that were perceived to be environmentally damaging. The end result was that the lessons achieved by some of the more pragmatically minded colonial foresters were quickly forgotten and there was a shift back to view fire as an evil. The anti-fire sentiment was reinforced in the 1980s when African governments instituted harsh penalties for burning, involving exorbitant fines and/or prison sentences, developments which ultimately produced a backlash as rural inhabitants resisted by (again) setting fires covertly and as a form of protest. The ultimate effect of the anti-fire campaigns was to heighten the animosity between the forest services and the rural population. Moreover, there was no indication that the amount of area burned was reduced; indeed, it is probable that by suppressing early fires, the anti-fire policies resulted in larger and more damaging late season fires. Villagers in Mali reported witnessing the largest and most fierce fires of their lifetimes during the anti-fire campaigns (Laris 2004).

Most recently, there has been a slight shift back towards a more pragmatic approach, as governments have moved from a strategy of fire exclusion to one of fire management (restricted inclusion), encompassing the use of early burning techniques (e.g. Republic du Mali undated; Government of Burkina Faso 1998). The latest shift in policy has arisen out of a combination of factors, including the local reaction to the anti-fire campaigns (Laris 2004), critical appraisals by independent scholars (Brinkerhoff 1995), and the region-wide move towards decentralized natural resource management (Ribot 2002). The new fire code in Mali emerged only after a series of discussions between villagers and foresters that revealed the intense opposition to the total ban on fires by the rural population. Although the present codes include provisions to allow early burning, the regulations still tend to be restrictive, requiring that users obtain permits, cut fire breaks, and sign on to state-approved forestry management plans (Bassett and Zuéli 2000; Goldhammer *et al.* 2004).

It is important to note that each of the reported shifts in fire policy during the past 60 years was implemented without the aid of data on the actual patterns of burning, and largely without consulting the views of the indigenous population. The following case study, using remotely sensed data, documents the spatiotemporal pattern of burning for the savanna of southern Mali. Combining the data on the patterns of fire and data gathered from previous interviews with that from the burning experiments is a starting point for developing a more effective fire policy.

The case of Southern Mali

The study area

The study area (Figure 2) is located at the southern edge of the Soudan Savanna belt in Mali. The area lies in what is arguably the most frequently and extensively burned region on earth (Menault *et al.* 1991; Barbosa *et al.* 1999; Dwyer *et al.* 2000). The

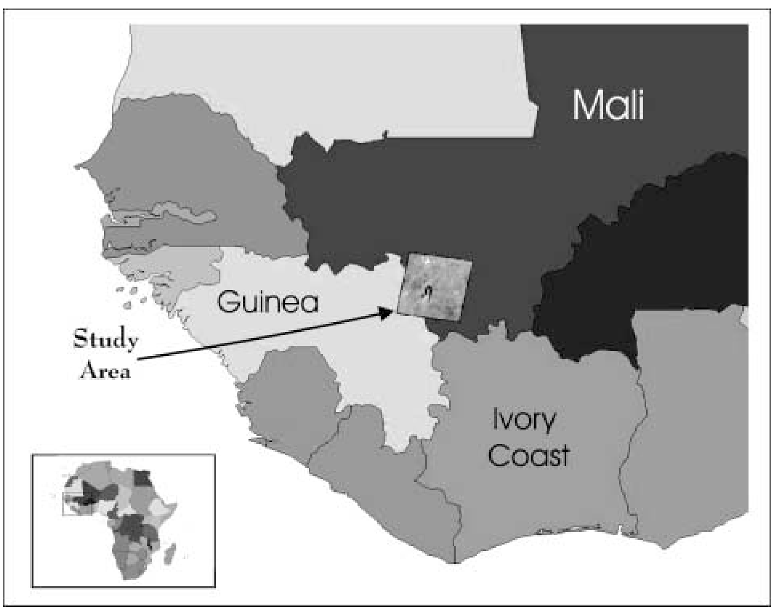

Figure 2 The study area in Mali bounded by the UTM coordinates 492200 W, 1381600 N and 711600 E, 1174800 S corresponding to the Landsat ETM + scene: WRS-199/52
Source: Reprinted from Laris (2005) with permission from Elsevier

majority of the study area is in Mali although it includes a small segment of Guinea. This area lies just to the north of where Aubréville set up his original experiments. The region is characterized by a rainy season that begins in June and extends into October. The average annual rainfall varies between 1000 and 1200 mm (Nasi and Sabatier 1988; Diarra and Sivakumar 1995). The subsequent dry (fire) season normally begins in late October and runs through to May. Fires can occur throughout the dry season, but activity peaks in late December and early January (Dwyer *et al.* 2000; Laris 2005)[7].

Vegetation

The vegetation in the study area is predominantly composed of a mixture of grasses, trees and shrubs, arranged in a complex mosaic (Nasi and Sabatier 1988). The tree/grass ratio varies considerably and is probably mainly determined by underlying soil structure, human land use, herbivory and fire history. Except for the more intensively cultivated areas, a near-continuous layer of perennial grasses over 1 m in height (*Andropogon gayanus*, *Hyparrhenia dissoluta*, *Cymbopogon giganteus*, and *Schizachyrium pulchellum*) covers the more fertile soils. Trees are found in a wide variety of formations and may be widely scattered or clustered in clumps, as is common in many savannas. The vegetation in the more densely settled areas has been significantly modified. Perennial grasses are less common (except on long fallow plots of over 15 years), and portions of the landscape are covered by annual grasses, particularly *Andropogon pseudapricus* and *Pennisetum pedicellatum*.

Variation in soil structure, especially moisture-retaining capability, significantly influences the tree and grass cover throughout the study area. Riparian vegetation in the form of dense tree cover is found along the banks of most seasonal streams. In addition, as much as 25% of this savanna is classified as *Bowé*, a vegetation form found on laterite outcrops, gravels or hard-pan that is distributed in a highly uneven pattern. Patches of *Bowé* are dominated by a thin cover of short, annual, grasses (principally *Loudetia tongoensis*, but also *Andropogon pseudapricus*) with widely scattered trees.

Burn-scar mapping

Five Landsat ETM+ images were acquired for the study area and used to map the fire regime (Table 1). The series of images nearly cover the entire 2002–3 fire season. The first two images in the series capture the critical 'early' burning season from November through to late December; the 5 January image captures the end of the EDS or the transition from early to late burning; and the remaining two cover the late fires, January through to 10 March[8]. Although some burning occurs during the months of April and May, field observations, interviews, survey results and examination of satellite imagery for these months in earlier years indicate that the vast majority of burning is completed by the end of February.

Table 1 Landsat images for the study area

Date	Fire season
4 December 2002	EDS
20 December 2002	EDS
5 January 2003	EDS
6 February 2003	LDS
10 March 2003	LDS

EDS = early dry season; LDS = late dry season.

The method used to map burn scars was designed to take advantage of both the spectral and spatial patterns of the scars. An unsupervised clustering algorithm was applied using Erdas software to separate pixels into groups with similar spectral signatures. Individual clusters were then interpreted visually as burned or unburned by comparing the cluster images with the false-colour images[9].

Results: the 2002–3 burning regime

The burn-scar map for the 2002–3 fire season is shown in Figure 3. In general, the early fires produce small, irregularly shaped and highly fragmented burn patches. In areas where early burning is extensive and fragmented, which is the case for most of the landscape, the spread of later fires tends to be confined to the gaps between the existing burned and other barriers to fire spread (Figure 4a). Conversely, in areas where there is little early burning, later fires burn larger, more contiguous patches as is the case in the southeastern portion of the study area (Figure 4b).

The percentage of the total area burned for each image is presented in Table 2. A significant percentage (17.6%) of the landscape burned during the first four to six weeks of the fire season (by 4 December). This finding is consistent with earlier research which has found that on average 15–20% of the landscape burns by the end of November (Laris 2002). By 5 January a total of 41% of the landscape had been burned. Given that the cut-off date for the EDS is 31 December, and that the total

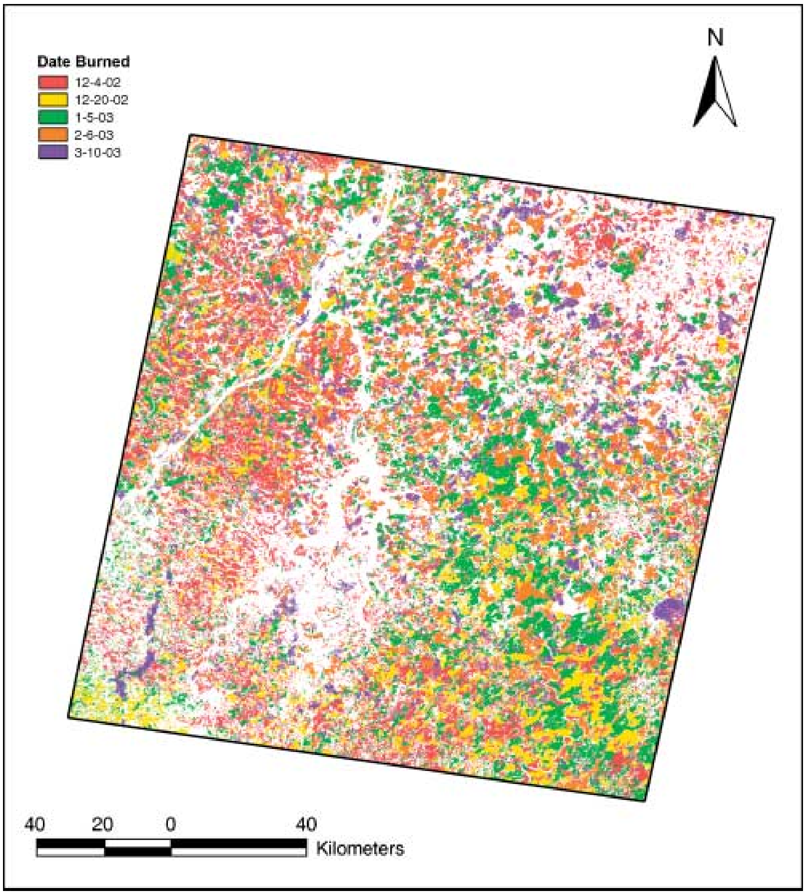

Figure 3 Burn-scar map for the study region for the 2002–3 fire season. Note how the earliest fires in black (red in the color version) have the most fragmented fire pattern while later fires produce a more contiguous pattern
Source: Reprinted from Laris (2005) with permission from Elsevier

Table 2 Burned area for the 2002–3 fire season

Image date	Total area burned (%)	P/A ratio
4 December 2002	17.56	0.305
20 December 2002	8.09	0.275
5 January 2003	15.80	0.195
6 February 2003	10.54	0.217
10 March 2003	4.91	0.429

Note: Also shown are values for the Perimeter to Area (P/A) ratio. The P/A ratio gives a good indication of the degree of fragmentation of the burn surface in the images. Lower P/A ratios indicate a more contiguous burn scar pattern, while higher values indicate a fragmented pattern.

area burned for the entire fire season was 57%, it is clear that the majority of burning is EDS (72%). These findings are also in line with previous studies (Laris 2002).

Discussion: a reinterpretation of the burning experiments

> It is thus confirmed by the conclusions of these two experiments of 16 and 9 years long that our forest policy in the region of the Guinean wooded savanna is based on well-established data. Our observation of nature had convinced us earlier but nothing is as valuable as the rigor of numbers to convince those who doubt.
>
> Aubréville 1953, 10

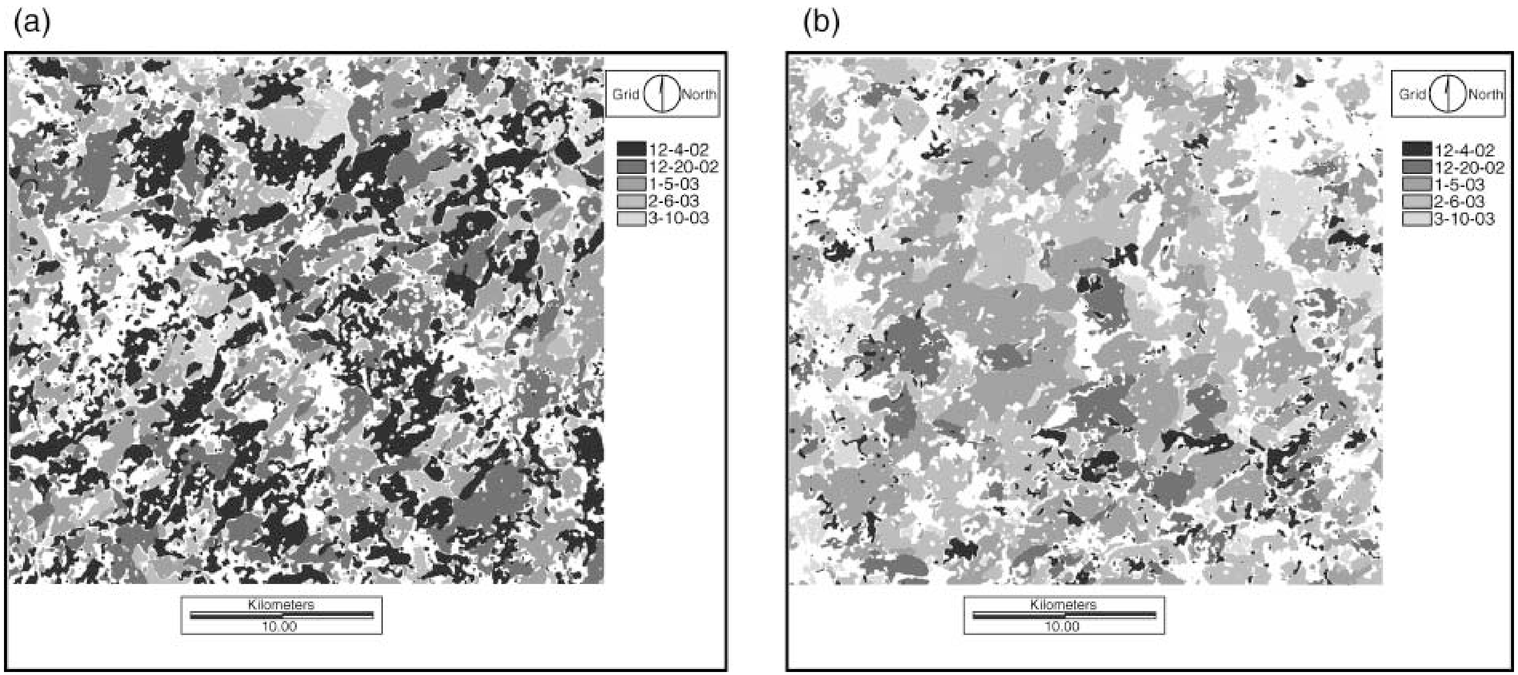

Figure 4 Close-up views of burn scars for 2002–3 fire season illustrating two contrasting patterns. Note the highly fragmented, patch-mosaic burn-scar pattern in (a) compared with the larger and more contiguous burn scars in (b). Widespread and patchy EDS burning (dark patches in (a)) results in fewer and smaller LDS fires (lighter patches) than when there is little EDS burning as in (b)

As noted, a key limitation of the burning experiments was that they were conducted on isolated plots which did not reflect the temporal and spatial pattern of African burning regimes. Nonetheless, Aubréville (quotation above) and others interpreted the results as evidence that indigenous farming and burning practices had caused savannization – a process which would have required large areas to be repeatedly burned late in the dry season. Conversely, this study finds that the vast majority (72%) of burning occurs early in the dry season, a finding that is supported by several recent broad-scale studies which find that most burning in the region is early with the peak of fire activity in late December (Barbosa *et al.* 1999; Dwyer *et al.* 2000; Silva *et al.* 2005). Furthermore, data from a survey of rural inhabitants conducted in a northern sub-set of the region (Laris 2002) indicate that the majority (67%) of areas with trees most susceptible to damage from late fires – young fallow lands (5–10 years old) – are regularly burned *early* in the dry season[10]. Only densely wooded areas (predominantly of secondary growth and less susceptible to fire damage) were burned late (January or later) for the majority of the time (64%).

A regime that is predominantly early burning will not cause widespread savannization, although it may serve to *maintain* the existing mix of trees and grasses on some landscapes. The study confirms that an important aspect of the indigenous early burning regime is that it produces a spatial pattern that fragments the landscape so as to restrict the spread of LDS fires. The survey and interview results demonstrate that the mosaic pattern is intentionally re-created annually and that a primary reason for setting fires is to fragment the landscape to limit the spread of LDS fires.

Interviews with village elders in southern Mali suggest that the widespread practice of setting fires to numerous patches of savanna at an early stage in the dry season does not differ significantly from practices of the last century. Thus, with the exception of brief periods when fire suppression efforts were taken to an extreme (such as during the late 1980s), the broad-scale burning regime appears to have changed little. Undoubtedly, burning regimes have shifted at the local scale, especially in areas where population growth has resulted in a reduction of fallow land and flammable biomass, or when cattle numbers have increased to such an extent that grazing has reduced the fuel load sufficiently to limit the spread of fire. Comparing satellite images of fires from the early 1970s and mid-1980s shows a remarkable stability in the burning regime, especially the critical early regime. Given that the broad pattern of burning has remained relatively consistent during the past 30 years, there is reason to believe that seasonal-mosaic burning has been the most common form of disturbance for a century, if not longer. Since this pattern of burning restricts the amount of tree-damaging late season fires, it can be argued that indigenous burning practices are not likely to have caused widespread savannization, as has been suggested. In contrast, customary burning practices provide a generally useful model for living in and managing a highly fire-prone savanna environment. This concurs with similar findings in a different context (Russell-Smith *et al.* 1997a). Indeed, a study comparing tree cover in the study area on long-term fallow plots (over 30 years) with that on unfarmed plots (both of which burn regularly) found that the fallow plots contained more and larger trees. This is not to suggest that tree cover has not declined in parts of the study area – it has. What this study demonstrates is that indigenous burning is not the principal driver of woodland loss. Indeed, a recent study in nearby northern Ivory Coast reached similar conclusions (Goetze *et al.* 2006). The expansion of the area under agriculture coupled with a reduction in the fallow cycle is a more probable cause of tree cover decline[11].

Patch-mosaic burning

The case study finds that the indigenous patch-mosaic burning regime in Mali produces a distinct spatiotemporal pattern – a seasonal-mosaic landscape composed of early burned, late burned and unburned patches[12]. How might the findings of the original burning experiments be reinterpreted in light of this pattern? Landscape ecology and patch-mosaic theory suggest three ways in which fire pattern affects ecological processes in support of the assertion that the a-spatial fire triad model requires rethinking:

1 patterns of vegetation and early burns affect how fire spreads across the landscape;
2 mosaic burning regimes can ‘fire guard’ patches of vegetation, thereby preventing them from burning; and
3 mosaic burning regimes create landscape heterogeneity, including critical habitat edges which support biodiversity. In addition, it is important to consider how different user groups utilize the mosaic landscape created by fire.

Landscape ecology assumes that the spatial arrangement of land-cover patches has ecological implications and thus provides a suitable framework for incorporating the effects of spatial pattern on ecological processes such as fire. Forman and Godron (1986) define the landscape as a kilometres-wide area where clusters of interacting stands or patches are repeated in similar form. Together, these patches form a matrix or mosaic (White and Pickett 1985). In recent decades, empirical research and theoretical developments in the field of landscape ecology make it increasingly clear that heterogeneity and pattern are integral characteristics that affect ecosystem structure, function and resilience (Turner 1989).

Accordingly, a savanna can be conceptualized as a heterogeneous environment composed of a mixture of grasses, trees, shrubs and other biotic and abiotic patches which form a mosaic (du Toit *et al.* 2003). Research has determined that disturbances, such as fire, which have a spatial dimension, have strong mutual interactions with landscape patterns. For example, studies have shown how landscape heterogeneity strongly affects the potential of a fire to permeate a landscape (Turner and Bratton 1987).

Patch-mosaic burning has been shown to create an array of patch types that act as natural firebreaks limiting the spread of fires (Minnich 1983; Press 1988). When this pattern of burning is repeated annually, the burnt areas can act to fire guard particular vegetation patches and create a diverse landscape where some patches burn regularly and others burn rarely. For example, researchers have documented that the timing of fires is critical for protecting gallery forests in savanna areas. When surrounding savanna grasses were burned before the forest fuels were sufficiently dry, the burned areas acted as a buffer zone protecting the fire-sensitive species within the gallery forest. Thus, although fuels in the forested areas can become dry enough to burn late in the dry season, fire entry is frequently precluded by the tendency of fires in the surrounding savanna to occur earlier in the dry season (Kellman and Meave 1997; Biddulph and Kellman 1998).

The dry-season savanna landscape can thus be conceived as a complex mosaic composed of different vegetation types and burned patches with two key implications for ecology and fire management. First, the nature of the mosaic pattern at a given moment in time influences the spread of fire through the landscape; because the mosaic pattern is continually shifting over time during the dry months, both spatial and temporal components are important. Second, early fires are critical because the early burn pattern sets the stage for the pattern of later fires. As the Mali data indicate (see Figure 4), where early burning is extensive, later fires are more contained, a finding which supports a fundamental premise of landscape ecology – pattern affects process[13]. Indeed, an analysis of a multi-year burned area database for the study region indicates that seasonal-mosaic burning protects some critical woodland patches from fire because these patches are annually 'ringed' by early fires (Laris 2006b).

Finally, mosaic fire regimes have implications for biodiversity conservation because heterogeneity is a key source of biodiversity (Pickett *et al.* 1997; Pickett and Rogers 1997). As research has demonstrated in other wet–dry environments, such as the Australian savanna, mosaic burning regimes support biodiversity because species adapt to long-term disturbance regimes (Denslow 1980) and to the heterogeneous landscapes created by fire (Braithwaite 1996). Patch-mosaic fire regimes are known to create *edges* – boundaries of ecological areas – that tend to increase ecosystem biodiversity (Russell-Smith *et al.* 1997b; Parr and Brockett 1999). The basic assumption here is that the burning patterns of fires are an effective surrogate measure of biodiversity; that is, the more diverse the burning patterns, the higher the biodiversity. Diverse burning patterns are developed by applying a range of numerous burns throughout the fire season, thereby developing a heterogeneous mosaic of species and structural diversity in the vegetation (van Wilgen *et al.* 1998; Brockett *et al.* 2001).

In many regions of the world, patch-mosaic regimes have ancient human origins, but only in a few of them, such as parts of the African savanna, do these indigenous regimes persist. The negative ecological consequences of the loss of indigenous burning have only recently been understood. Indeed, in some areas efforts are under way to mimic or otherwise recreate lost indigenous burning regimes (Trollop 1999).

An indigenous perspective on burning patterns

Much of the rural population in Mali, as in other West African countries, considers regular burning a necessary component of resource management. Fire is critical for managing savanna resources for key productive activities, such as improving pasture and hunting grounds, preparing fields for agriculture, as well as for preventing destructive fires. Survey results find the rural inhabitants recognize that late fires are more damaging to trees (Hough 1993; Mbow *et al.* 2000; Laris 2002). Malians in the study area who set fires claim that early burning is the only viable means of preventing damage to woodlands and pasture from late season fires[14]. Indeed, this view is widely held by the rural population in Mali according to the results of a national survey (Republic du Mali 1991).

Interviews with Malian villagers suggest that they conceptualize the savanna as a heterogeneous landscape in which different patches of vegetation have different potential uses. Some patches, which have little or no productive use, are best burned-off annually to create fire breaks. For example, Malians commonly set fires to the drier upland patches called *Bowé* early in the dry season because these areas are considered wasteland. Once 'destroyed' by fire, the patches create the initial breaks in the landscape that allow the mosaic pattern to unfold during successive months. It is also widely understood that fire timing is critical for achieving a green flush of new perennial grass shoots which is stimulated by fire if it occurs before the vegetation is completely desiccated. The practice of progressively burning patches with different grass and soil types throughout the dry season *creates* a rare source of fresh fodder for domestic and wild animals, as these grasses will re-sprout when fire is appropriately timed. Some colonial foresters and agriculturalists commented on how burning is a practical means of *extending* the availability of green grasses long into the dry season (Vigne 1935; Moor 1935; Lynn 1937)[15]. Finally, as has already been well documented, fires have a number of additional benefits, such as eliminating pests and snakes, improving mobility and visibility, aiding in hunting and gathering and as a culturally significant phenomenon (Hough 1993; Kirby 1999; Mbow *et al.* 2000; Laris 2002).

Conclusion: fire as evil, necessary evil, or necessity?

For the past 50 years fire policy in the savanna of West Africa has been guided by a simple fire triad model which holds that the timing of annual savanna fires is a major determinant of vegetation cover. The origins of the model lie with a few influential colonial scientists who viewed indigenous burning as inherently destructive and who devised the burning experiments to test their convictions that the savanna was anthropogenically derived and maintained[16]. The experiments were repeated numerous times and were interpreted as providing proof that indigenous burning practices were a principal cause of widespread savannization which needed to be curtailed. The experimental results were then mapped onto fire policy where they remain influential. This paper has argued that, although the burning experiments provide a rare and valuable long-term view of the effects of repeated fires on savanna vegetation, the results of the experiments need to be reinterpreted in light of new quantitative data on fire regimes, theoretical developments in ecology and recently gathered information on the logic of indigenous burning practices.

The original burning experiments were designed to demonstrate a mechanism by which fire could cause woodland loss, but, as has been argued here, the laboratory-like design severely limits the applicability of the experimental results to real world situations. In particular, the a-spatial fire ecology model, derived from the burning experiments, cannot account for the key ecological effects of the spatiotemporal pattern of burning, and thus should not be the sole guide for setting policy.

Many contemporary savanna ecology models and fire management strategies remain deeply influenced by the ideas of colonial scientists. In part, this is because fire management approaches continue to assess the impacts of fire from the perspective of the isolated patch rather than the broader landscape. From this narrow perspective, the negative aspects of fire may appear to outweigh the positives. When viewed from a landscape ecological perspective, however, the more beneficial impacts of indigenous burning come into focus.

The data presented here demonstrate that the majority of burning in the region occurs early in the dry season, a finding which suggests that fires are not as damaging to tropical dry forests as has long been suspected. More importantly, this research has also shown that the indigenous burning regime in southern Mali tends to fragment the landscape, thereby preventing some large, sweeping LDS fires which are most damaging to trees. Similar burning regimes have been detected for other parts of the region (Bucini and Lambin 2002; Mbow *et al.* 2000; Wardell *et al.* 2004). It is concluded here that widespread burning which begins early in the dry season is critical to creating the seasonal-mosaic pattern and thus may be one key to effective fire management strategies in a highly flammable environment.

Despite decades of failed fire suppression campaigns and recent developments in patch-mosaic theory, which demonstrate the positive effects of burning, fire policy and management strategies in West Africa remain predominantly anti-fire. On occasion, pragmatic approaches to fire management have emerged, such as during the late colonial period, which have allowed, and occasionally promoted, early burning. But even these policies viewed fire as a necessary evil at best – its sole benefit coming from the fact that when set early, fire is less damaging to trees. This view contrasts deeply with that of rural farmers, hunters and herders, who view fire as a necessary tool for preventing damaging fires, as well as a necessity for rendering the savanna landscape useful for a wide variety of productive activities. Interview results from Mali indicate that the burning regime is not haphazard, rather it is a function of human intent that is guided by multiple goals, which include reducing fire hazard and increasing landscape usefulness in a multitude of ways (Laris 2006a). From this perspective, early fires are understood to be an essential component of a broader savanna management strategy rather than as a necessary evil.

From a biogeographic perspective, the impact of a fire depends on a suite of variables, including vegetation type and conditions, soil moisture content (a function of weather and physical properties), and landscape pattern. But whether savanna fires are perceived as evil, necessary evil or necessity depends ultimately on the perspective of the land manager. Forestry Departments aiming to manage reserves for the production of timber and non-timber forest products continue to aim to reduce the impact of fire on vegetation cover, as do a growing number of villages with high population densities where biomass is in short supply[17]. Elsewhere, however, pastoralists and land managers set fires with the goals of promoting the growth of preferred grass species and reducing tree and shrub cover. The large amount of biomass burning in Africa is also of concern to the Framework Convention on Climate Change, whose main objective is to reduce the contribution of savanna burning to greenhouse gas concentrations in the atmosphere (Barbosa *et al.* 1999).

Those seeking to eliminate fire from the savanna should take note of the historical evidence which indicates that past fire suppression policies in Africa have failed dramatically. Not only have such policies failed to reduce the amount of burning, but, in some cases, they have increased the most damaging kinds of late fires by suppressing traditional early burning practices. And, in many cases, anti-fire policy has resulted in deep distrust, occasional hostility and even violence between foresters and villagers, an atmosphere that is clearly not conducive for creating effective fire use and management policy (Pyne 1997; Kull 2004; Laris 2004).

In Mali, following the fall of the Traoré regime in 1991, a series of government-sponsored village meetings catalyzed a national debate over fire that ultimately resulted in a new fire code. In Burkina Faso a national consultative process also resulted in changes in fire policy and legislative instruments (Cherel *et al.* 1993; Government of Burkina Faso 1998). However, official views on fire often appear unchanged; the policies invariably still seek to suppress fire and regard early fire as a necessary evil (Wardell and Reenberg 2006). The Malian code stipulates that villagers must seek a government permit and cut a fire break before even early fires can be set. In practice, it is impossible for villagers to adhere to such a code. The indigenous fire management system in southern Mali is built around the concept of setting fires as soon as grasses are dry enough to burn. A large portion of fires are set by hunters, herders and other resource users moving through the countryside often noting when a particular area is ready for burning. There is not sufficient time or labour to adhere to, or to enforce the code. Similar constraints have been reported from Sénégal (Wardell *et al.* 2004).

This is not to argue that fire reduction is not a goal of some rural West African communities or that mosaic burning should be regarded as the sole solution to fire management for the region. The point is that fire management problems need to be framed at a more local level and to be conceptualized in accordance with the needs and epistemologies of local resource uses. It is worth noting that in areas of Mali, where population density is increasing and causing a reduction in available biomass, communities often seek to reduce burning. This is consistent with similar findings from northeast Ghana, Burkina Faso and Sénégal (Amanor 2001; Wardell *et al.* 2004). In the Malian study area, for example, several villages are actively working together to develop local institutions designed to reduce fires in strategic areas such as flood plains which provide a critical late season source of pasture and thatching materials. These local efforts tend to seek a middle ground between total suppression and wide-scale mosaic burning, but have only had limited success in Mali (Laris 2006a). In neighbouring Burkina Faso, state institutions have started to harness the knowledge and skills of local resource managers to improve fire management in and around protected areas (Salokosi and Ouédraogo 1999). The first formal recognition by the State of the need 'to leave the initiative to local communities to develop the modalities for forest fire management appropriate to their own terroirs' was provided by the Prime Minister in 1997. This was subsequently endorsed by the promulgation of a Rural Bushfire Decree a year later. This suggests that such an approach could provide a model for cooperative fire management strategies, if only government agencies would relax the strict anti-fire code and offer assistance to villages seeking to modify (but not extinguish) local burning practices. It will also require complementary changes to the curricula and training offered to both political leaders and the technical staff in local government.

The persistent rift between indigenous and official views of the role of fire has left fire regulation at a disjuncture (Kull 2002). In Mali, as in other countries, the rural population continues to set fires as they see fit without permits or firebreaks, blatantly disregarding the requirements of the official fire code, while government agents turn their heads and avoid enforcing the code, perhaps fearing another peasant rebellion. But if history is any indication, fire conflicts will reignite, perhaps as soon as the next drought. A shift in policy is needed to head off future conflict and the environmental degradation which will likely accompany it, by bringing fire policy into line with rural practice. A reasonable first step in developing a new policy would be to replace the old view, rooted in colonial thinking and grounded by the results of the burning experiments, with a new one rooted in indigenous practice and supported by landscape ecology and cooperative management strategies.

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Notes

1 It is commonly suggested in the literature that fires set to burn agricultural plots escape and burn uncontrolled into the surrounding savanna; however, there are few data to support this claim. Laris (2002) found that the escaped agricultural fires rarely burn large tracts of savanna. Agricultural field preparation in the region is conducted near the end of the dry season by which time a large percentage of the savanna landscape has already burned and is fragmented in a way that prevents the spread of fires. Farmers note that the preferred time to burn a field is at the end of the dry season just prior to planting – otherwise weeds sprout and nutrients may be lost to the wind. It is unlikely, therefore, that escaped agricultural fires are the cause of the bulk of the fires in West Africa which occur much earlier in the dry season.

2 Savannization as described here has two meanings: (i) the conversion of forest species to savanna species (the conversion of non-fire resistant species to fire resistant ones), and (ii) the conversion of dry forest and woodland into grass-dominated savanna.

3 Colonial forestry science attained its zenith in the period 1920–40. It was influenced by developments in ecology, described by some scholars as a 'science of empire' (Robin 1997; Tilley 2003), although the notions of vegetation climax and succession owe their origins to the work of *inter alia* Warming and Clements.

4 Different perceptions of the fire 'problem' within forestry departments may have led to the first prototype experiments to assess the effects of bushfires on vegetation in the region. These were established by the Gold Coast Forestry Department as instructions to political (district) officers to limit burning of shea nut trees (*Vitellaria paradoxa*) in the Northern Territories of the Gold Coast (Mcleod 1922). The Nigerian Forest Department subsequently established a bushfire experiment in the Olokemeji Forest Reserve in 1929 (MacGregor 1937; Mackay 1936; Charter and Keay 1960). It is also likely that this interest was galvanized by three Empire Forestry Conferences (Robertson 1957) and the specific recommendations on the 'Control of Fires' which emerged from the First International Sylvicultural Conference held in Rome in 1926 (Anon 1926).

5 It is interesting to note that in Southern Africa, where the interest in fire lay with its potential for reducing tree and shrub cover, the experimental design differed accordingly because in these countries fire is considered necessary to *maintain* grasses for pasture and to prevent shrub and tree encroachment (Trollope *et al.* 1995; Trollope and Trollope 2004).

6 Guinea instituted a total ban on burning in 1972 which was backed by severe penalties including the death penalty (Fairhead and Leach 1995).

7 A complete description of the principal occupants and land uses in the study area can be found in Laris (2006a).

8 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. The Malian Forest Service defines the cut-off between early and late season as 31 December in the zone covered by the study region (Republic du Mali nd), thus although the 5 January image likely includes some LDS burn scars, the majority of the burned areas captured in this image are assumed to have occurred prior to 1 January.

9 A detailed description of the methods can be found in Laris (2005).

10 The survey instrument instructed rural inhabitants to recall the time of year that particular types of vegetation regularly burned (Laris 2002).

11 Recent research suggests that the transition to intensified land use may initially involve a loss of woodland but can lead to increased planting and protection of useful trees on farmlands and maintained biomass levels (Mortimore and Turner 2005; see also Mather and Needle 1998).

12 Others have used the term 'patch-mosaic' to describe similar patterns of burning in savannas (e.g. Russell-Smith *et al.* 1997a; Parr and Brockett 1999). The term 'seasonal-mosaic' is preferred for the West African context because burning annually reproduces a seasonal pattern.

13 The main exception to the seasonal-mosaic pattern for the study is the area in the southeast where there is little early burning followed by a flurry of larger, more contiguous fires in January and February (Figure 4b). Interviews with inhabitants in the southeast give two reasons for the exceptional

pattern of fire: first, they note that their region has less area of *Bowé* and therefore, fewer patches of vegetation are sufficiently dry to be burned early in the dry season; and second, the lower population density of the zone means that the landscape is less humanized and thus less heterogeneous. In particular, there are fewer patches of fallow land, which are dominated initially by annual grasses that can be burned earlier than most perennials.

14 Several villagers explained that during times of drought, such as during the 1970s and 1980s, it was critical to begin setting fires very early in the dry season. It was understood that trees were more vulnerable to fire damage during a drought and that creating a degree of landscape fragmentation was the only viable means of preventing late season fires from sweeping through the landscape and killing more trees.

15 It should be noted that the practice of burning to create a 'green flush', which is critical to pasture management in the Soudan and Guinea belts, is not used by pastoralists in the more northern Sahel. Grasses in this region are primarily annuals and thus do not regenerate following a burn.

16 Towards the end of his career Aubréville modified his long-held view of the influence of anthropogenic fires in forming West African savannas, arguing that climatic determinants were also important (Aubréville 1962).

17 Burning regimes in other biomes (such as the Sahel) and/or in areas with different livelihood systems (such as those with intensive agriculture) will differ (Mbow *et al.* 2000).

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