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Fire ecology and fire politics in Mali and Madagascar

Christian A. Kull and Paul Laris

7.1 ABSTRACT

Anthropogenic fires dominate Africa, where they have long shaped landscapes and livelihoods. Humans evolved in Africa's fire-prone grasslands and savannas, eventually taking ignition into their own hands. This chapter reviews current knowledge about and concerns over fire in two African countries, Mali and Madagascar. Vast areas of land burn in both countries each year as people light fires to shape vegetation communities for a number of often overlapping and sometimes competing reasons, ranging from pasture and game management, to crop field preparation, to pest and wildfire control. In Mali, hunting and agropastoral fires shape vegetation zones along the gradient between the dry north and the more humid south. Their anthropogenic nature removes much of the interannual variation common in fire regimes elsewhere—they are a regular, predictable feature of the landscape. In Madagascar, fires prepare and maintain the vast pastures of the interior, and enable farmers to cultivate farther into the few remaining stands of forest. Although rural populations rely upon fire for numerous livelihood activities, they sometimes struggle to control fire. Policy makers have long criticized the fires for reducing tree cover and contributing to land degradation, raising the specter of desertification in Mali and deforestation in Madagascar. As a result, colonial and independent governments have periodically tried to eradicate—or at least minimize—landscape burning. These efforts wax and wane with the political context, with drought cycles, and with periods of international concern. Government fire restrictions are frequently perceived by rural residents as an imposition on their way of life, and enforcement has led to animosity against government agents. Given people's resistance, as well as fire's inevitability in wet–dry grassy landscapes, fire management is largely at a standstill. Some form of co-management is likely the only viable solution, yet in order for this to work, governments will have to accept the usefulness and inevitability of many fires.

7.2 INTRODUCTION

Africa is aflame (Figure 7.1; Schmitz, 1996; Goldammer and de Ronde, 2004). Satellite images consistently show the continent red with fire. The fire zone looks like a deformed backwards "F", with a thin top bar extending from Cap-Vert in the west to the Rift Valley in the east, a thick middle bar crossing through much of south–central Africa, and the vertical axis bending along the east coast all the way south to the Cape of Good Hope. Madagascar adds a flaming period. Fire is missing only from the deserts—the Sahara, the Kalahari, the Somali (where there is too little to burn)—and from the wet forests of the Congo basin (where it is usually too wet to burn). Most of these fires are lit by people, for a plethora of reasons, many still poorly understood.

This chapter investigates current knowledge about and concerns over fire in two countries in the African crescent of fire—Mali and Madagascar—and emphasizes the

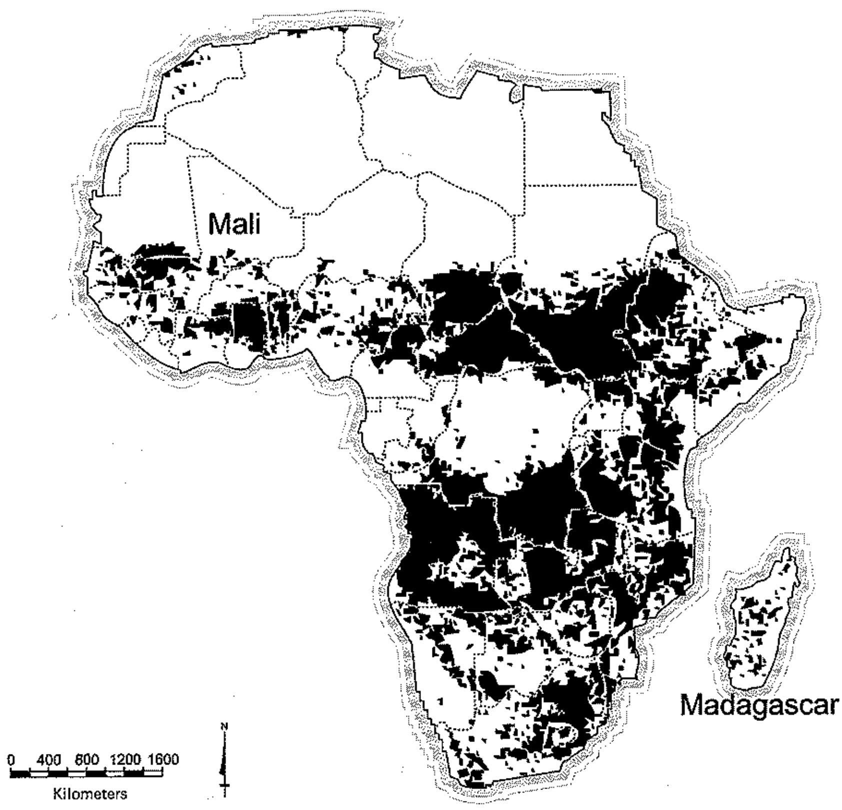


Figure 7.1. Generalized map of areas burnt in Africa in year 2000 (data processing and cartography by S. Chandra and P. Scamp, 2008; data source: Global Burnt Area 2000 project, based on SPOT-4 VGT satellite data of 1 km^2 resolution, available at *www.grid.unep.ch/activities/earlywarning/preview/ims/gba/*).

anthropogenic nature of African fire. Mali straddles the West African Sahel; the large island of Madagascar lies just a few hundred kilometers off the East African coast. Both have vast areas of land in flames each year, Mali during the northern hemisphere dry season (November to May), Madagascar in the southern hemisphere dry season (June to November).

Both landscapes have burned for ages, lit by lightning, but Mali's history of anthropogenic fire is deep (probably over 10,000 years) while Madagascar's is shallow (~1,500 years). Most fires in both places are currently human-lit, as fire is a common land management tool. People burn for multiple livelihood-oriented goals including pasture renewal, hunting, path clearing, fuel control, plant management, pest elimination, and field clearance for agriculture. Despite similar fire uses, the fire users in both countries follow slightly different social logics. Mali's fires derive in part from a culture of burning to support a mosaic landscape ideal for hunting and agropastoralism; meanwhile, Madagascar's fires support cultural ideas of landscape maintenance for pastoralism in some areas and as a tool for agriculture elsewhere.

Fire attracted increasing attention as a policy issue in both countries during French colonial rule. Fire policy in both Mali and Madagascar was—and continues to be—deeply influenced by the views of French colonial foresters and botanists. The use of fire by Africans was often perceived as careless and overly destructive (as has been the case for many indigenous populations around the world—Pyne, 1997). Colonial foresters and botanists also assumed that fire led to negative landscape transformations, contributing to desiccation and a southward shift of Sahelian and savanna zones in Mali, and contributing towards deforestation and soil degradation in Madagascar. This logic reflects two concerns of foresters and botanists about savanna/forest dynamics in the tropics—one economic and the other ecological. First, it was feared that practices of shifting agriculture followed by regular burning would reduce wood production or timber availability, cause a reduction in soil fertility and threaten economic development. And second, it was thought that the human actions were transforming "naturally" forested or densely wooded landscapes into grass-dominated savanna, and that this was undesirable. There has long been a lively debate over the origins of savanna hinging on the issue of origin: Were savannas human-derived or naturally occurring (Aubréville, 1953; Cole, 1986; Scholes and Archer, 1997; Keeley and Rundel, 2005)? In the early 20th century, the theory of human origin dominated, and this perspective influenced fire policy throughout the zone. These ideas continue to shape land and fire use policy in many West African countries (Fairhead and Leach, 1996; Bassett and Koli Bi, 2000; Laris and Wardell, 2006).

While the validity of these ideas is still being debated, there is an emerging counter-view that holds that the amount and rate of degradation presumed to have been caused by humans was overstated (Fairhead and Leach, 1996; Kull, 2004; Keeley and Rundel, 2005; Bond *et al.*, 2008; Laris 2008). The real problem is that misconceptions about the impacts of indigenous fire use fueled conflict between rural people and foresters that ultimately proved detrimental. Throughout much of the 20th century, colonial and independent governments in both countries implemented fire suppression policies aimed at reducing fire's impact on the landscape. Rural land users in both places perceived these interventions as illogical, overly harsh, or damaging to their livelihoods. The resulting conflict, which has persisted for nearly a century, has periodically contributed to flashes of violence (such as Madagascar in 1947 or Mali in the 1980s). These politics of fire management played themselves out differently in the two countries over the past century, as we review later in this chapter. Colonial foresters were slightly more willing to compromise in Mali than Madagascar (perhaps due to the presence of more economically and botanically precious forests in the latter, an island hotspot for biodiversity conservation—Goodman and Benstead, 2003), and independent government cycles of harshness and leniency follow different cycles in the two countries. Regrettably, however, the conflict in both countries has prevented the development of cooperative fire management. Despite strong anti-fire policies within both colonial and post-colonial governments, local inhabitants have largely succeeded in continuing to burn, taking advantage of the vast territory, of fire's own propagation and inevitability, and of gaps in government commitment to and enforcement of restrictive policies leaving fire management at a kind of stalemate.

Numerous issues persist in both countries in terms of how to best manage fire at local, regional, and national levels. Both countries have major issues in terms of forest conservation, land degradation, and agricultural productivity, and widespread anthropogenic fire continues to be seen as worsening these problems. But both countries are also among the world's poorest, and their rural land users in many cases depend on fire to manage landscapes conducive to their livelihoods. This chapter compares and contrasts the cases of Mali and Madagascar, documenting the diversity of fire regimes, fire uses, and fire landscapes, demonstrating the kinds of fire knowledge held by rural land users and how this relates to their livelihoods and ways of life, and showing how fire policies attempted to address the perceived fire problem. We now know more about fire regimes and the consequences of them than ever before, but there are few new ideas on how to manage fire effectively in a poor, rural, fire-prone environment. In the conclusion, we make the suggestion: Perhaps, in a landscape of anthropogenic fire, time has come for a new form of co-management that recognizes the central role of anthropogenic fire in these landscapes.

7.3 BIOPHYSICAL CONTEXT

Africa's fires burn in the broad transition zones encompassing the vast savannas between the humid forests and the dry deserts, where people, plants, and animals have shaped biomes under the constraints of geology, topography, and climate.

7.3.1 Mali and West Africa

West Africa's low-elevation hills and plains are strongly dominated by a north–south gradient in precipitation. Distinct vegetation formations stretch from west to east in roughly parallel belts beginning with the Sahara desert in the north, stretching into

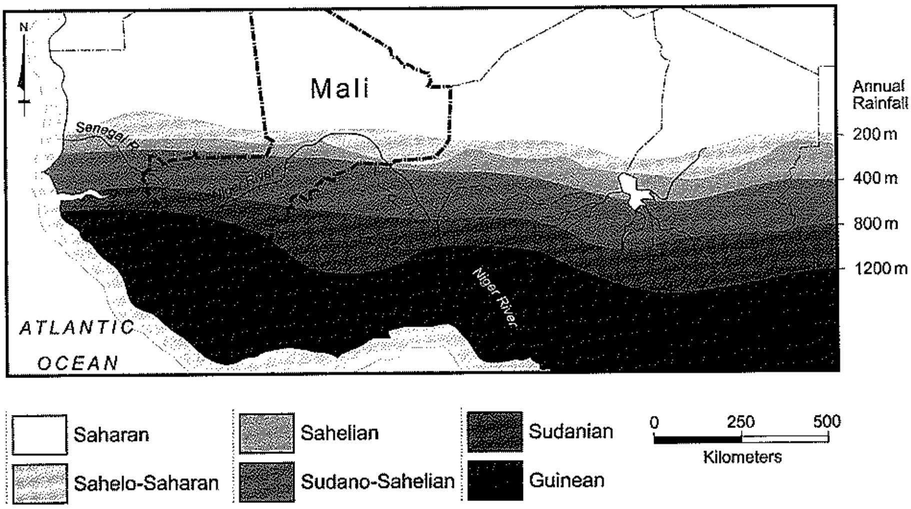


Figure 7.2. West African bioclimatic zones (drawn by P. Scamp, 2008).

the savannas—the Sahel, the Sudanian savanna–woodland, and the Guinean savanna–forest mosaic—before reaching the rainforest nearest the coast (Figure 7.2).

The vast majority of burning in the region is confined to the savanna belts, especially the Guinea Savanna and the Sudan Savanna. Savannas by definition contain grasses and trees and include plant communities of diverse floristic composition and varying physiognomy (Cole, 1986; Scholes and Archer, 1997). They may be more or less wooded and are thus sometimes referred to as wooded savanna, or simply woodland (White, 1983). A common characteristic of all savanna formations is a near-continuous layer of grasses beneath the tree canopy.

In many savannas, trees and grasses persist under disequilibrium conditions. That is, the coexistence of these two vegetation forms requires frequent changes in the environment (i.e., disturbances such as fire) to prevent the extinction of either form, or temporarily bias conditions in favor of one or the other (Scholes and Archer, 1997). For the African continent, Sankaran *et al.* (2005) demonstrated that in ecosystems where mean annual precipitation is greater than 650 mm, savannas persist under unstable conditions because rainfall levels are sufficient to support the closure of the woody canopy and the elimination of grasses. Indeed, Bond (2005; Bond *et al.*, 2005) has argued that woody vegetation cover in the mesic savannas of Africa would double at the expense of grasses in a fire-free world because fires prevent or suppress the replacement of the herbaceous strata by woody species.

Throughout the West African region, the movements of the Intertropical Convergence Zone (ITCZ) determine the quantity of rainfall in a particular summer. There is high interannual variability in precipitation especially in the Sahel zone. During the winter, the climate pattern shifts, the ITCZ moves southward, and hot dry winds (known as the Harmattan) blow from the north, desiccating the vegetation.

Mali is composed of two principal savanna zones, the Sahel and the Sudan Savanna. These two zones reflect the distinction in savanna types determined by

Sankaran *et al.* (2005). The Sahel is a narrow belt that varies in width from a few hundred kilometers to over 1,000 kilometres. The average annual rainfall varies from approximately 600 mm in the south to about 200 mm in the north. Most rain falls in the summer months of May to September, followed by a 6-month to 8-month dry season, during which time the woody vegetation loses its leaves and the grasses dry. Common woody species include many *Acacia* and several *Ziziphus* species, *Commiphora africana*, *Balanites aegyptiaca*, and *Boscia senegalensis*, and the herbaceous cover is dominated by annual grasses (*Panicum turgidum*, *Cymbopogon schoenanthus*, and *Arista sieberana*) which desiccate early in the dry season (Burgess *et al.*, 2004).

The annual rainfall in the Sudan Savanna varies from 1,600 mm in the south to approximately 600 mm in the north—sufficient rainfall to support closed-canopy woodland. Rainfall in the zone is highly seasonal, but the season is longer than in the Sahel. The dry season normally lasts from November through April. The vegetation is composed of a complex mosaic of grasses and trees. Most trees are deciduous except for those located in riparian areas (Nasi and Sabatier, 1988).

Tree species are numerous, but common trees of the Sudan Savanna in Mali include *Daniellia oliveri*, *Detarium microcarpum*, *Lannea acida*, *Bombax costatum*, *Combretum glutinosum*, and *Pericopsis laxiflora* with some *Acacia* in the north. In the moister areas *Afzelia africana*, *Burkea africana*, *Combretum glutinosum*, and *Terminalia laxiflora* are most common. In the southern Sudan Savanna *Isoberlinia* woodland is common (White, 1983; Nasi and Sabatier, 1988).

Much of the vegetation in Mali reflects the long history of human occupation and agriculture. Areas of secondary growth (fallows) are associated with *Pterocarpus erinaceus*, *Lannea acida*, and *Combretum lecardii*. Frequently farmed and fallowed areas or "parklands" are dominated by *Vitellaria paradoxum*, *Parkia biglobosa*, or *Adansonia digitata* which are highly valued species (Nasi and Sabatier, 1988; Duvall, 2007; Laris, 2008).

There is an understory of tall grasses, shrubs, and herbs. Principal perennial grass species in southern Mali include *Andropogon gayanus*, *Hyparrhenia dissoluta*, *Cymbopogon giganteus*, and *Schizachyrium pulchellum* which commonly grow over two meters tall, but there are also areas of shorter annuals including *Loudetia togoensis*, *Andropogon pseudapricus*, and *Pennisetum pedicellatum* especially on fallowed lands. Small grassy floodplains are found throughout the ecoregion, as are patches of dense woodland and some dry forest especially along rivers and streams. Farther south, the Sudan Savanna transitions to the Guinean forest–savanna mosaic, an ecoregion composed of scattered patches of dense forest of *Isoberlinia doka* and *Uapaca togoensis* intermixed with tall-grass savanna (Nasi and Sabatier, 1988).

7.3.2 Madagascar

Much of eastern and southern Africa—including Madagascar—is elevated over 1,000 m above sea level, and precipitation gradients are strongly influenced by this topography. In Madagascar, for example, highlands run the length of the island from north to south, intercepting the prevailing easterly winds off the Indian Ocean. This orographic effect creates an east–west precipitation gradient on top of the standard north–south gradient, with the result of a humid east coast and escarpment (more humid towards the north), a seasonally wet center and west (with longer dry periods the farther west one goes), and an arid southwest. Closed-canopy humid forest was thus characteristic of the east prior to human settlement, while deciduous dry forests and woodlands grew in the west and a unique "spiny desert" vegetation in the southwest (Figure 7.3; Goodman and Benstead, 2003). The character of pre-human vegetation in the wet–dry center of the island remains debated. The dominant 20th-century view was that this area was covered in various transitional woody vegetation formations; recent paleo-ecological and biogeographic evidence suggests that fire-maintained or herbivore-maintained C_4 grasslands were common before human arrival (for more detail see Section 7.4.3; Gade, 1996; Lowry *et al.*, 1997; Kull, 2000; Burney *et al.*, 2004; Bond *et al.*, 2008).

Malagasy grasslands, which cover some 40 million hectares, are composed chiefly of pan-tropical perennial grasses (Kull, 2004). Typical grassland communities differ regionally and locally (Bosser, 1954, 1969). In the west, grass communities vary based on the underlying soils, with *Heteropogon contortus* or *Aristida barbicolis* on sandy soils, *A. rufescens* on eroded soils, *Bothriochloa glabra* in humid bottom soils, or *Trachypogon polymorphus* in gravelly soils. In the lower elevation, western parts of the highlands, an association of *Hyparrhenia rufa* and *H. contortus* is common, with significant populations of *A. rufescens*. Mid-level highland regions are commonly dominated by *A. rufescens*, but with a variety of communities dependent upon soils, local climate, and land use history. Farther east, and on the higher plateaus, where the dry season is shorter and winter drizzle possible, *Aristida* spp. mix with *Loudetia simplex*, *Ctenium concinnum*, and others. Finally, in the grasslands of the humid east, where decades or more of slash-and-burn cultivation have removed woody cover, the fire-maintained grasslands are dominated by *Imperata cylindrica*, *H. rufa*, and *A. rufescens*. While the traditional view is that these grasslands are floristically impoverished (Perrier de la Bâthie, 1921; Bosser, 1954), recent research counters this view (Bond *et al.*, 2008).

7.4 PREHISTORY

7.4.1 Generalities on prehistoric African fire and issues of vegetation "origin"

Fire has shaped terrestrial ecosystems since the first land plants emerged (Scott, 2000). According to charcoal data from sediment cores off the west coast of Africa, fire incidence in the region was low until about 400,000 years ago, but since that time intense episodes of vegetation fires have occurred, especially during periods when climate was changing from interglacial to glacial mode (Bird and Cali, 1998). There is no detectable evidence in charcoal records that humans were responsible for wide-scale altering of the natural fire regime until the Holocene, although it is quite possible that hunters began manipulating fire prior to that time. What is interesting

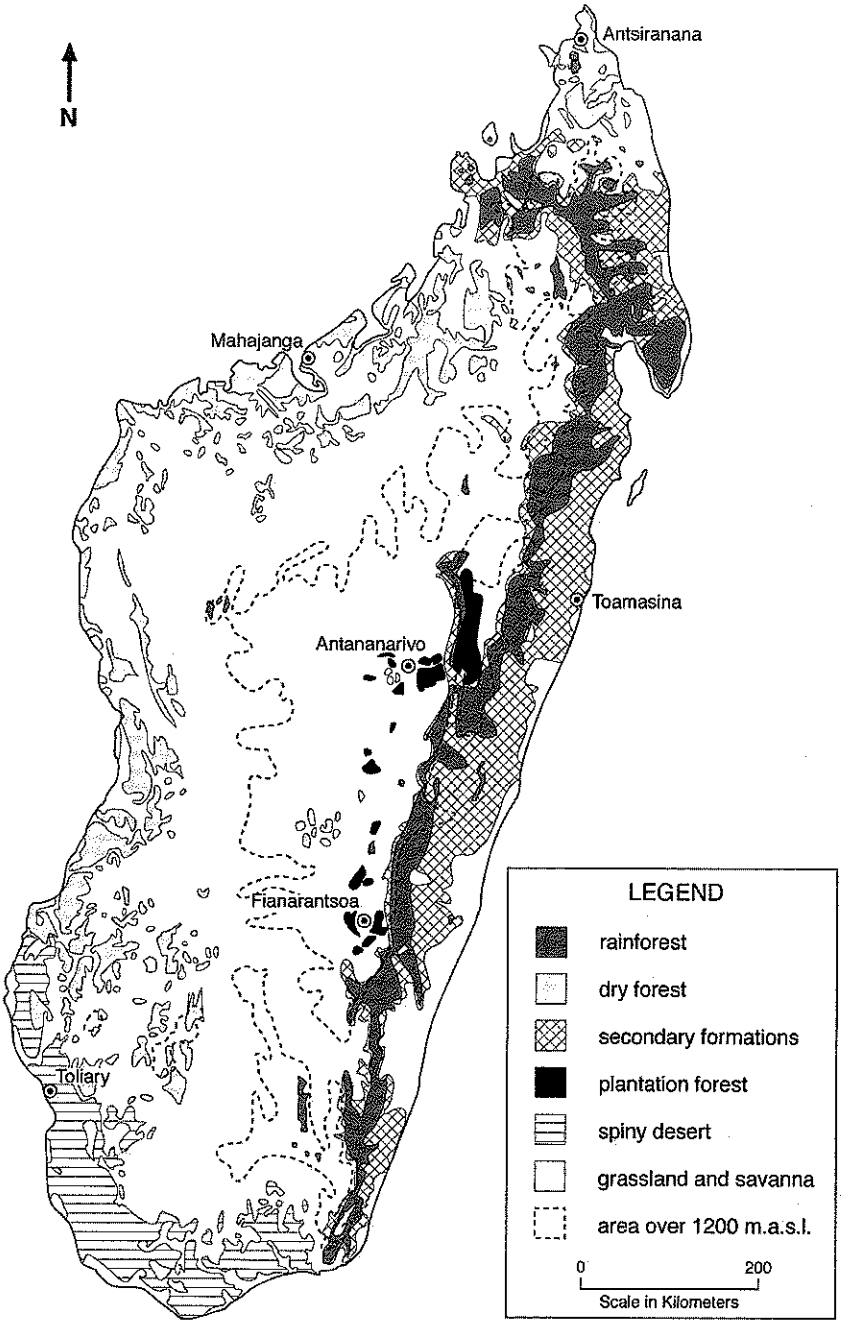


Figure 7.3. Madagascar's current vegetation zones. The category "secondary formations" includes cut forest and various stages of forest regrowth and brush, largely corresponding to areas of slash-and-burn farming (source: Kull, 2004).

in the continental African context is that vegetation, fire, and hominids have evolved together over a much longer period of time than anywhere else. The development of bipedal hominids in fire-prone savanna landscapes also poses important evolutionary questions (Keeley and Rundel, 2005; Ségalen *et al.*, 2007; Bowman *et al.*, 2008).

Over a million years ago, our ancestors observed that the animals they hunted congregated on the flush of new grass after lightning-strike fires, or that different useful plants grew in burned areas. They picked up burning sticks and carried fire to new places, and learned to maintain and stoke fires. By 400,000 years ago—the earliest date with reliable evidence of domestic fires—humans had fully mastered fire tending, including ignition. Ever since, humans have relied on fire to manage their environment wherever they have lived (Stewart, 1956; Sauer, 1975; James, 1989; Schüle, 1990; Westbroek *et al.*, 1993; Rolland, 2004).

One persistent question, particularly in Africa, is what the relative roles of natural and anthropogenic fires have been in shaping vegetation. As noted, it is now well established that anthropogenic fires serve to *maintain* the mixture of trees and grasses in savannas by keeping the tree canopy open, but the question of savanna *origin* remains a matter of some debate. Although it has frequently been argued that anthropogenic fire caused widespread conversion to savanna, recent research suggests that it is more likely that savannas developed naturally and have since been maintained by anthropogenic fire. Savannas composed of C_4 grasses first began to form a distinct vegetation type some 6 Myr to 8 Myr ago (Cerling *et al.*, 1997). Although anthropogenic fires undoubtedly extended areas of flammable vegetation, there is now abundant evidence that natural fires occurred long before humans (Scott, 2000) and that flammable ecosystems predate anthropogenic burning by millions of years.

The appearance of C_4 grasses has been attributed to decreasing atmospheric CO_2, which favors the C_4 photosynthetic mechanism (Ehleringer *et al.*, 1997). Keeley and Rundel (2005) argue that late-Miocene climate changes created a fire climate capable of replacing woodlands with C_4 grasslands. Critical elements were seasonality that sustained high biomass production part of the year, followed by a prolonged dry season that greatly reduced fuel moisture, coupled with a monsoon climate that generated abundant lightning-ignited fires. As woodlands became more open from burning, the high light conditions favored C_4 over C_3 grasses, and in a feedback process, the elevated productivity of C_4 grasses increased highly combustible fuel loads that further increased fire activity. Their hypothesis is supported by paleosol data that indicate the late-Miocene expansion of C_4 grasslands was the result of grassland expansion into more mesic environments and by charcoal sediment profiles that parallel the late-Miocene expansion of C_4 grasslands.

Among grasses, the Andropogoneae family dominate many humid grassy ecosystems with the climate potential to form forests worldwide (Barkworth and Capels, 2000). According to Bond *et al.* (2003), these grasses have several characteristics that promote frequent fires. The sudden appearance of C_4 grass-fueled fire regimes must have presented a formidable obstacle to tree recruitment and survival, especially in the context of falling CO_2 levels. As such, fire-dependent ecosystems such as the African savannas are not merely an artifact of recent anthropogenic burning because they have existed long enough to evolve distinctive biotas (Bond *et al.*, 2005).

While the paleo-ecological data are relatively clear on the dates for the emergence and spread of C_4 savanna grasses, the dates for the shift to a humanized fire regime are much less certain, especially for West Africa where humans have maintained a very long presence. Efforts to pin down dates for the emergence of an anthropogenic fire regime are hampered by the lack of good paleo-ecological data sources and by the fact that both natural and humanized burning regimes leave similar signals.

7.4.2 West African anthropogenic fire history

Humans are known to have migrated to West Africa as early as 30,000 years ago. Archeological excavations for the Lake Chad basin provide evidence for the introduction of pastoralism by around 4000 BP and the domestication of *Pennisetum* (millet) by at least 3000 BP (Breunig *et al.*, 1996). Analysis of charcoal data from sediment cores off the coast of West Africa detects a human signal in the form of a change in the carbon concentration in the sediments at the beginning of the Holocene, indicating that humans have impacted fire regimes at the regional scale for at least 10,000 years. Specifics for local-scale human impacts are more difficult to come by especially in the Sudan and Guinea zones. Uncertainties associated with reconstructing West African climates and vegetation in these areas are largely due to the paucity of paleo-ecological sites. Despite the lack of data (or perhaps because of it) it has often been assumed that these vegetation zones were formerly covered by closed forests and that human impact rather than climate caused degradation to modern savannas (e.g., Aubréville, 1953; Anhuf, 1997) although recent findings cast doubt on this line of thinking.

The few paleo-environmental studies generated from lake sediments in West African savanna sites document the presence of charcoal throughout the Holocene indicating that grass fires were frequent and were probably important in promoting the open character of the vegetation. But the authors of the majority of these studies are unable to distinguish a specific point in time for the shift from natural to anthropogenic fire regimes (Salzmann, 2000; Salzmann *et al.*, 2002; Rasse *et al.*, 2006). Salzmann (2000), for example, stressed that the frequency of charcoal in lake sediments from his work in the Sudan zone remain remarkably constant even into the late Holocene.

It is evident that the region went through a number of important climate shifts and that fire interacted with these shifts, resulting in vegetation changes. The data indicate that the early Holocene was relatively wet, but from 6800 BP onwards a gradual drying period caused a southern shift of the savanna belts, an opening of woodlands, and a drop in lake levels. The drying intensified about 3700 BP before becoming wetter during the last two millennia. As a result, major vegetational changes are recorded at nearly all West African paleo-ecological sites at the beginning of the late Holocene (e.g., Lezine, 1989; Ballouche and Neumann, 1995; Salzmann, 2000; Salzmann *et al.*, 2002). From approximately 2700 BP onwards, the dry forest and woodlands were gradually replaced by highly diversified savannas.

It is clear that, by the late Holocene, humans had modified vegetation at several West African sites. On the Dogon Plateau in the Sahel of Mali, for example, Huysecom *et al.* (2004) find fine deposits, dating to 3200 BP rich in charcoal and organic material. Humans had modified the landscape creating a large-scale mosaic, dominated by savannas with shea butter trees (*Vittelaria paradoxa*) and Combretaceae, alternating locally with *Isoberlinia* woodlands. Farther south, Salzmann (2000) finds increasing sedimentation rates around 2800 BP, indicating increasing human population and modification of the landscape for his site in the Sudan Savanna, Burkina Faso. Such evidence provides a clear indication of human modification of the landscape but these changes do not necessarily coincide with a detectable shift in the fire regime. There are thus two competing hypotheses as to the origins of an anthropogenic fire regime: (i) humans modified the natural fire regime gradually during climate shifts prior to the Holocene; or (ii) humans modified the fire regime relatively rapidly during the Holocene as populations and agriculture expanded, but this shift is not detectable, perhaps because a change from a natural regime to an anthropogenic one involved changes in fire timing as well as area burned and thus might not have produced a detectable change in the charcoal record.

Another factor complicating efforts to distinguish whether savannas in West Africa have human or natural origins are the recent data that indicate that farming and other livelihood practices can cause a shift from grass-dominated savanna to a more wooded landscape (e.g., Guelly *et al.*, 1993; Amanor, 1994; Fairhead and Leach, 1996; Laris, 2008) (see Section 7.7.2). As such, the hypothesis that land use practices such as farming and burning created savannas from forests is highly suspect. As noted, paleo-environmental data indicate that savannas were *naturally* created. Undoubtedly, cutting of some woodlands, followed by farming, abandonment, and frequent burning, served to expand savanna in some areas. An alternative hypothesis for the broad-scale pattern would be that naturally created grasslands were burned by people throughout the Holocene (and perhaps earlier) as part of hunting and gathering strategies. This anthropogenic fire regime served to maintain the savanna structure in spite of recent climate shifts that favor trees over grasses in the Sudan and Guinea belts.

7.4.3 Madagascar

In contrast with West Africa, the human history of Madagascar is relatively brief. Along with New Zealand, this island was one of the world's last major landmasses to be settled. The earliest known permanent human settlement dates only to 1500 years ago, though there are traces of human visits 2300 years ago (Burney *et al.*, 2003, 2004). Evidence is now accumulating about the impacts of fire-bearing human arrival and spread on the island's vegetation cover and fauna; however, several debates persist.

A key debate centers on the nature of pre-human vegetation cover, particularly in the central portions of the island, and the role of fire in that vegetation (Kull, 2000; Gade, 2008). One school of thought presumes that pre-human landscapes were mostly forested, and that lightning fire played only a minor role, if any at all, in these ecosystems (Perrier de la Bâthie, 1921; Gade, 1996; Grubb, 2003). The contrasting point of view asserts that natural grasslands shaped by lightning strike fires and herbivores (now extinct) were widespread (Grandidier, 1898; Dewar, 1984). Others argue for intermediate positions, such as the presence of herbaceous vegetation in the understory of occasionally burnt closed-canopy woodlands (Lowry *et al.*, 1997), or for a forested pre-human landscape "punctuated with non-forested expanses caused by episodic non-human disturbance" (Gade, 2008).

As in the case of West Africa, two lines of evidence increasingly suggest that fire and grasslands were important pre-human landscape components. First, pollen and charcoal in sediment cores from highland lakes show a strong presence of non-forest taxa together with periodic fire before human arrival (Burney *et al.*, 2004). Second, analysis of grassland floral and faunal endemism and diversity suggests that grasslands pre-date humans and their fires (Bond *et al.*, 2008). These authors go on to suggest that grasslands arrived in Madagascar after the late Miocene as part of a global expansion of flammable C_4 grasses.

One can reasonably speculate that pre-human fires were more common in areas with marked dry seasons yet with sufficient moisture for vegetation growth (i.e., the highlands and west), and in areas with ignition sources (such as mountain lightning, or, until the mid-Holocene, volcanism in the central highlands) (Burney, 1996). Fire was rare in eastern humid forests, though possible in mountain regions susceptible to lightning strikes and with flammable ericaceous vegetation (perhaps this explains why a fire-tolerant tree, *Agarista salicifolia*, is common at the treeline and the western forest fringe) and in the somewhat drier Farafangana–Ihosy gap).

Partly as a result of the lack of agreement about the nature of pre-human vegetation cover, our understanding of the role of anthropogenic fire in shaping the modern landscape remains incomplete. Whatever the precise mix of grassy vs. woody vegetation, it appears likely that early settlers and their cattle found ideal pasturing grounds over much of the island's interior. Early settlers' fires would have come to pre-empt lightning fires, burning earlier in the season and more frequently. As a result, grasses would have expanded at the expense of trees and the composition of frequently burned vegetation communities would have changed. These dynamics would also have been influenced by the simultaneous extinction of a number of large animals (Burney *et al.*, 2003; Dewar, 2003) and ongoing climate variations (Burney, 1996; Burney *et al.*, 2004).

7.5 CONTEMPORARY FIRE REGIMES AND IMPACTS

7.5.1 Mali

Each year as savanna grasses dry, people across West Africa set them ablaze. The fires begin the moment the annual rains stop falling and continue throughout the long dry season. Blown by warm, dry winds, fires gradually spread across the landscape ultimately charring thousands of square kilometers (Delmas *et al.*, 1991; Cahoon *et al.*, 1992; Dwyer *et al.*, 2000). West African savannas burn more frequently and extensively than any region on Earth (Dwyer *et al.*, 2000). In some areas, over half of the landscape is burned on an annual basis (Menault *et al.*, 1991; Eva and Lambin, 1998; Barbosa *et al.*, 1999; Laris, 2005).

Nearly all fires in Mali today are set by people and the humanized fire regime is dramatically different from what would occur naturally. Although climate creates the conditions conducive to an annual fire regime, human practices determine when and where fires will be set. The humanized regime has persisted for centuries and current vegetation structure is a function of it. Although these regimes maintain savanna vegetation in areas that would support woodlands or dry forests in the absence of fire, this does not mean that all savannas would be replaced by forest if people stopped setting fires. Fires would occur naturally from lightning strikes at the end of the dry season (Komarek, 1968; Gillon, 1983; Keeley and Bond, 2001) and of course, accidental fires are inevitable in a populated, fire-prone landscape.

Anthropogenic fire regimes are a function of numerous variables including climate, vegetation cover, livelihood system, culture, and politics. These factors combine in different regions of the country to create unique spatio-temporal regimes of fire. In general the fire season begins earlier in the dry season, there are more fires, and the burned area pattern is more fragmented than it would be naturally, but there is variation among different burning regimes and these produce differential impacts on vegetation formations.

In savanna environments, almost all fires are surface fires. They consume dead and drying grasses, tree and shrub litter, and some small trees and shrubs. Canopy fires are extremely rare, although "torching" of individual trees can occur. Fires may burn small patches less than a single hectare (as in the case of an agricultural fire), or large areas on the order of tens of square kilometers. The burned areas left behind by fires may be highly fragmented (as in the case of early fires) or contiguous.

Each year, fires burn a wide swath of vegetation in the savanna belt of West Africa (Figure 7.1). Fire maps[1] generated from satellite images reveal distinct annual spatial and temporal patterns of fire reflecting different ecologies and human land use practices. When viewed from the regional scale, climate appears to be the dominant factor. The fires follow the southward retreat of the ITCZ which leaves the grasses to desiccate. As the wind patterns shift, the Harmattan aids the spread of fires. Fires begin first in the Sahel in September and October and then steadily move into the Sudan Savanna by October and November, before reaching the Guinea Savanna by December. Fires continue throughout the dry season (until May) with an annual peak in burning in late December/early January. The majority of the fires are early dry-season fires (Dwyer *et al.*, 2000; Nielsen and Rasmussen, 2001; Laris, 2005).[2]

[1] There are two basic ways of producing fire maps from remotely sensed imagery. The "active" fire approach involves detecting the flaming fire front, while the "burned area" approach involves mapping the char and ash left behind by a fire.

[2] The onset of the dry season varies according to latitude. The onset of the dry season will begin in September in the far north and November in the south. Similarly, the dividing date between what is considered "early" vs. "late" fire will differ by latitude.

While this broad pattern reflects the influence of regional climate, examination at finer scales reveals how various additional factors cause unique spatio-temporal patterns. In general, fires are most common in the savannas of the southern part of the country and least common in the Sahel. The spatio-temporal pattern of burning also differs between these zones. There are fewer fires in the Sahel, but individual fires tend to be larger and burn the landscape in a more contiguous pattern. Fires in the south are more numerous, smaller, and burn in a highly fragmented pattern. The explanation for these differences is part ecological, part human. Prolonged moist conditions and the heterogeneous vegetation structure of the southern savanna (that include patches of dense woodlands) constrain the spread of fire, especially when fires are set early in the dry season. Fires are larger and more contiguous in the more open savannas, such as the Sahel, where there is sufficient grass production to support annual fires, but not necessarily sufficient tree growth to allow canopy closure. From a human perspective, burning practices vary between these zones due to land use—the northern zone is more pastoral than the south and there is an important difference in herbaceous cover as perennial grasses, which resprout after a fire, are more common in the south (Mbow *et al.*, 2000).

In savanna climates, fire intensity is primarily a function of fire timing or seasonality (Govender *et al.*, 2006). Specifically, 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 juveniles) than fires burning early in the dry season (Menault *et al.*, 1995; Govender *et al.*, 2006). Mature savanna trees can withstand intense fires, although there is some evidence that if burned late, when diseased or drought-stressed (for multiple years), fire can kill even large trees (Swaine, 1992). Since the majority of the fires in West African savannas are early dry-season fires it can be assumed that most are of low intensity.

In general, fire—particularly late dry-season fire—serves as a buffering force preventing the establishment of new trees. Burning experiments 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; 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 a landscape subjected to a regime of early fires will support a mix of savanna trees and grasses. Finally, the studies demonstrated that when protected from fire, savanna patches will evolve into dense woodland with a near-closed canopy.

Estimates for the frequency and annual area burned find that, globally, fires are most frequent and prevalent in savanna ecosystems. Menault *et al.* (1991) found that 5%–15% of the Sahel, 25%–50% of the Sudan Savanna, and 60%–80% of the Guinea Savanna in West Africa burned annually. Eva and Lambin (1998) found slightly lower values of 1% for the Sahel, 28.2% for the Sudan zone and 51.8% of the Guinea zone of central Africa. Barbosa *et al.* (1999) found higher levels of burning in the Sahel (15%) and Sudan zone (70.1%), and lower values in the Guinea zone (57.7%). While these values paint a general picture of the fire regimes in West Africa, it should be noted that estimates of area burned vary widely (see below).

Within all zones, the amount of area burned tends to decrease with increasing agricultural activity, probably due to the combined effects of the low levels of available biomass, highly fragmented agricultural landscapes, and active efforts to suppress fire. For example, the densely populated peanut basin in Senegal and central Burkina Faso experience few fires (Langaas, 1993; Wardell *et al.*, 2004).

There have been few reliable studies on the interannual variability of fires in Mali or West Africa more generally. Few multi-year fire datasets exist and those that do suffer from relatively high levels of error because only a fraction of the total fire activity for any given period is detected and mapped (Eva and Lambin, 1998). The error associated with these data make it difficult to quantify differences in burned area and fire intensity between years, in part because algorithms have been designed to err on the side of reducing commission error at the expense of increasing omission error and thus underestimate the area burned (Boschetti *et al.*, 2004; Laris, 2005).[3] This bias may explain, in part, why studies aimed at linking interannual variability of savanna fires with rainfall data find little correlation (e.g., Koffi *et al.*, 1995).

Undoubtedly, the timing and amount of rainfall affects the date of the onset of the fire season and will have some impact on the area burned, but this will likely vary by zone. In some areas of the more arid north, drought may severely suppress grass production, limiting the fuel for fires and thus the area burnt. In the moister south, multiple low-rainfall years may result in fires burning into more wooded areas (Justice *et al.*, 1996). In general, however, a striking characteristic of the fire patterns in the savanna belts is the regularity of the annual regime of fire (Barbosa *et al.*, 1999; Laris, 2002).

7.5.2 Madagascar

In Madagascar, the largest expanse of fire occurs in the grasslands that currently cover two-thirds of the island. Here, an estimated 25%–50% of the land burns annually. As for slash-and-burn fires in forest zones, it is estimated that between 2,000 km^2 and 7,000 km^2 burn annually. Overall, tens of thousands of square kilometers, and perhaps up to 200,000 km^2, burn annually on this 587,000 km^2 island. Unfortunately, estimates remain wildly divergent (Kull, 2004).

As is the case with Mali, Madagascar's fire regimes differ sharply by region and locality. General trends do emerge, however. The annual fire season tends to begin in the western lowlands, where the dry season is the most marked. Here, numerous fires can already occur in April or May. Fires then move east towards the interior highlands, but only become frequent and large starting in August, once the fog and drizzle of the cool winters has abated (see photo series in Kull, 2002a). The last region to burn is the humid eastern coastal plains and escarpment, where farmers light fires after the short dry periods that occur during the pre-monsoon months of September to December.

[3] An omission error is defined as failure to detect a fire that has occurred, while a commission error is a false detection.

Fire size and severity vary by region and have not been systematically described. Most fires in the lightly populated grasslands of the west and center are of low to moderate intensity and result in near-complete combustion of above-ground grasses and forbs.[4] Typical pasture fires cover anything from 0.5 ha to over 100 ha. Individual fires can, in certain instances, burn vast areas, on an order of magnitude of 100 km^2, though early-season burns tend to interrupt the free rein of such wildfires. Woodland fires tend to remain in the understory, with varying intensity depending on fuel load and moisture. Observations of flame length in *Uapaca* woodlands in the central highlands (Kull, 2004; cf. Grubb, 2003) varied from 20 cm flame heights in short green grass in the early dry season to 6 meters in thick grass in the late dry season; crown fires were only observed in areas invaded by exotic *Pinus*. In more densely settled areas of the center and east, where landscapes are a mosaic of cropfields, woodlots, and open pastures, the vast majority of fires are small (measured in single hectares); the biggest individual fires rarely extend more than 1 km^2. In humid forest areas and adjoining areas of fallow scrub and secondary forest, slash-and-burn agricultural fires tend to be limited to single-crop fields, consuming most of the vegetation, save the larger woody matter. Residual moisture in un-slashed vegetation, as well as farmer vigilance, usually limits the spread of such fires; however, several occasions have been noted where such fires escape, burning significant areas of montane forests (Vignal, 1956; Kull, 2004).

The vast majority of fires in Madagascar are now human-lit. However, lightning fires are a strong possibility, particularly in high-relief mountain areas and in the months before the arrival of the monsoon (Kull, 2004). Lightning activity over much of the center and west is observed at over 20 flashes/km^2/yr, far higher, for example, than the lightning-prone fire areas of the western United States (Christian *et al.*, 2003).

In contrast with the regularity of Mali's fire regime, in Madagascar fire activity can vary sharply from year to year, shaped by variations in fuel availability and ignition sources. Fuel availability and condition are shaped by climate. At a global level, droughts increase fire in humid forest areas whereas wet periods increase fire in fuel-limited arid zones; such links are less consistent in transitional grassland zones (van der Werf *et al.*, 2008). Droughts in Madagascar tend to be correlated with El Niño events. Ingram and Dawson (2005a) find that El Niño events are associated with lower vegetative productivity on the island and conclude that this leads to more wildfires. However, satellite modeling of fire emissions during the 1997–1998 El Niño showed lower than average fire activity in humid eastern Madagascar but higher than average fire activity in central and western Madagascar (van der Werf *et al.*, 2004). Variations in fire ignitions in this anthropogenic fire regime depend on social and political trends. Rural Malagasy people have lit different amounts of fire in different years due to variables such as threats of enforcement or moments of political instability (Kull, 2002b, 2004).

[4] A broadleaf herb or weed.

7.6 HUMANS AND FIRE IN LANDSCAPE MANAGEMENT

7.6.1 Why do Africans burn the land?

Humans evolved in Africa in the presence of fire. Little is known, however, about the interconnections between human evolution and the flammable savanna biome (Keeley and Rundel, 2005; Ségalen *et al.*, 2007; Bowman *et al.*, 2008), nor about exactly how or why humans first shepherded, kept, lit, and used fire. Given our species' long history of fire use, it should be no surprise that modern human fire use is complex and woven into many overlapping (or sometimes conflicting) aspects of land management. Many fires have multiple useful outcomes—at different time scales or with respect to different management goals—so simple classification is difficult. Here we summarize key uses of fire—with selected examples from around the continent—categorized by management outcomes.

Although it is often spoken of in terms of specific uses or applications (e.g., burning to clear a field for agriculture or burning to improve pasture), fire is perhaps best thought of as a tool for modifying vegetation at the landscape scale. From the perspective of the land manager, fire is used to cause the greatest modification with the least amount of effort. Fire may be used to accomplish a very specific task on a small parcel of land, such as burning the slash on a new clearing to prepare it for farming, or fire may be used as a process for converting or modifying the majority of the dry-season landscape. In Mali, for example, people progressively burn relatively small patches of vegetation, creating a seasonal mosaic. The fires often serve multiple purposes simultaneously. For example, fires set to improve pasture will often also serve to improve transportation and visibility while eliminating pests. A series of such fires also serves to provide the land manager with security from more dangerous (and possibly damaging) late dry-season fires.

In Sections 7.6.1.1–7.6.1.8, we list some common uses of fire in Africa, recognizing that some of these uses may be competing while many others are complimentary. Numerous studies demonstrate that local actors have a profound knowledge of the differential impacts of varying fire regimes (e.g., Hough, 1993; Mbow *et al.*, 2000; Laris, 2002; Kull, 2004; Wardell *et al.*, 2004). These studies and others document the plethora of reasons for setting vegetation fires in Africa. A key weakness of many studies is the failure to link fire with key variables such as timing and vegetation type.[5] A summary of some of the most common reasons follows.

7.6.1.1 Fire is used to hunt

Hunters have long used fire for two general purposes. First, fires are set early to create patches with a new flush of green grass and to eliminate tall stands of grasses that reduce visibility. Second, fires are set later in the dry season to flush game from patches of unburned vegetation.

[5] See Section 7.6.2 for exceptions.

7.6.1.2 Fire is used in livestock husbandry

In tropical wet–dry grasslands, much more grass grows in the wet season than can be grazed. Grassland fire removes old, lignified grass, simultaneously facilitating the growth of new shoots and making them accessible for consumption. This "green pick" often comes at a lean time of year, when it is crucial to cattle sustenance. A strategic regime of burning can extend the availability of fresh grass well into a long dry season. Later, more intense fires may also serve to prevent the encroachment of woody plants into rangelands, and have been used to reduce tick infestations.

7.6.1.3 People manage vegetation using fire

The frequency and timing of fire influences species composition and vegetation structure in a given area. For example, at the forest–savanna boundary in Ivory Coast, early-season fires favor trees, while later fires favor grasses (Bassett and Koli Bi, 2000). People may also time fires so as to encourage certain grasses over others (Kepe and Scoones, 1999), to encourage the production of valued fruits and nuts such as the shea nut, and to activate exudation of gum arabicum from *Acacia*.

7.6.1.4 Fire can be used to manage useful insects

Several cases exist where rural residents burn woodlands in order to manage insect populations. Late dry-season fires in Zambian *miombo* cause a new flush of leaves that stimulate the breeding of a valuable marketable caterpillar (Eriksen, 2007). Likewise, in the dry evergreen woodlands of central Madagascar, fires encourage the dominance of *Uapaca bojeri* trees, a prime food source of native silk worms (Kull, 2002d). Fire is also used around the continent to facilitate the collection of honey (e.g., Langaas, 1992; Hough, 1993; Eriksen, 2007).

7.6.1.5 Fire is used to control pests and other threats

Regular burning is used across the continent to reduce bothersome tick populations (Bartlett, 1956). Damaging locust invasions occur every decade or two in parts of the continent; during these potentially disastrous events people light fires with the goal of using the smoke to ward off the swarms from their crop fields, and to kill them as they rest in the grass at night (Kull, 2004). Finally, people burn around homes, fields, and paths to reduce habitat and cover for agricultural pests like rats or crop-eating birds, or for physical threats like snakes or lions.

7.6.1.6 Fire can facilitate gathering

Fire is a tool for removing grass cover so as to facilitate the gathering of tubers, fruits, and nuts and to expose mineral outcrops (Bartlett, 1956; Langaas, 1992; Hough, 1993; Laris, 2002).

7.6.1.7 *Fire is used for agriculture*

Aside from its role in clearing vegetation off a plot to facilitate cultivation, fire also aids agriculture as a tool for fertility management. While permanent agriculture relies upon fertilization, weeding, and soil manipulation to guarantee good harvests year after year, slash-and-burn agriculture relies upon time and fire. Soil fertility is maintained through fallow periods longer than cultivation periods, and the burning of the standing vegetation before planting provides a crucial input of nutrients (Bartlett, 1955; Richards, 1985; Peters and Neuenschwander, 1988; Kull, 2004; Ericksen, 2007). Fire in slash-and-burn systems can also keep crop predators at bay, kill the seeds of some weeds, and may make the soil more friable (Peters and Neuenschwander, 1988; Brand and Pfund, 1998).

7.6.1.8 *Fire is used for risk management*

Many fires are set with the intent of creating a landscape mosaic that prevents the spread of more dangerous late dry-season fires. Not all fires, after all, burn the landscape in a controlled manner. Some are lit for malicious purposes—for reasons of jealousy, spectacle, and political protest—and others are accidental, including hunting, sparks from railways, automobiles, cigarettes, cooking, and general carelessness. As such, fires are often set early in the dry season as a form of wildfire control, to prevent fires from burning villages with grass thatch roofs or natural resources such as agricultural fields, pasture, orchards, or woodlots (Bartlett, 1956; Langaas, 1992; Fairhead and Leach, 1996; Laris, 2002).

It should be emphasized that most fires in tropical Africa—and those which we describe—occur on lands for which the management systems are neither "private" nor "public" (categories more familiar to Western fire managers). Most land in Mali and Madagascar, and indeed in much of Africa, is best described as "village land". They are typically formally claimed by the state, but *de facto* under the control of rural residents. Cropfields are "privately" held by individuals or families, at least during the cropping season. Fallow fields and pastures tend to be more communally managed. More often than not access to village lands is regulated through customary institutions. Relatively small areas of land are formal "private" lands (like commercial plantations) or formal "public" land with government management (like protected areas).

7.6.2 Seasonal mosaic burning in Mali

The use of fire in the West African savannas is tied broadly to the livelihood system of which there are two basic types: pastoralism with some dry-season millet farming is found in the more arid Sahel, while agriculture, often intermixed with livestock grazing, predominates in the more humid south. As noted, the fire regimes differ significantly between these two zones. Although parts of the Sahel do burn each year, fire is generally undesired by the rural population. The exceptions are small fires set for agricultural field preparation and for burning small, isolated lowland patches or depressions used for livestock grazing (Mbow *et al.*, 2000). Section 7.6.2.1 describes the logic, regime, and impacts of burning in the southern Sudan Savanna of Mali (Figures 7.4a–e).[6]

7.6.2.1 The spatio-temporal pattern of fire

The spatio-temporal pattern of annual burning for southern Mali embodies a seasonal mosaic regime where some patches of the landscape regularly burn early, others late, while some patches rarely if ever burn (Laris, 2002; Laris and Aziz, 2008). There is a distinct spatial and temporal pattern of burning that is repeated annually. Early fires produce small, irregularly shaped, and highly fragmented burned patches while a few late-season fires result in larger and more contiguous burned patches (Figure 7.5).

Most of the fires are set early in the dry season (by the end of December) and the majority (over 70%) of the total area affected by fire is burned early, according to survey and satellite image analyses. The vast majority of the early fires burn relatively small areas (on the order of a square kilometer and often less) and they leave a highly fragmented pattern of burned patches on the landscape. A significant percentage (on the order of 20%) of the entire landscape burns during the onset of the fire season (the first four to six weeks). The pattern of early burning is highly fragmented and discontinuous suggesting a widespread effort by the rural population to set fires early to patches of grasses as soon as they are dry enough to burn.

Burning peaks in late December or early January when fires tend to be somewhat larger and more contiguous, especially in those areas where little early burning has occurred. Burning continues in January and February although there are fewer fires and less area is affected. The burning largely tapers off by the month of March. By this time, most fires burn themselves out as they reach the edges of previously burned areas or other barriers, creating a complex mosaic of early, late, and unburned patches.

7.6.2.2 Linkages to soil/vegetation patterns

The timing of fires is closely linked to the vegetation type and is influenced by livelihood activities, the agricultural calendar, and fire policy. Fires set during the onset of the dry season in late October or November are restricted to patches of short-grass savanna on laterite outcrops and dry gravelly soils which are dominated by short annual, unpalatable grasses (principally *Loudetia togoensis*, but also *Andropogon pseudapricus*) with only widely scattered trees. These patches are viewed as "waste-land" and are nearly always burned off early. Early fires may also be set on recently fallowed land, dominated by annual grasses including *Andropogon pseudapricus* and *Pennisetum pedicellatum* which desiccate rapidly after the rains stop. Early fires often burn through patches of annual grasses and into adjacent perennial grasses composed

[6] Laris (2002, 2005; Laris and Aziz, 2008) combined survey results, in-depth interviews, transect walks, and analysis of a multi-year dataset of burn scars generated from Landsat imagery to document the spatio-temporal pattern of burning and the logic behind it for an area of southern Sudan Savanna in Mali.

of *Andropogon gayanus*, *Hyparrhenia dissoluta*, *Cymbopogon giganteus*, and *Schizachyrium pulchellum*. When set early, these fires typically burn themselves out after partially burning patches of these deeper rooted grasses. These well-timed fires create edges of "green bite" where perennial grasses re-sprout creating a key source of dry-season fodder for wild and domestic animals.

The end of the harvest in late December/early January is marked by a flurry of burning. By this point, people setting fires do not have to worry about damaging neighboring crop fields. The timing of these fires also coincides with the official government deadline for early-season fires (January 1). Late-season fires predominate on more mature woodlands and older fallows or secondary growth areas dominated by perennial grasses and mature trees. The deeper root systems of the perennial grasses, combined with the shade from the tree cover, normally prevents these areas from burning thoroughly before the end of December, although they may be partially burned in a patchy manner at earlier dates.

7.6.2.3 *Reasons for the pattern*

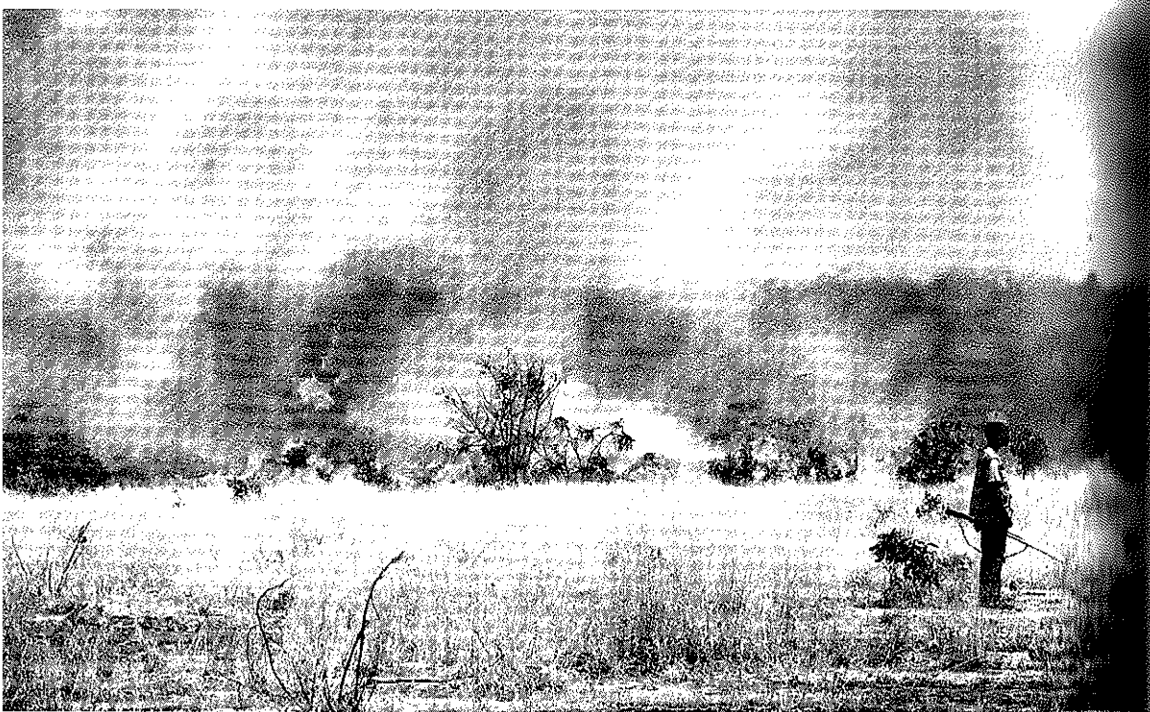
According to surveys of farmers, herders, and hunters who regularly set fires, the most common reasons for burning early are to protect areas from fire and/or to prevent later more damaging fires (Table 7.1). People burn to protect trees, agricultural fields, orchards, and villages from later fires, as well as to prevent damage from

Table 7.1. Linking burning logic in Mali to vegetation type and spatio-temporal regimes. Results on the left derive from satellite image analysis for the entire study area while those on the right reflect survey and interview data for the villages surveyed (modified from Laris, 2006).

Date imagery	*Area burned (%)*	*P/A[a] index*	*Fire type*	*Vegetation type*	*Rural calendar*	*Most common reasons to burn (for more detail, see Laris, 2002)*
12/04/2002	17.56	.305	Early	Short-grass savanna	Peanut harvest	Protect against late fires, separate landscape to clear paths and form firebreaks, prepare hunting grounds, regenerate pasture, eliminate pests
12/20/2002	8.09	.275	Early	Short-grass savanna and short fallow	Millet harvest	
01/05/2003	15.8	.195	Early	Fallow lands	Harvest end	
02/06/2003	10.54	.217	Late	Long fallow/ woodland	Cool season	Hunt, clear grasses and pests to promote wood cutting or gathering, accidents, unknown
03/10/2003	4.91	.429	Late	Long fallow/ woodland	Hot season	Hunt, field preparation accidents, unknown

[a] The perimeter/area (P/A) ratio gives a good indication of the degree of fragmentation of the burn pattern (higher values indicate high fragmentation).

Figure 7.4. Series of photos illustrating fire in Mali. (*This page, top*) Malian hunter lighting an early dry-season fire. (*This page, bottom*) active early-season fire. (*Facing page, top*) Patchy fire scar following an early burn (note green vegetation in background). (*Facing page, bottom*) green bite after an early fire; note a second fire is burning the remaining stubble. (photos reproduced by the kind permission of C. Strawn, 2005). *See also* Color section.



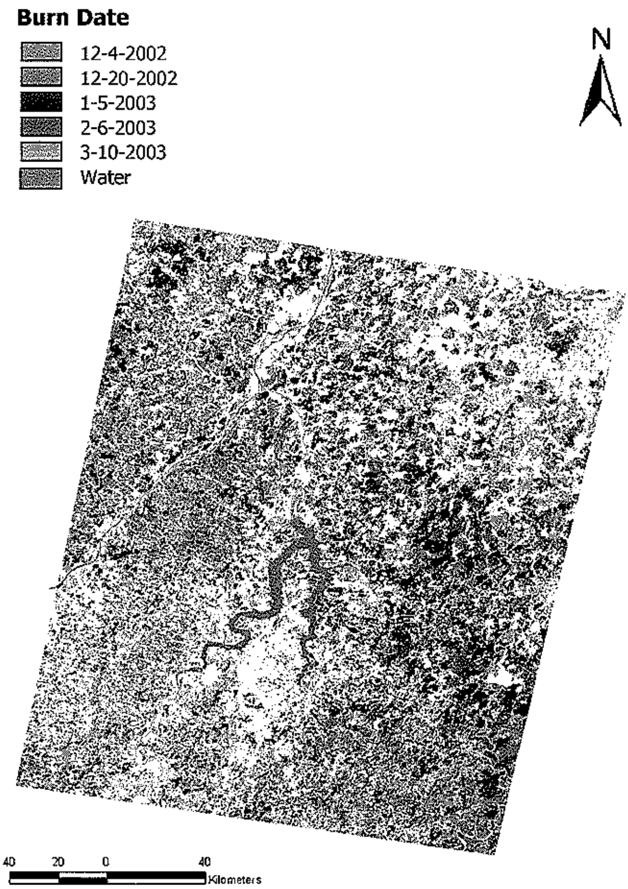


Figure 7.5. Satellite image of fire mosaic, 2002–2003 fire season, in study area in southwestern Mali (source: Laris, 2005). *See also* Color section.

later fires in general. They burn to clear paths, eliminate pests, and improve pasture and hunting areas. Although people give many reasons for setting a specific fire, "separating areas" (which prevents the spread of fire while creating edge habitants) is another critical strategy behind burning early because it renders the landscape useful for a wide variety of dry-season activities.

Some burning also occurs in the middle of the dry season. These fires may be set as part of a hunting strategy or to facilitate grass regrowth in low-lying areas or the gathering of wild fruits and nuts. Finally, some burning also occurs at the end of the dry season during field preparation (April and May), but the area burned by these fires is relatively small since by this point in time the landscape is generally too fragmented to burn extensively.

7.6.2.4 Ecological and biogeographical implications

Numerous scholars have argued that the spatio-temporal pattern of burning affects ecosystem function and can result in distinct vegetation formations. In particular, a regime of small, fragmented, or patch mosaic fires, will produce a different vegetation formation than a regime of large, contiguous fires. Research shows that patch mosaic burning results in two key ecological impacts, the creation of *edges*—boundaries of ecological areas—that tend to increase ecosystem biodiversity, and the suppression of large, contiguous, and more intense fires later in the season (Russell-Smith *et al.*, 1997; Boyd, 1999; Parr and Brockett, 1999).

The striking finding of a survey of rural Malians was that many savanna patches are burned at approximately the same time each year. Indeed, on the lands that burned annually, 80% of these burned at approximately the same date each year. The pattern is especially regular for the early part of the burning season. Satellite image analysis of a multi-year dataset finds that fires set in November and early December tend to burn the same patches of savanna every year (see Figure 7.6). For example, the average burn date for all patches of short-grass savanna was December 8 and, according to the survey, 96% of these patches are burned early every year.

The data suggest that specific patches of vegetation regularly burn early (in some cases annually), late, or never. Short-grass savannas and young secondary growth areas tend to burn early, mature woodlands burn later, while densely wooded patches, riparian areas, and the areas immediately surrounding villages rarely if ever burn. The data also show that a large percentage of the study area (nearly 90%) was

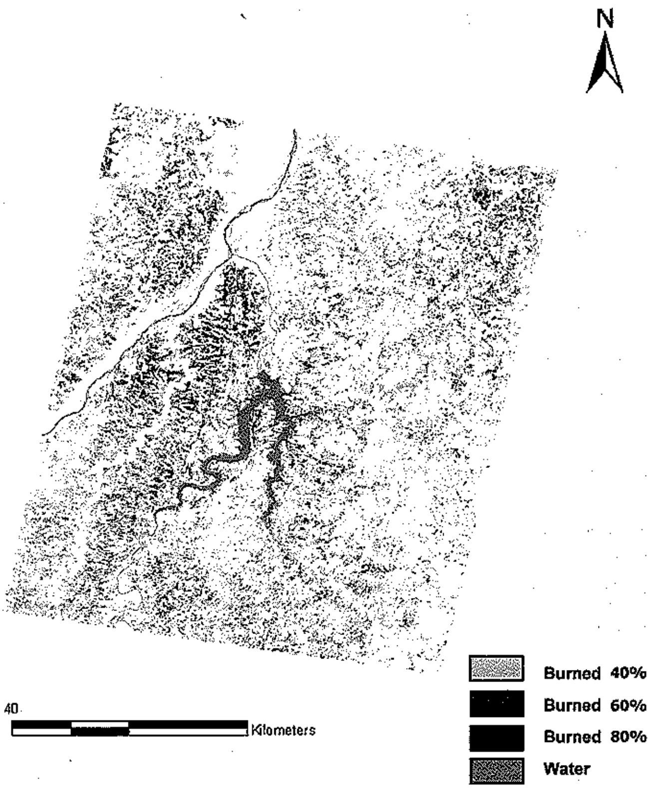


Figure 7.6. Burn frequency for early fires in southern Mali. The burn frequency values are in terms of the percentage of the time a given patch burns based on the analysis of November burn scars for eight fire seasons. *See also* Color section.

affected by fire at some point during the study period, while 71% of the area burned more than once.[7]

Based on the results presented here, an argument can be made that the heterogeneity of the Malian savanna landscape is a function of a regularized anthropogenic burning regime. As such, one would expect that the broad vegetation pattern (the mix of tree and grass patches at the landscape scale) would also be relatively stable as opposed to shifting over time (especially in areas with a low degree of agricultural pressure). This is precisely the conclusion of two recent studies which found that forest/savanna boundaries in West Africa are remarkably stable over time, in spite of frequent burning (Goetze *et al.*, 2006; Henneberg *et al.*, 2006).

There are two notable variations in the general mosaic burning regime. First, areas with few patches of short-grass savanna tend to have fewer early fires and a more contiguous pattern of burning later in the dry season (see the southeast section of Figure 7.5). And second, in areas with a large influx of cattle, such as the northern Ivory Coast, the number of early fires may initially increase and timing of fires may become earlier as herders seek to increase the area of green bite. Ultimately, however, a large increase in grazing animals will result in a reduction in burned areas as animals eliminate the fuel source. Under these circumstances, shrub encroachment can occur, further reducing the amount of area burned (Bassett and Koli Bi, 1999).

In summary, the typical indigenous pattern of burning annually produces a mosaic landscape of burned and unburned patches of vegetation. There is reason to suspect that this burning regime has persisted for centuries as it is well suited to the hunting culture and agropastoral livelihood system of the indigenous people. Similar regimes have been observed in the neighboring countries of Senegal, Gambia, Burkina Faso, and northern Ivory Coast (Dwyer *et al.*, 2000; Mbow *et al.*, 2000; Nielsen *et al.*, 2002), as such, it is probable that the vegetation and biodiversity of the zone is a function of the fire regime documented here.

7.6.3 The culture of fire use in Madagascar

Several main "fire cultures" exist in Madagascar (Figures 7.7a–e).[8] The first centers on the use of fire for agriculture in forested landscapes. Such "slash-and-burn" farming, often described under the label *tavy*, is mainly used to cultivate rain-fed rice, the national staple. Fire serves to clear slashed vegetation and fertilize the soil. Increased use of tavy by growing populations displaced from other lands, and their practice of relatively short fallow times, have contributed to progressive forest loss along the whole length of the humid, eastern forest (Kull, 2004; Styger *et al.*, 2007). Slash-and-burn cultivation in the drier west-coast woodlands, linked to market

[7] These figures are based on the analysis of a multi-year Landsat dataset covering the years 1972–2003.

[8] Based on Kull (2004), which used a multi-sited ethnographic approach together with archival and documentary research to assess the use of fire in Madagascar.

demand for maize, has also decimated certain forest areas (Seddon *et al.*, 2000; Réau, 2002; Blanc-Pamard *et al.*, 2005).

Tavy typically begins along the valley bottoms, proceeding progressively uphill over time, leaving steep slopes, poor soils, or rocky terrain for last. Cultivation rights typically belong to the descendents of the first person to clear a plot, and extend uphill from the original plot (Coulaud, 1973; Dandoy, 1973; Brand, 1998, 1999; Laney, 1999; Pfund, 2000; McConnell, 2002). Farmers cultivate the vast majority of *tavy* fields, not in primary forest but in previously secondary forest or bush, often known as *savoka* (Goldammer *et al.*, 1996; Brand, 1998; Pfund, 2000). This is because primary forests are more remote, harder to clear, in less attractive sites, and more protected.

Once a site is chosen, farmers cut the standing vegetation with axes or machetes, typically between August and October. The size of the cleared plot varies from 0.25 ha to 1 ha (Coulaud, 1973; Le Bourdiec, 1974; Brand, 1998, 1999; Gautier *et al.*, 1999). As opposed to elsewhere, such as western Madagascar (Genini, 1996) or Guinea (Sirois *et al.*, 1998), in eastern Madagascar no trees are left standing. The mass of branches, wood, and leaves is left to dry for at least two or three weeks. Farmers sometimes clear fire breaks around the edges of the field, spurred by forest legislation as well as the need to protect sacred forests, tombs, or other crop fields (Kull, 2004). Farmers set fire to *tavy* fields once the slash is sufficiently dry, typically in October or November, just before the rainy season. Most burning occurs in the afternoon (Goldammer *et al.*, 1996).

Following the fire, tavy fields are sown with rice and other crops for one or more years—strategies vary by farmer and region (Kull, 2004). After cultivation, tavy plots are left to fallow. The time in fallow varies widely, however, depending upon the soils, the plot history, land availability, and family needs. In Betsimisaraka country, east of the capital, the mean fallow length was five years, but the average varied from 3 years in younger lands at the forest frontier, to 12 years in soils used for longer periods (Brand, 1998, 1999; Brand and Pfund, 1998; Pfund, 2000). Several researchers document farmers shortening fallows to 3 or 4 years in response to population pressure and poverty (Gautier *et al.*, 1999; Laney, 1999; Styger, 2007). While fields fallow, they can be used for numerous purposes, including woodfuel, medicinal plants, construction wood, fibers, and pasture (Pfund, 2000).

Slash-and-burn cultivation proceeds in a similar fashion in the western dry forests. For example, in the Morondava region, forest undergrowth is cut between June and September, and then burned in October. This fire kills all the surface vegetation save large, standing baobabs. Maize is cultivated for 2–3 years, with a yield of perhaps 2 t/ha. Afterwards, the plot is reburned to clear weeds and it is cultivated for another 2–3 years. Then the plot is left to fallow, more due to an increase in weed invasions than to decreasing soil fertility (Genini, 1996). In the Tulear region, most field preparation fires occur in August–October. In the hatsake (slash and burn), cultivation of maize is carried out on plots ranging from 1 ha to 10 ha in size. A recent boom in maize cultivation significantly threatens regional forests (Seddon *et al.*, 2000; Blanc-Pamard *et al.*, 2005; Lasry *et al.*, 2005).

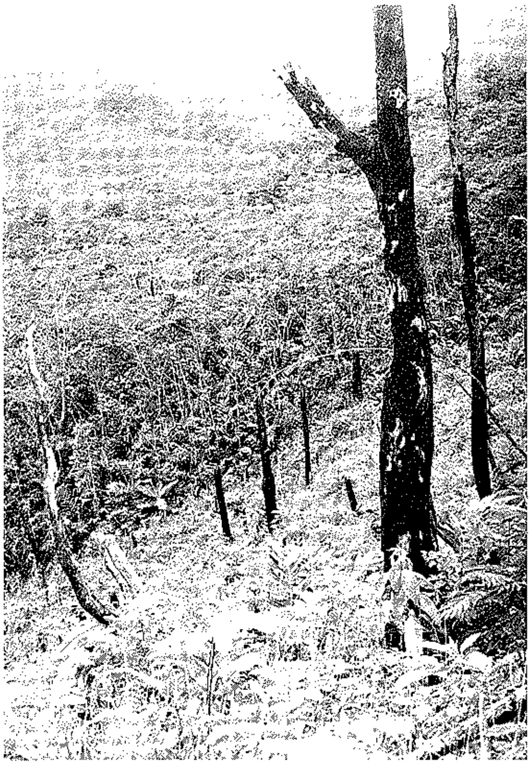
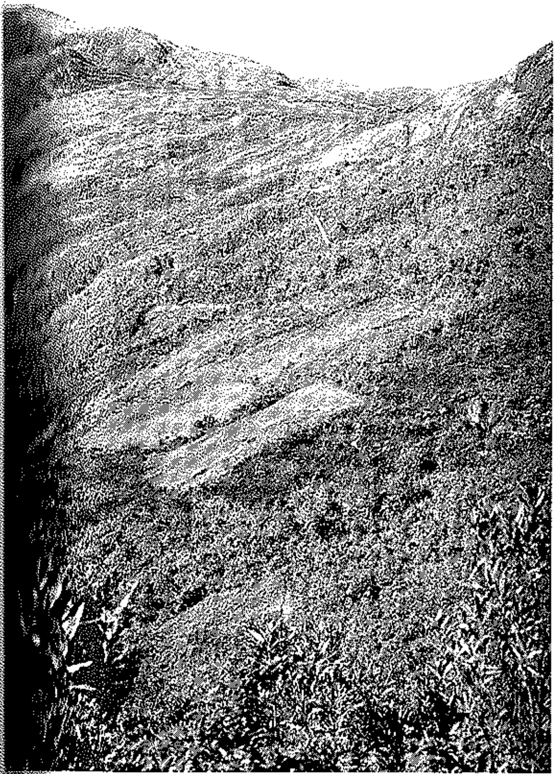
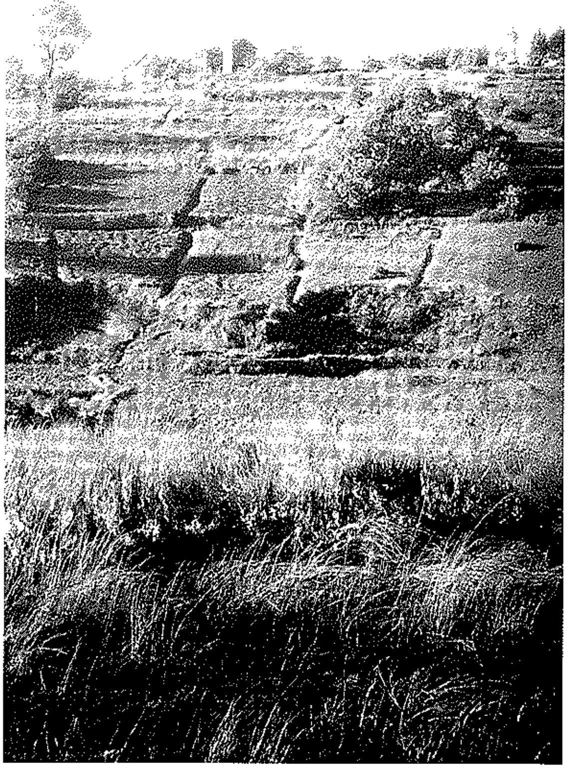


Figure 7.7. Photos illustrating fire in Madagascar. (*This page, top*) Burned tree trunks in regenerating *tavy* slash-and-burn field, surrounded by patchwork landscape of plots in various stages of regeneration (northeastern Madagascar, near Andapa) (photo by C. Kull 1994). (*This page, bottom*) Small forest blocks remaining in Zafimaniry country (east of Ambositra) on Madagascar's formerly forested escarpment. Clearance due to tavy fires followed by repeated fires (photo by C. Kull, 2001). (*Facing page, top left*) Cropfields cleared by fire in secondary scrub in humid montane forest zone (Zafimaniry country, east of Ambositra, highland Madagascar). Fire scar clearly extended farther than cultivated plots (photo by C. Kull 2001). (*Facing page, top right*) Small pasture fire in densely settled agricultural zone of highland Madagascar (near Ambositra) (photo by C. Kull 1999). (*Facing page, bottom*) Smoke from pasture fire in vast grasslands of the western highlands, near Tsiroanomandidy (photo by C. Kull, 1999). *See also* Color section.





The second major fire culture in Madagascar centers on pastoral fires in open landscapes. These fires serve the island's cattle economy, essentially managing fodder for the country's ten million head of cattle (Cori and Trama, 1979; Kull, 2004). They take place in the vast grasslands of the center (Kull, 2004), the savannas of the west (Lasry *et al.*, 2005), and in the deforested pastures of the humid east (Pfund, 2000). The fires defend rangelands from bush encroachment and assure cattle survival by providing a nutritious green bite. They also reduce populations of bothersome ticks and protect the hills against unpredictable and destructive wildfires.

Pasture burning follows an unseen, unwritten management plan. Management is opportunistic, in the sense that people exploit environmental opportunities like a dry spell (Westoby *et al.*, 1989; Behnke and Scoones, 1992) as well as social opportunities (like a reduced chance of enforcement, or happening to be passing through an area that needs burning) to ignite fires. Despite the opportunism, the result demonstrates a distinct logic. Sufficient areas burn to maintain pasture, and spatial and temporal rotation ensures resource patchiness and fire control. While people ignite fires throughout the year, the winter months (June and July) begin the normal cycle of pasture renewal. August, which marks the beginning of warmer spring days and reduced humidity, results in a great batch of pasture-renewing fires. By September and especially in the heat of October, burns fill in unburned patches. The coming of the rains in November and December slows the burning.

The "green bite" (Jolly, 1989), provided by these fires, fits well with Madagascar's agropastoral calendar. In winter, few herders take cattle to the broad pastures; instead they allow them to feed on crop stubble in fallow fields, on green streamside vegetation, or, in some regions, on piles of rice straw, cassava, or hand-cut grasses. From September onwards, however, crop stubble and rice resprouts in the valley bottoms are plowed under in preparation for the growing season, leaving only lignified pasture grasses to the cattle. Burning serves several roles at this point. For one, it stops bush encroachment. Without such fire, grass litter begins to accumulate and enrich the soil organic horizon. Depending upon the climate, seeds, and soils, woody plants, and other non-herbaceous species may invade, and pasture is lost. Common woody invaders in Madagscar include the leguminous *Sarcobotrya strigosa*, the guava bush *Psidium guyava*, *Erica* spp., *Helichrysum* spp., bracken fern, and introduced *Acacia* or *Pinus*.[9] Furthermore, fire removes the dry stalks of old grass which can impede the access of cattle to new shoots; it releases nutrients back to the soil, fertilizing the new growth; it overrides the competitive effects of selective grazing, giving favored forage species a better chance; and it exposes the soil to the sun, which in areas of sufficient moisture may accelerate the growth of the resprouts (Cori and Trama, 1979; Kull, 2004). This green bite is critical to the health of the cattle, for the protein-rich resprouts—even of poor quality forage species like *A. rufescens*—carry the cattle through the annual hungry season. The logic of the green bite explains the hesitance of Malagasy farmers to engage in late or early fires advocated by some technical experts, as they do not provide the green shoots at the right moment.

[9] Granier (1965), Cori and Trama (1979), Koechlin (1993); see Holland and Olson (1989) for a detailed analysis of Malagasy woody pioneers.

As is the case in Mali, the opportunistic rotation of patch burns also serves as a built-in protection against running wildfires. Fires lit at the beginning of the dry season and during cool, overcast, humid winter days tend to progress slowly, burn incompletely, and are easily controlled. By burning piece by piece, month by month, this creates a patchiness in the grassland landscape which later serves to check the spread of hotter, hard-to-control late dry-season fires, including the inevitable accidental burns resulting from escaped crop fires.

A third fire culture is in cropfield management outside the forest zones described above, in the open grassland areas, and farm landscapes of the center. Here, typical crop field fires range between 0.01 ha and 0.2 ha and are lit in the months leading up to the rainy season. Farmers most often just burn the standing vegetation in the plot they intend to cultivate; this vegetation may be uncultivated grassland, long-fallow fields covered with grass, ferns, or bushes, or short-fallow fields covered with grass, weeds, and crop stubble. Sometimes, farmers collect additional fuel to burn in their fields, including rice straw or shrubs (Blanc-Pamard and Rakoto Ramiarantsoa, 2000). After burning a plot, farmers plow the ashes into the soil, later planting crops like cassava, sweet potatoes, beans, or corn.

Other agricultural fires take place outside the actual cropfield. Farmers sometimes manipulate erosion using fire—burning, for example, on the slopes above rice paddies—in an effort to concentrate nutrients or soil particles where they will be most productive. Burning the catchment basin above rice paddies can also facilitate quicker run-off during the first rains, aiding the all-important quest to fill one's rice paddies with water for transplanting, as bare ground reduces retention and infiltration and leads to faster runoff. Finally, farmers use fire to clean irrigation canals and field edges (Kull, 2004).

Several additional fire cultures exist on the island, particular to specific regional ecologies. In the "tapia" woodlands of the highlands, named for the key species *Uapaca bojeri*, fire appears to play a role in maintaining woodland composition favorable to the production of tapia fruit and of an endemic wild silkworm that feeds on tapia leaves. Both products are important to local livelihoods (Gade, 1985; Kull, 2003b). Elsewhere, in the wetlands surrounding Lake Alaotra, people burn the native reeds (*Cyperus madagascariensis*) as well as invasive water hyacinth in order to gather an introduced fish (*Channa maculata*) that burrows in the lake sediments exposed by the dry season (Copsey *et al.*, 2008).

7.7 ESTIMATING FIRE IMPACTS

While the basic impacts of fire on vegetation, albedo, and emissions have been quantified through numerous local-scale studies (e.g., van Wilgen and Scholes, 1997, SAFARI *http://daac.ornl.gov/S2K/safari.html*), lack of reliable data on broad-scale fire regimes limits the applicability of these findings to understanding the impacts of fire for the broader African region and for West Africa in particular.

Remotely sensed (satellite) imagery is frequently cited as the ideal data source for mapping and monitoring fire in Africa (e.g., Levine, 1991; Ahern *et al.*, 2001; Roy *et* *al.*, 2005). If accurate burned area and fire intensity maps could be produced, it would be possible to estimate the impacts of fire on such key factors as emissions and vegetation change at the broader continental scale. Yet, while there is generally good agreement in terms of the broad spatio-temporal patterns of fire, regional-scale fire maps contain high levels of error in terms of area burned despite recent improvements in data and detection algorithms (e.g., Nielsen *et al.*, 2002; Boschetti *et al.*, 2004; Laris, 2005; Roy and Boschetti, 2008).

Scale is of critical importance, since most available data sources with temporal frequency suitable for mapping fire patterns are of a scale too coarse to capture the fine-scale mosaic pattern of burning created by people in many African savannas. Spectral heterogeneity is also an issue. For example, in areas composed of mixtures of dry grasses and green woody vegetation, the error in detecting whether a pixel has burned is far greater than if the pixel was composed of dry grasses alone. A critical problem is that the bias built into burned area detection algorithms is highest in the parts of the savanna where burning is also greatest—the wooded savanna. In these areas, which are often burned in a mosaic pattern such as described above, omission error is commonly as high as 90% (e.g., Nielsen *et al.*, 2002; Laris, 2005; Roy and Boschotti, 2008). Although use of higher resolution data such as MODIS has resulted in improvements in burned area estimates, the best estimates of burned area for the African continent still capture only 60%–75% of the total (Roy and Boschetti, 2008).

In general, studies of African savanna fires tend to overestimate burned areas that are large and homogeneous while underestimating areas affected by small, patchy fires. Burned area detection algorithms also tend to perform much better where savannas are burned by a few, large fires (Eva and Lambin, 1998; Maggi and Stroppiana, 2002; Silva *et al.*, 2005). This "low-resolution bias" has hampered efforts to develop correlations between fire and other key variables such as inter-annual variability in rainfall (Koffi *et al.*, 1995), land cover change (Erlich *et al.*, 1997; Eva and Lambin, 2000), and emissions (Hoelzemann *et al.*, 2004).

7.7.1 Climate and hydrology

The impact of fire emissions on global climate, particularly on radiative forcing, is complex, not yet fully understood (Bowman *et al.*, 2008), and not our focus here, except to say that in the case of African grassland and savanna biomes, fire (whether natural or anthropogenic) has a long presence and calculations of changes to radiative forcing must grapple with difficult characterizations of changes to fire regimes.

The local impact of fire and associated vegetation cover change on climate and hydrology is subject to many assertions, but little consensus. For example, in Madagascar and Mali, critics of fire have long blamed vegetation burning and resulting land cover changes for drying up water sources, delaying the arrival of the rains, or of causing drought. Some Malagasy farmers, on the other hand, assert that fire can bring rainfall in the short term (Kull, 2004). Neither category of assertions has been investigated on the island. Research elsewhere *has* established links between forest cover, rainfall, and hydrology (Bruijnzeel, 2004) and between fire smoke and precipitation events (Andreae *et al.*, 2004), yet in all cases the mechanisms are complex, with multiple feedback loops, and regionally particular. Moreover, little is known as to how the shift from natural to anthropogenic fire regimes might have impacted climate and hydrology.

7.7.2 Land cover conversion and vegetation change

Fire maintains certain vegetation covers while changes to fire regimes bring shifts in vegetation communities and sometimes wholesale conversion of land cover. Here it is important to distinguish between two types of fire: fires for rotational agriculture and fires that burn standing vegetation such as savanna or grass fires. The former have a more dramatic and immediate impact on vegetation cover, the latter affect a much larger area.

In many parts of Mali and Madagascar, the impact on vegetation cover over the long term can be understood as a function of both types of fire. Once an area has been cut and burned for agriculture, it is often farmed for a few years and then abandoned to fallow. At this point, the vegetation on fallow plots may be subjected to frequent fires, especially in the savanna but even in forested areas.

Numerous studies have documented that fire reduces tree regeneration and retards transition to adulthood because seed mortality, seedling mortality, and topkill all increase with fire fuel load and intensity (Biggs *et al.*, 2003; Govender *et al.*, 2006; Weigand *et al.*, 2006). Tree seedlings may persist as juveniles or "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). As such, clearing of woodlands followed by repeated burning could suppress tree growth. However, if fire is suppressed (or if fire intensity is altered) for a number of years, trees may grow tall enough to escape the flames and become large and mature (van Wilgen *et al.*, 1990; Laris, 2008).

There has been a long debate over the impact of these two kinds of fire on woody vegetation cover and specifically on the tree/grass ratio in both countries. It has been argued that cutting and burning of woodlands for agriculture, followed by annual burning, results in a reduction in the tree/grass ratio, sometimes referred to as "savannization" (Aubréville, 1947). However, a growing number of recent studies provide evidence to counter this hypothesis, especially for West Africa.

Several studies have found that daily life activities of West Africans such as farming, burning early, and grazing animals can increase tree cover, casting doubt on the savannization hypothesis. Fairhead and Leach (1996) documented a widespread increase in tree cover in settled and farmed areas of the savanna mosaic of Guinea. Bassett and Koli Bi (1999) documented how a shift in burning and an increase in cattle grazing resulted in tree and shrub encroachment in northern Ivory Coast. Finally, Laris (2008) documented a significant increase in tree cover and biodiversity on long-fallow plots in spite of regular burning in the southern Sudan Savanna of Mali.

In many of the forest zones that fringe Madagascar, fire—as a tool for agricultural land clearance—is the key proximate cause of deforestation. Farmers cut the standing vegetation and then burn it; fires after successive crop–fallow cycles prevent forests from re-establishing and eventually serve to maintain fire-derived pastures. This process drives forest loss both in the humid east (Green and Sussman, 1990; Agrawal *et al.*, 2005; Styger *et al.*, 2007; Harper *et al.*, 2007) and in portions of the drier west (Blanc-Pamard *et al.*, 2005; Ingram and Dawson, 2005b; Harper *et al.*, 2007). In most cases, the conversion of land cover negatively affects faunal diversity as well (Goodman and Benstead, 2003; Pons and Wendenburg, 2005).

In the island's interior, the impacts of fire on vegetation cover depend on one's assumptions about pre-human forest cover, which, as noted previously, is strongly debated. If, as paleo-ecological and biogeographical evidence suggests, the center contained significant areas of C_4 grasslands before human arrival, this would have facilitated the spread of anthropogenic fires across the vast territory. This new fire regime would have helped expand the grasslands at the expense of whatever amount of woody vegetation existed. It would also have contributed to a transition in the character of grassland species. The established view of grassland dynamics in Madagascar is that frequent burning has replaced high-quality, nutritious *H. rufa* and *H. contortus* pasture with low-value *Aristida* spp. (Perrier de la Bâthie, 1921; Kuhnholtz-Lordat, 1938; Bosser, 1954; Granier, 1965; Cori and Trama, 1979; Koechlin, 1993; Herinivo, 1994). However, the ecological dynamics of Malagasy grasslands remain poorly researched.[10]

7.7.3 Fragmentation and connectivity

It is important to be specific about the kind of fire when judging impacts on fragmentation and connectivity. Fires associated with slash-and-burn or rotational agriculture can result in an increase in woodland fragmentation, particularly when they are associated with short-fallow cycles. Patch mosaic regimes, such as that documented above for Mali, create a fragmented or heterogeneous landscape during the dry season. Although the long-term impacts of patch mosaic burning on landscapes requires further study, it is probable that this type of burning is a factor in

[10] The ecology of Malagasy grasslands has elicited relatively little research interest due to the attraction of the forest (Koechlin, 1972; Rakotovao *et al.*, 1988) and to the widespread image of the grasslands as degraded pseudo-steppe occupying once-forested lands. The primary sources are Bosser (1954, 1969), Granier (1965), Granier and Serres (1966), and a review by Koechlin (1993). Most efforts by rangeland specialists focused on the introduction and cultivation of improved forage species (e.g., Razakaboana, 1967). Research on grassland fire ecology is likewise in its infancy in Madagascar, owing to the long-established bias against fire as a legitimate range management strategy. Early efforts—not always related to rangeland management—included experiments at Kianjasoa in the Middle West in the 1950s (mentioned by Dez, 1966 and Albignac, 1989), as well as research reported by Metzger (1951), Dommergues (1954), Bailly *et al.* (1967), and Gilibert *et al.* (1974). A few encouraging recent efforts investigate fire ecology in or near protected areas (Razanajoelina, 1993; Herinivo, 1994; Bloesch, 1997, 1999; Rakotoarisetra, 1997; Schnyder and Serretti, 1997; Rabetaliana *et al.*, 1999). Interesting recent studies on Malagasy grasslands like Rakotoarimanana and Grouzis (2006), Rakotoarimanana *et al.* (2008), and Bond *et al.* (2008) should provide an impetus for further research.

maintaining or "stabilizing" savanna/woodland boundaries (Goetze *et al.*, 2006; Henneberg *et al.*, 2006). It is also clear that complete fire suppression (were it possible) would result in a closing of much of the savanna–woodland canopy (Sankaran *et al.*, 2005).

7.7.4 Atmospheric and health effects of emissions

Savanna and forest fires have significant atmospheric effects through the release of large amounts of trace gases and aerosol particles that modify atmospheric chemistry and affect climate (Crutzen and Andreae, 1990). Estimates of the amounts of biomass burned each year around the globe suggest that savanna fires are the single largest source of pyrogenic emissions. The African savannas are estimated to contribute up to 49% of the carbon emitted from global biomass burning (Dwyer *et al.*, 2000; van der Werf *et al.*, 2003); however, the main impact of savanna fires on global atmospheric CO_2 derives from their impact on vegetation cover (specifically the tree/grass ratio) because the carbon is effectively resequestered annually when grasses regrow.[11] The low incidence of rain during the fire season also enhances the atmospheric lifetime of the pollutants, and allows them to be dispersed over long distances (Scholes and Andreae, 2000).

In order to generate realistic patterns of dispersal and transformation, atmospheric chemistry and climate models require trace gas and particle flux estimates for large regions (Scholes and Andreae, 2000). Current estimates of atmospheric emissions rely on a model developed by Seiler and Crutzen (1980) and the results from a few controlled field experiments of savanna combustion, some of which were undertaken in West Africa (Lacaux *et al.*, 1995) and others in South Africa (Korontzi *et al.*, 2004). Remote sensing can provide estimates of the total area burned from which the total biomass burned may be estimated (Menault *et al.*, 1991). However, because combustion efficiency varies by time and space as a function of ecosystem type and vegetation moisture and flammability (Pereira, 1999) current estimates of emissions for Africa will have high levels of uncertainty and presently available data are not sufficient for reliable quantitative estimates (Scholes and Andreae, 2000; Korontzi, 2005).

The first uncertainty comes from the error associated with estimating area and type of vegetation burned and the second uncertainty comes from the error associated with combustion and emissions estimates (Lambin *et al.*, 2003). Recent analysis finds that early burning in grasslands leads to higher amounts of products of incomplete combustion, despite the lower amounts of fuel consumed compared with late dry-season burning. In contrast, early burning in woodlands results in lower emissions, in both products of complete and incomplete combustion, because less fuel is consumed than in the late dry season (Korontzi, 2005).

Emissions from fire also affect air quality (Goldammer, 1990; Bowman and Johnston, 2005). In Madagascar, smoke from slash-and-burn fires on the eastern

[11] This does not mean that the emissions are inconsequential, however, since the forms that they come in (e.g., CO vs. CO_2) change their level of impact.

escarpment envelopes highland cities for a few days or weeks almost every year in October or November, aggravating lung-related diseases or even snarling traffic (Kull, 2004).

7.8 FIRE POLITICS

Bureaucratic perceptions of fire in both countries remain deeply influenced by views established early in the colonial era. The French sought to restrict burning to protect productive assets and to avoid perceived processes of degradation, whether desertification and savannization in Mali or soil loss and deforestation in Madagascar. Some administrators, however, recognized fire as a legitimate management tool, a "necessary evil". After independence, restrictive anti-fire policies were upheld in both countries by the central administrations, though swings in implementation differ between both places along with national politics and climatic cycles like drought. Throughout the past century, most rural people have viewed restrictions on fire as a loss of "rights" and an unwelcome imposition. Recent experiments in both countries, with community co-management of fire, are a positive step forward, though many complexities remain (including Madagascar's swing to a harder anti-fire position).

7.8.1 Early fire policies

For most of the distant past, African farmers and herders likely managed fires at a local level through mutual understandings, evolving traditions, and indigenous conflict resolution mechanisms overseen by elders or royalty (in the case of damaging fires). In the 19th century, after several wars of unification, Madagascar's fiefdoms were transformed into a sophisticated modern state, leading to the first recorded state-level regulation of fires. These rules applied only to the burning of forest—valuable as a source of timber—not to cropfield or savanna fires (Dez, 1968; Kull, 2004).

Government regulation and management of all kinds of fires began in earnest when France took control of Mali (as part of French West Africa) and Madagascar in the 1890s. In both colonies, the French quickly established institutions to oversee natural resources deemed important for the political or economic mission of the colony. They established a *Service des Eaux et Forêts*, or Water and Forest Service, which was given jurisdiction over fires. Its approach was based on French experience with fire and forest management in France (Bergeret, 1993; Pyne, 1997) and in Algeria (Prochaska, 1986; Davis, 2007), and was informed by the agency's ultimate goal of protecting forests for economic and environmental goals, shaped by dominant ideas in circulation at the time about the perceived threat of fire-induced vegetation change to local climate, hydrology, and land productivity (Laris and Wardell, 2006).

The earliest colonial fire policies reflected the need of French officers to administer the colonies for economic profit and political stability (neither colony was fully pacified until the first decade of the 20th century). Foresters in both colonies were alarmed by what they saw as wasteful and hazardous fires that threatened tree cover, and thus economically valuable timber (in Madagascar), crucial rainfall and river flows (in West Africa), and land productivity (in both places) (Fairhead and Leach, 1998; Kull, 2004; Laris and Wardell, 2006). However, their anti-fire enthusiasm was not always shared by colonial officers attuned to economic imperatives. Tentative restrictive policies in Madagascar, for example, met with resistance from colonists and locals alike, and were reversed in 1904. During the next 20 years, economic concerns remained fundamental. Legislation began to restrict burning to protect forests, soils, and agricultural resources, but made room for some fires linked to pastures for cattle production.

Fire policies hardened in the 1920s and 1930s, shaped by a pan-colonial set of ideas about fire and land degradation (Pyne, 1997). Influential colonial botanists argued that woodlands (in West Africa) and forests (in Madagascar) were the natural vegetation cover of the regions, and that fire was the key cause of tree loss ("savannization" in West Africa, "deforestation" in Madagascar). Furthermore, fires were also feared to cause increased soil erosion, thus threatening agricultural production, perceptions bolstered by the Dustbowl experience in the United States. Fires were even linked, at least in West Africa, to a progressive drying out of the landscape, or "desiccation", a precursor to the later concept of "desertification". From the perspective of Aubréville, the influential French botanist and forester, the principle drivers of savannization and desiccation in West Africa were slash-and-burn agriculture, combined with frequent and widespread burning of the savanna. Similar ideas were echoed in Madagascar by eminent specialists Humbert and Perrier de la Bâthie. They, and most of the foresters of the era, vilified customary uses of fire for agricultural, livestock, forestry, and other livelihood activities (Perrier de la Bâthie, 1921; Humbert, 1927; Chevalier, 1928; Stebbing, 1937; Aubréville, 1947, 1949; Fairhead and Leach, 1996, 2000; Pyne, 1997; Kull, 2000; Bertrand *et al.*, 2004; Laris and Wardell, 2006).

As a result, the threat of fire to soils and valuable woodland and forest assets preoccupied French and British forestry administrations of the period. In Madagascar, abusive logging of tropical hardwoods added an additional threat (Jarosz, 1993). Together, these fears underscored foresters' arguments for greater state control over forest resources and repression of fire. As a result, state-led fire criminalization was entrenched in strengthened legislation. By 1937, for example, Madagascar's Forest Decree called for a general ban on *all* fires, whether slash-and-burn fires in forests, clearing fires in cropfields, or widespread pasture burns (Kull, 2004). In West Africa, by the late 1940s, numerous colonial states had already attempted campaigns to ban burning (Wardell *et al.*, 2004).

Rural farmers, hunters, and herders perceived these regulations as an imposition on their way of life. Lower level administrators and touring foresters found the regulations at times difficult to impose, and enforcement was far from complete—due to such sympathies, to a lack of means, and to local resistance. Rural residents associated anti-fire rules with colonial domination—indeed for many farmers and herders this was their key interaction with the colonial state. Unsurprisingly, when the French in Madagascar faced a serious anti-colonial rebellion in 1947, foresters and forest plantations were a prominent target of violence (Kull, 2004).

7.8.2 Fire as a necessary evil: a late colonial softening

Even as regulations were being tightened, a few dissenting forestry and agricultural officials recognized that complete fire suppression was both impractical and undesirable (Tilley, 2003; Kull, 2004; Laris and Wardell, 2006). By the 1950s, these voices were being heard, particularly in West Africa. Field agents had observed indigenous burning practices and realized the futility of total fire protection, as well as the benefits of early burning, such as to protect forests from later wildfires. Scientists investigating experimental fire plots showed that early burns were least damaging to woody vegetation. Forestry departments recognized that their small budgets and restricted personnel did not allow adequate policing of rural areas. The pragmatic solution was to accept fire as a necessary evil—the effects of which needed to be minimized, rather than eliminated.

As a result, in 1955 the governor of French Sudan (Mali and Senegal) issued a decree reversing an existing ban on fire and promoting early burning. In 1956, France promulgated a new set of fire management laws for all its African colonies that incorporate these new ideas—early fires, useful fires, preventive fires, and the burning of fire breaks. Following this, the Forest Service in French Sudan instituted a widespread campaign to circle forests and young fallow lands with a band of early burning. In so doing it drew upon the participation and knowledge of the rural population. Indeed, elderly Malians recall a time when foresters would distribute matches to village leaders and the hunters would use them to set fire to the grasses early in the dry season (Laris and Wardell, 2006).

Interestingly, the colonial administration in Madagascar delayed issuing an applicatory decree for this new pan-colonial law until 1958, and strengthened many of the law's provisions to make it more compatible with a harder anti-fire line. Early burns were at best tolerated, never encouraged, and other fires were more strictly controlled. This difference in perspective likely reflects the different environmental context, given the island's more valuable forest resources as well as a perception that interior grasslands were artificial consequences of fire in a landscape that should have been forest (Dez, 1968; Kull, 2004).

7.8.3 Post-colonial approaches: strong words, weak enforcement

Both Madagascar and Mali gained independence in 1960. The new governments, led respectively by Philibert Tsiranana and Modibo Keita, only tweaked the essence of French colonial fire policy. Drawing from colonial rhetoric about the dangers of land degradation and the value of trees, both governments made calls from the highest levels to stop the fires, but enforcement lagged behind.

Madagascar re-wrote its fire legislation in 1960, making room for some fires in the spirit of the new pan-colonial rules of the 1950s. However, for the rural farmer or herder, little had changed. While the legislation allowed field clearance fires and counter-season (rainy season) pasture fires, it was still framed by the anti-fire ideology, strongly maintained by the Forest Service. Legal pasture and *tavy* fires were subject to a complicated and time-consuming process to gain "exceptional" authorization. Many more fires burned than were authorized, despite foresters continuing their role as active policemen of fire.

Anti-fire rhetoric and legislation toughened from the 1960s through the early 1980s within a turbulent political and economic context. Drought years in 1967 and 1968 led to a particularly incendiary fire season in 1968, and President Tsiranana, a long-time champion of tree planting, convened high-level commissions that sought to tighten the rules for fire. His government's attitude was bolstered by the attention to deforestation given by an important 1970 international conference on natural resource conservation held in the capital city (Kull, 1996, 2004).

Tsiranana was ousted in 1972. Following violent power struggles and riots, in 1975 Didier Ratsiraka came to power touting isolationist and socialist policies. Foreign conservation initiatives were suspended, while government fire enforcement became increasingly draconian. By 1977, illegal fires could—in principle—result in a death sentence. At the same time, the government spent 40 million to 90 million Malagasy francs per year on an anti-fire program, sponsoring a barrage of anti-fire propaganda and awareness efforts and field tours of joint military, *gendarme*, and Forest Service teams. Cattle raisers and forest farmers felt attacked by the unfair legislation (Cori and Trama, 1979) which the administration largely failed to enforce, in part as a result of the contradictory rhetoric of the time which gave "power to the people" and sought to distance itself from the legacy of French rule (Fanony, 1989; Kull, 2004).

As for Mali, during the 1960s Modibo Keita called upon his citizens to refrain from burning the savanna so that Mali would reverse perceived degradation and become more forested. Elder farmers recall that Keita's vision was for Mali to become greener, more like the economically more successful Ivory Coast. According to local accounts, Keita's plan to suppress fire was a complete failure. A portion of the population experimented with fire suppression but quickly realized that fire was impossible to eliminate. Fires reportedly burned larger areas in a more hazardous manner and the rural population quickly rejected restrictions on burning.

Colonel (later General) Moussa Traoré, who came to power in a military coup in 1968, continued to draw heavily on the degradation discourse in establishing anti-fire campaigns. He, like Keita, essentially continued colonial policy, though without strict enforcement. However, Keita ruled during a time of unusually high rainfall while Traoré ruled during one of the longest and most severe droughts in modern times. This contributed to an important policy shift in the 1980s.

7.8.4 From drought to revenue: fire in 1980s' Mali

In 1980, Traoré sparked a radical shift in fire policy and enforcement. In a speech to the entire nation, Traoré banned fire outright, drawing heavily on the idea that fire was causing massive environmental degradation. This occurred in the context of the Sahelian droughts of the 1970s and 1980s, which led to the resurrection of concerns over "desertification" (Swift, 1996) at the same time as international environment development organizations were becoming more involved in the region. Concern over desertification fueled a move to criminalize indigenous behaviors such as burning and fuelwood cutting. For example, the Plan of Action created at the 1977 U.N. Conference on Desertification became a blueprint for the Malian *Campaign against Desertification* which sparked Traoré's *Fight against Fire* (Laris, 2004). Some argue that Traoré instituted oppressive anti-fire policies, as well as strict hunting and tree-cutting policies, in order to appeal to the environmental concerns of major donor agencies (Ribot, 1995).

What is unique in this decade in Mali is that the harsh words led to strong actions. Foresters policed fires assiduously and levied numerous fines—to the point that by the mid-1980s, receipts increased seven-fold and revenues from fines constituted over a third of the budget of the Forest Service (RDM, 1994).[12] The number of field agents rose five-fold between 1975 and 1990. A confluence of institutional factors facilitated this outcome. Like most African government agencies, the Forest Service had limited budgets, low salaries, cumbersome civil service personnel policies and practices, and few rewards for good performance (Brinkerhoff, 1995). Fire fine revenues provided a solution, in that they fed a fund over which the service had discretionary authority. Individual agents—many of whom were former military personnel placed in the service through the regime's military connections—had incentives to enforce fire and other forest code violations, as they received a percentage of the fines. Indeed, during the late 1980s, when the state failed to pay salaries, agents compensated by stepping up fining and associated bribery. Finally, the Forest Service followed a strategy of collective village penalties for fires on village lands, which solved the problem that most illegal fire starters remained anonymous (RDM, 1994).[13]

Ironically, while foresters were gaining an enthusiasm for policing and enforcement, foreign donor initiatives supported the strengthening of the Forest Service's institutional capacity, especially in terms of an extension service with social forestry techniques and expertise. But this effort to couple forestry policing with social forestry proved difficult, particularly given the paramilitary ethos of many of the forest guards. So while Forest Service leaders espoused a participatory extension message, field agents engaged in increasingly abusive policing practices. In the end it was policing and fining that came to define the period (Brinkerhoff, 1995). Malian peasants perceived (perhaps rightly) the forest agents as policemen, not rural extension agents. Perhaps most importantly, corruption was rampant as there were many reports of forest agents pocketing fines, taking bribes, and even setting fires so as to collect the fines later (Laris, 2004).

As a result, the policy and its implementation were complete failures. Forestry records show an increase in the area burned during this period. Rural peasants recall witnessing the largest and most damaging fires, as the suppression policy initially resulted in a reduction in preventative early burning and thus an increase in large,

[12] This situation is not unique—in 1950s' and 1960s' Madagascar some (but not all) Forest Service districts were self-financed through fines (Dez, 1968).

[13] Collective village fines was a strategy frequently resorted to during the colonial era as well—though administrators recognized a tension between its efficacy and its unpopular outcome which could backfire politically (for Madagascar, see Kull, 2004).

late, damaging fires (Laris, 2002, 2004). The anti-fire campaign resulted in social and economic costs as well, as fines were typically nearly equivalent to the annual per capita income of a Malian citizen. Finally, the ultimate effect of Mali's anti-fire campaign was to heighten the animosity between the foresters and the rural populace. Animosity peaked when villagers set fires during Traoré's visits in a form of protest. When the Traoré regime fell in 1991, individual forest agents who had earned a reputation for abuse and repression were singled out for reprisals (Brinkerhoff, 1995; Laris, 2004). Unfortunately, this rift persists to this day and continues to hamper collaborative natural resource management efforts.

7.8.5 Biodiversity hotspot: fire in 1980s'–1990s' Madagascar

At the same time as Mali's experiment in anti-fire politics, Madagascar continued its strict anti-fire rhetoric, yet with few results on the ground. A 1980 interministerial report criticized the apathy, laziness, and pyromania of the rural populations, and resulted in *Opération Danga*, which ran until 1987. The operation mobilized the army, the *gendarmes*, as well as the Forest Service to "teach" rural residents about the dangers of fires, undoubtedly creating an impression of intimidation. Actual enforcement, however, became more and more inconsistent, particularly as the government struggled through the 1980s with a collapsing economy and austerity measures (Kull, 2004).

Similar to the way in which 1970s'–1980s' desertification concerns revitalized anti-fire approaches in Mali, it was 1980s'–1990s' biodiversity conservation concerns that further strengthened anti-fire rhetoric in Madagascar. A National Strategy for Conservation and Development in 1984, followed by an international conference on natural resource conservation in 1985, laid the groundwork for a World Bank–brokered 15-year, multi-million dollar Environmental Action Plan beginning in 1990. Madagascar had become the place for the big international development agencies to be seen to be "green", and projects on the island were a feather in the cap for environmental NGOs. International environmental actors gained prominent political influence (Kull, 1996; Duffy, 2006). In the rush to save the island's biodiversity, old colonial era ideas about fire were resurrected, and as a result fires were denounced with renewed vigor. For example, 1994–1995 was proclaimed the Year of the Fight against Bush Fires (Kull, 2004).

The grand ideas, intentions, and programs launched at the national and international level, however, had little impact on fire enforcement outside a few protected areas. Economic and political crises paralyzed the nation and its civil servants. Fires burned more or less uncontrolled and enforcement lagged. The conundrum of the period is symbolized in the decision, around 1990, by the Forest Service to stop giving the "exceptional" fire authorizations made possible by the 1960 law. It was a low-budget attempt to show the National Assembly that it was doing something about the perceived fire problem (Kull, 2004).

7.8.6 The 1990s' community devolution movement

The 1990s saw anti-fire approaches notionally softened, particularly through the adoption in both countries of widely circulated ideas about community-based natural resource management (Agrawal and Gibson, 1999). In Madagascar, for example, a team of consultants proposed the devolution of forest and pasture management—hence, in principle, fire management—to local communities in the mid-1990s. However, while some communities gained access to timber or ecotourism revenues, no real impact was felt in fire management. This was because official biases against legitimate uses of fire persisted in the agreements signed between communities and the Forest Service, and because most devolution projects occurred in forest, not pasture, areas (Kull, 2002a, 2004).

The impact in Mali, due to concurrent political events, was stronger, than in Madagascar. Traoré's regime was overthrown in 1991. This led to the retraction of the fine-seeking Forest Service from rural villages and provided space for local voices to shape fire policy. The importance of the "right to burn" was demonstrated during town meetings designed to discuss forest management issues. A new fire code emerged by the year 2006, after a series of discussions between villagers and foresters revealed the intense rural opposition to the total ban on fires. Although the wording of the new policy still treats burning as a necessary evil rather than an important land management practice, it takes a more pragmatic approach, including the legitimization of early burning techniques.

7.8.7 Today

Despite the 1990s' policy shift, the official view of the Malian government remains that there is far too much fire and that fire threatens the economic and environmental livelihood of the country. Although it is well established that burning retards the regrowth of valuable woody vegetation, there remains little recognition of the important and often positive impacts of indigenous burning practices (Laris and Aziz, 2008). Moreover, the withdrawal of the Forest Service from the hinterlands remains in place (it was disbanded in the 1990s and replaced by a natural resources service). As a result, there exists a kind of stalemate. Although early burning is now allowed, parts of the rural population struggle with fire control especially in areas where population density is increasing and biomass is in short supply. Some believe there is too much late burning. Coordinated efforts between villages to establish no-burn zones, such as for pasture or woodlots, often fail because it is difficult to police boundaries and local policies are sometimes not well communicated to the broader community. There is a need for government assistance in fire control and communication in these instances, but the response of the government remains "hands off" for the moment.

Recent developments in Madagascar contrast sharply with Mali's hands-off approach. In 2002, President Ratsiraka was ousted after a contested election by businessman Marc Ravalomanana. The new President reinvigorated the old fight against fire with strong rhetoric and a performance-based policy. By decree in August

2002, he linked the funding of rural municipalities (*communes*) to their success with respect to fire eradication. His speeches assert that "if we want to develop quickly, we must stop the burning of forests and hills," and do not allow for any useful fires (*Express de Madagascar*, May 17, 2003). His administration's cult of performance-based management has led to sharpened enforcement of illegal tavy fires in forest areas.

Ravalomanana's keen fire enforcement has recently been given a potential boost due to the utilization of new fire surveillance technologies. In September 2007, the Ministry of the Environment, Water, and Forests, together with U.S.-based environmental group Conservation International and a USAID-funded project launched a "fire alert" system that provides real-time satellite monitoring of fires (see *firealerts.conservation.org*; Butler, 2008). The University of Maryland provides technical assistance, and MODIS satellite data come from NASA. This service sends daily email fire alerts—with latitude–longitude coordinates and links to Google Earth—to clients from the Ministry, to NGOs, to the general public. The impact of this new technology—which allows government agents to keep tabs over vast areas from their desk—has yet to be investigated.

7.8.8 Lessons

The recurrent efforts of policy makers in Mali and Madagascar to control fires—and the stubborn unwillingness of rural residents (and the fires themselves) of being controlled—provide a number of important generalizations and lessons.

First, government perceptions of fire, and the policies they create, remain deeply influenced by early colonial views that rightly linked fire with loss of woody cover, but wrongly take this to the impractical conclusion that all fires must (and can) be excluded. Based in the ideas of colonial forestry, fire policy has often taken a hierarchical form in which fire exclusion is considered the ultimate management objective; thus most fire is actively discouraged and generally illegal, yet some agricultural or early-season fires are deemed acceptable as a "necessary evil" but only under specific, controlled circumstances. Thus while policies in both countries technically make room for a "middle ground" where legislation permits certain useful fires, their practical application (like cumbersome permit systems) and ideological framing (like constant publicity about the fight against bush fires) strongly carry the weight of anti-fire attitudes. Similar policies regulate fire in numerous other West African countries (e.g., Fairhead and Leach, 1995; Bassett and Koli Bi, 2000; Wardell *et al.*, 2004).

Second, global sets of ideas about environmental change have periodically added particular weight and urgency to the fight against fire, without necessarily making room for contextual, localized understandings of fire as a management tool. These include 1930s' concern over soil loss, desiccation, and deforestation, 1970s'–1980s' concerns over desertification, and 1980s'–1990s' concerns for biodiversity conservation.

Third, approaches to fire were also shaped by the particular political, institutional, and climatic situation of each country. Droughts in Madagascar in

1967–1968 and in the Sahel in the 1930s, 1970s, and 1980s inspired cycles of anti-fire action. Regime changes, economic crises, and institutional gaps inspired moments of harshness or tolerance.

Fourth, it is obvious from both the previous ecological discussions of fire and actual experience in both countries as a result of suppression of preventative burning practices that complete suppression of fire is not possible, except in Madagascar's humid forest areas. In wet–dry grassland and savanna areas of both countries, suppressing annual or early fire results in later, bigger, and more intense fires. Some villages may aim to reduce fire but fall victim to neighbors' burning.

Finally, most rural people view fire restrictions as a loss of rights and resist fire suppression policies. They rely on fire for their livelihoods, and in wet–dry areas are more than aware of the dangers of unburned landscapes. As a result, they resent the criminalization of fire and the associated militarization of forestry. For example, in the 1980s when African governments instituted harsh penalties for burning involving exorbitant fines or prison sentences, a backlash resulted as rural inhabitants resisted by setting fires covertly, or as a form of protest. The final result is a rift between locals and the forest service that reflects other political divides in the countries (urban/rural, powerful/weak).

7.9 CONCLUSION

Anthropogenic fire has long shaped the landscapes and livelihoods of much of Africa. Humans appeared in Africa in a context of fire-prone grassland and savanna ecosystems; they eventually took ignition into their own hands. People burn to shape vegetation communities for a number of often overlapping and sometimes competing reasons, ranging from pasture and game management, to crop field preparation, to pest and wildfire control. The result is a particular set of landscapes and fire regimes. Although rural populations rely upon fire for numerous livelihood activities, they sometimes struggle to control fire. Fire by its own nature is capricious, and a shift in winds can lead to unwanted damage to woodlots, thatch-roofed huts, or cropfields; this is especially prevalent during periods of land use transition, such as a shift from an extensive to a more intensively farmed or grazed landscape. In Mali, fires shape vegetation zones along the gradient between the dry north and the more humid south. Their anthropogenic nature removes much of the interannual variation common in fire regimes elsewhere—they are a regular, predictable feature of the landscape. In Madagascar, fires prepare and maintain the vast pastures of the interior, and enable farmers to cultivate farther into the remaining stands of forest.

Political attempts to eradicate or reduce fire over the past 100 years have struggled against fire's inevitability in wet–dry grassy landscapes, and against people's dependence on this tool. As a result, fire management is largely at a standstill, despite periodic efforts at strict enforcement or community control. Some form of co-management is likely the only viable solution, yet in order for this to work, governments will have to accept the usefulness and inevitability of some fires, which will not come easily given the strength of inherited colonial forestry ideas. A co-management model would require the mending of the rift between foresters and rural populations, and would need to be structured to facilitate the avoidance of simple dichotomies such as "good fire/bad fire".

New remote-sensing fire surveillance technologies can aid technical oversight at a national level, but given levels of rural poverty and poor infrastructure, it is unclear how these new technologies might become useful for decentralized natural resource and fire management. The temptation will be to use them to return to stricter fire enforcement regimes, renewing tensions with rural people and igniting the potential for resistance and protest. A more productive use of these technologies would be to monitor general fire trends, agreed to in conjunction with rural communities. For example, in Mali, where later fires are often undesired by locals, remote sensing might be used by the state to identify areas where late fires have been avoided and award good management.

A future trend that may soon become relevant to African fire-setting nations may be global efforts to reduce carbon emissions in the face of climate change. Various programs may come to impact on fire management in Mali and Madagascar. Carbon offset programs, for example, may seek to link rich-world industries or people wanting to offset their emissions with poor countries that can do so through land management (Bumpus and Liverman, 2008). One such program already exists in northern Australia, where an Aboriginal community receives funding from a natural gas plant in exchange for instituting an early-season burn plan to avoid late dry-season conflagrations, thus lowering carbon emissions (Lendrum, 2007). The practicality of such projects in Africa remains to be seen, particularly given consequences on landscapes, impacts on people's livelihoods, and problems with equitable and effective governance.

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