Response of *Acacia sieberiana* to Repeated Experimental Burning

Daniel Aleper,[1] Kåre A. Lye,[2] and Stein R. Moe[3]

Authors are [1]Research Fellow, [2]Professor, and [3]Associate Professor, Norwegian University of Life Sciences, Department of Ecology and Natural Resource Management, PO Box 5003, NO-1432, Ås, Norway.

Abstract

We conducted a study on how *Acacia sieberiana* respond to repeated burning in the Kidepo National Park in northeastern Uganda. The study was conducted to understand effects of common burning regimes (early dry season, late dry season, and no burn [control]) in the area on *Acacia sieberiana*. The three treatments were applied for three consecutive years to 14 replicate blocks in a randomized block design. All *A. sieberiana* trees were number tagged and monitored for height and girth (diameter at breast height) growth. All fires were set as head-fires and attained intensity ranging between 422 and 5693 kW $\cdot$ m^{-1}. Both early and late dry season burning increased the number of small ($<$ 49 cm) *A. sieberiana* trees after 2 yr. Burning did not affect the growth rates. Although the number of trees $<$ 49 cm increased after 2 yr, the mortality in this height class was also increased by the late dry season burning, and after 3 yr of consecutive burning there were no statistical treatment differences in the height class $<$ 49 cm. Late dry season burning also led to high mortality among trees $>$ 250 cm in the third year. Mortality attributed to elephant browsing was important in all treatments but a substantial portion of mortality could not be attributed to any particular cause. In the late burn, fire was the most important mortality factor. Thus, 2 yr of burning may be used as a tool to stimulate recruitment of *A. sieberiana*, but additional years of late dry season burning will increase the mortality of older trees.

Resumen

Realizamos un estudio sobre como la *Acacia sieberiana* responde a la quema repetida en el Parque Nacional Kidepo en el noreste de Uganda. El estudio se llevó a cabo para entender los efectos de los regímenes comunes de quema (temprana, tardía, en la época secas y sin quema (control)) en el área de *Acacia sieberiana*. Se aplicaron tres tratamientos por tres años consecutivos en 14 bloques repetidos bajo un diseño de bloques al azar. Los árboles de *Acacia sieberiana* fueron numerados y monitoreados en su crecimiento de altura y grosor (dbh). Todas las quemas se programaron como fuegos de cabecera y la intensidad obtenida varió entre 422-5693 kW $\cdot$ m^{-1}. La quema incrementó el número de árboles pequeños ($<$ 49 cm) de *A. sieberiana* en todos los años experimentales y también las tasas de crecimiento en la época seca e inicios de la época húmeda; y solo la quema tardía tuvo este efecto a finales de la estación húmeda, excepto en los árboles de clase de altura de 150 a 249 cm. Aunque le número de árboles menores a 49 cm aumentó, la mortalidad de esta clase de tamaño de plantas también aumentó en la quema a final de la estación seca. Para el tercer año, la quema a fines de la estación seca también produjo a una alta mortalidad entre árboles mayores a 250 cm. La mortalidad atribuida al ramoneo por elefantes fue importante en todos los tratamientos, pero una porción substancial de la mortalidad no pudo ser atribuida a una causa en particular. En la quema tardía el fuego fue el factor más importante de mortalidad. Así, uno o dos años de quema pueden ser usados como herramienta para estimular el establecimiento de *A. sieberiana*, sin embargo, la quema a fines de la estación seca en años subsecuentes incrementará la mortalidad de árboles viejos.

Key Words: *Acacia sieberiana*, browsing, fire intensity, *Loxodonta africana*, mortality

INTRODUCTION

Fire is considered to be a major factor in the evolution and maintenance of savanna ecosystems (West 1971). It is widely recognized as a driving force modifying and influencing the structure, productivity, and diversity of both plant and animal communities in these ecosystems (Moreira 2000). Within Africa, savanna ecosystems are subjected to recurring natural (West 1971) as well as anthropogenic fires (Trollope 1993). In addition to accidental anthropogenic fires, fire has been purposely employed to maintain or restore desirable ecological elements such as plant and animal composition and distribution (Trollope et al. 1996). Thus, a substantial number of studies have focused on how fire determines and maintains the structure and species composition of the savanna ecosystems (e.g., Pellew 1983; Williams 1998; Bond et al. 2003).

Beneficial effects of fire include increases in plant productivity, species diversity, and nutrient cycling, and reduction in moribund vegetation (Moe and Wegge 1997; Shackleton and Scholes 2000), whereas deleterious effects include an escalated mortality of species and loss of vigor, nutrients, productivity, cover, and soil structure (Bigalke and Willan 1984). These effects have been extensively studied and often generalized at a global scale. It is important to be aware that different biogeographic and climatic regions may respond differently to disturbance factors such as fire (Roberts 2000).

The extensive use of savannas for livestock production has led to the concentration of research on the effects of fire on

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Correspondence: Stein R. Moe, Norwegian University of Life Sciences, Dept of Ecology and Natural Resource Management, PO Box 5003, NO-1432, Ås, Norway. Email: stein.moe@umb.no

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grass composition, biomass, and productivity (Nkemi and Gakahu 1989; Silva et al. 1990). The effect of fire on shrubs and trees has been less studied and limited to the use of fire in the control of bush encroachment and in timber production.

Several studies have emphasized the role of tree height in tree vulnerability to fire, and generally concluded that younger trees, approximately 3 m or less, are more susceptible to high-intensity fire damage compared to larger or taller mature trees (Sabiiti and Wein 1988; Nkemi and Gakahu 1989; Dublin et al. 1990; Bond et al. 2001). Thus, it is generally accepted that fires suppress tree regeneration. The suppression of tree regeneration by fire depends on the interaction between fire intensity, browsing, climate, and soils (Laws et al. 1970; Stronach and McNaughton 1989). In Amboseli National Park, Kenya, Western and Maitumo (2004) reported that browsing by the African savanna elephant, *Loxodonta africana* Blumenbach, in the absence of fire prevented woodland recovery. However, fire and elephant browsing do occur simultaneously in African savannas.

Park managers in Kidepo, as in savannas elsewhere (Russell-Smith 1995), burn habitats early in each dry season in order to promote patchiness and reduce intensity and occurrence of wildfires late in the dry season. Fires are therefore common in the Kidepo National Park in northeastern Uganda and at present the elephant population is increasing (Aleper and Moe 2006). It is pertinent to understand the influence of fire in the presence of elephant browsing. The objective of this study is to assess recruitment and growth of *Acacia sieberana* D.C. subjected to experimental early and late dry season annual burning program.

METHODS

Study Area

Kidepo Valley National Park lies in the extreme northeastern part of Uganda (lat 3°52′N, long 33°50′E). Its northwestern section forms part of the international Uganda–Sudan boundary. Proclaimed in 1962, the park covers 1 442 km^2 and comprises two valleys that make up the upper Kidepo and Narus drainage systems. Topographical variation is pronounced, with elevation rising from about 1 000 m on the valley floors to 2 749 m at the top of Mount Morungole. The Kidepo Valley lies in the northeastern part of the park and receives annual rainfall of 635 mm; the more humid Narus Valley to the southwest receives 889 mm annual rainfall. The wet season is confined to April–September. The two valleys flow intermittently and join into one in the southern Sudan (Oliver 1992). A detailed account of the vegetation characteristics of the area is given by Langdale-Brown et al. (1964) and Harrington and Ross (1974). This study was conducted in the upper Narus Valley where, in the late 1960s and early 1970s, the woody part of the vegetation was primarily comprised of *Acacia gerrardii* Benth. that gave way to a *Lonchocarpus–Combretum–Lannea* tall grass savanna on higher ground. However, by the time of this study, *A. sieberiana,* a preferred browse species for the African elephant (Buechner and Dawkin 1961; Buss 1961; Calenge et al. 2002) in young regenerating stages became the dominating tree in the upper Narus (comprising over 85% of the woody vegetation). *Acacia sieberiana* is a major regenerating tree, particularly in the rangelands of East Africa. It is therefore important to understand the effect of fire on this species, as most of its savanna range is prone to fire. *Acacia sieberiana* is widely used for firewood, charcoal, tools, and timber for local construction. Leaves and fruit are used as fodder, and cut branches are used as fences (Katende et al. 1995).

Other common tree species in Kidepo are *Balanites aegyptiaca* Del., *A. gerrardii*, *Kigelia pinnata* (Jacq) D.C., and *Combretum* associations on the lower slopes.

The vegetation in the park can be described as open tree savanna, except on the mountainous areas where mosaics of forest and savannah woodland occur. The northeastern part of the park is drier and more prone to fire but experiences lower browsing pressure compared to other areas of the park. Also, this area supports a higher diversity of *Acacia* species; the dominant species being *Acacia drepanolobium* Harms ex B.Y. Sjöstedt and *Acacia seyal* Del., whereas *Lannea–Acacia* bushlands form patches of pure stands. Other species include *Acacia nubica* Benth., *Acacia senegal* (L.) Willd., *Acacia tortilis* (Forssk.) Hayne, and *Faidherbia albida* (Del.) A. Chev. The riverbanks are dominated by extensive belts of *Borassus aethiopum* Mart. palm forest with the fire-derived grass *Themeda triandra* Forssk.

The herb layer in Narus Valley is dominated by *Themeda triandra*, *Panicum maximum* Jacq., and *Hyparrhenia* grass species that grow to a height of 1–2 m. All vegetation communities are fire induced and burn annually or biannually.

Burning Experiments

Three treatments, early and late dry-season burning and no burning (control), were applied to 14 replicate blocks in a randomized block design for 3 yr. Burning was applied to the replicate blocks for three consecutive years. Each site comprised three 1-ha treatment plots. Treatments were randomly allocated to each plot. To avoid fire spreading to areas not to be burnt, areas to be burnt were delimited by a 5-m-wide firebreak from which the vegetation was mechanically removed. The early burn was administered as early as a fire could be maintained in November or December. The late burn treatment was applied in late March, just before the first rains. All *A. sieberiana* trees were individually number-tagged and monitored for growth (height and girth [diameter at breast height]). All the marked trees were measured every second month from the onset of the experiment in 1999 to 2001. Rates of tree growth (mean monthly increment of height) were calculated for three different seasons: 1) the early wet season defined as 3 mo after the first rains (April–June); 2) the late wet season (July–October); and 3) the dry season (November–March).

Stand density of *A. sieberiana* trees ($>85\%$ of the woody vegetation in all experimental plots) ranged between 5.1 and 53.6 ha^{-1} (mean 24.4). All fires were set as head fires after 1600 hours.

Frontal fire intensity was used as a measure of the ecological effect of fire and ranged from 422–4 992 kW $\cdot$ m^{-1} in the early burn to 666–5 693.3 kW $\cdot$ m^{-1} in the late burn treatments. Frontal fire intensity was calculated according to the Byram (1959) formula:

$$I = H \cdot w \cdot r \qquad [1]$$

where I = fire intensity (kJ $\cdot$ s^{-1} $\cdot$ m^{-1}), H = heat yield of fuel (kJ · kg^{-1}), w = dry fuel consumed (kg · m^{-2}), and r = rate of spread of the fire front (m · s^{-1}). It was assumed that grass fuels have a heat yield (amount of heat energy available for release per unit mass of fuel) value of 18 000 kJ · kg^{-1} as suggested by Trollope (1984).

Trees were divided into five height classes: < 49, 50–149, 150–249, 250–349, and > 350 cm. When testing for effects of burning on number of individuals in different height classes and for seasonal rate of growth we used one-way analysis of variance (ANOVA). When analyzing growth rates we used only the three smallest size classes because monthly rates of growth for the larger trees were small. Because every year of the experiment had a different fire history (e.g., not burnt, burnt 1 yr, 2 yr, and 3 yr), consecutive years of burning were treated as separate experiments and analyzed accordingly. Also, one-way ANOVA was used to test the effect of burning on tree mortality. A paired *t* test was employed to test whether burning resulted in trees changing from one height class to another. SYSTAT statistical software (SYSTAT Software, Inc., http://www.systat.com) was used for all statistical analysis.

In this study, the term tree mortality is used when the whole tree died. Because the trees were marked, individual trees were followed and those that dried up and ceased to grow were considered to be dead if no new growth was subsequently observed. Increases in trees in the smaller height class (< 49 cm) were normally resprouts from live stumps, although some occasional seed-germinated sprouts cannot be ruled out. Fire was considered to be the cause of death of trees that died following burning. Trees that died after the striping of bark around a ring of stem, uprooting, and breakage at ground level by elephants were considered to have died due to elephant browsing.

RESULTS

Two-year burning increased the number of small trees (< 49 cm) of *A. sieberiana* (Fig. 1). There was a significant variation in height class distribution in all 3 yr (year 1: $F_{4,10} = 4.125$, $P = 0.031$; year 2: $F_{4,10} = 4.153$, $P = 0.031$; year 3: $F_{4,10} = 4.948$, $P = 0.018$). Within height classes, although both early and late burning increased the number of small trees (< 49 cm), after 2 yr of burning there was no significant difference among the early and late burn (Fig. 1). Overall individuals > 250 cm were significantly reduced ($t = 2.611$, df = 14, $P = 0.021$) between the second and the third year of burning.

The late burn led to a significantly ($t = -3.26$, df = 9, $P < 0.005$) higher number of trees reducing in height from higher to lower height classes, whereas the early burn did not have any effect on height class changes ($t = 0.898$, df = 9, $P = 0.21$). A significant number of trees increased from lower to higher height classes in the control treatment ($t = 1.97$, df = 9, $P < 0.05$; Fig. 2).

Mean monthly growth rates were not affected by season, height class, or treatment (ANOVAs, $P > 0.05$; Fig. 3).

Overall, late burning did not increase tree mortality (one-way ANOVA, $F_{2,39} = 3.20$, $P = 0.052$; Fig. 4). However, considering separate height classes, the late burn significantly increased mortality among the smaller height class (< 49 cm) as compared to the early burn and no burn (one-way ANOVA, $F_{2,39} = 7.33$, $P = 0.001$, and Bonferroni post hoc test, $P < 0.05$). As much as 85.1% of the individuals in the small height class (< 49 cm) in the early and late burn plots were killed by the late dry season burn. Total mortality was 16.6% (Fig. 4). Late dry season fire contributed 5.5% to the mortality whereas early burn did not contribute much to the mortality (Fig. 4). Mortality attributed to elephant browsing was important in all treatments (Fig. 4). A substantial portion of mortality could not be attributed to any particular cause.

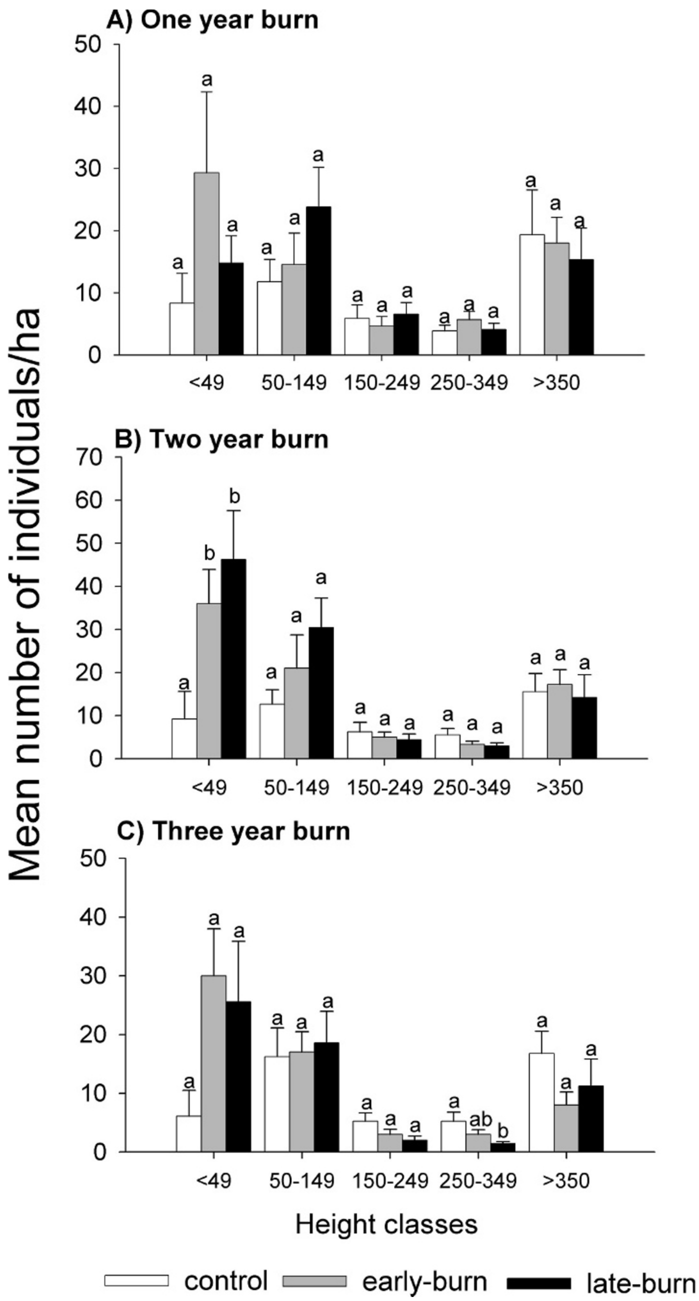

Figure 1. Tree height class distribution of *Acacia sieberiana* in **A**, 1-yr burn; **B**, 2-yr burn; and **C**, 3-yr burn during experimental burning in Kidepo Valley National Park, Uganda. Error bars (SE) show variation among 14 replicate blocks for each treatment. Different letters indicate a significant difference among treatments within height class, one-way ANOVA and Bonferroni post hoc test.

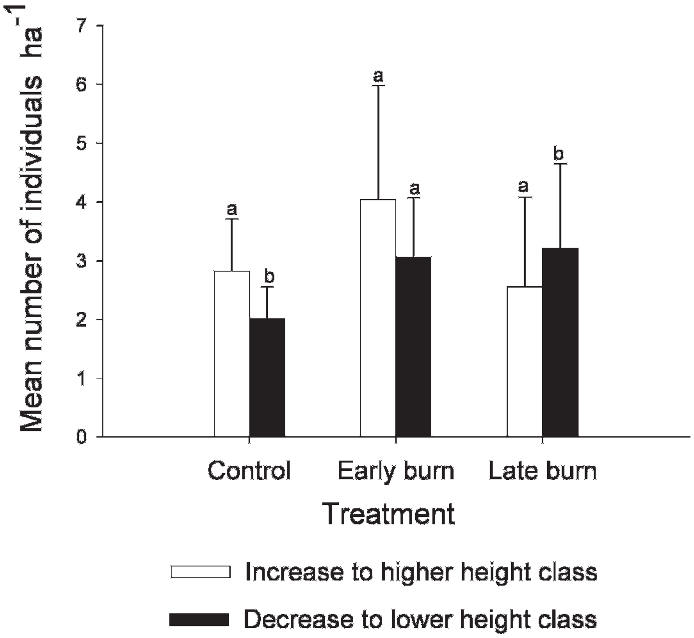

Figure 2. Height class changes in *Acacia sieberiana* trees in different treatments during 3 yr of experimental burning in Kidepo Valley National Park, Uganda. Error bars (SE) show variation among 14 replicate blocks for each treatment. Different letters indicate significant differences between numbers of trees, within a treatment, that increase to higher height classes and the number of trees that are reduced to lower height classes.

DISCUSSION

Compared to unburnt areas, early and late dry season burning increased the number of small individuals (< 49 cm) of *A. sieberiana* trees after two consecutive years of burning. A previous study has shown that fire may stimulate seed germination in *A. sieberiana* (Sabiiti and Wein 1988). Fire may also induce the propagation of live stems from individuals that previously had their aboveground parts killed by fire or suppressed by browsing (Nkemi and Gakahu 1989). Consecutive annual late dry season burning reduced the number of trees in the 250–349-cm height class in the third year of burning and generally reduced the number of individuals among the big trees (> 250 cm). Variation was high between the plots with respect to tree densities (range 5.1–53.6 ha^{-1}). Differences in densities may have caused some differences in fire temperature and thus affected mortality. However, this effect was not systematic because treatment blocks were assigned randomly.

Burning did not affect growth rates in any height class or season. Previous studies have shown that increased growth rates may follow from reduced competition between the young trees and the herbaceous layer that is removed by fire (Setterfield 2002; Western and Maitumo 2004). Although the reduced competitions with grass may be a reason for the observed increased recruitment following 2 yr of burning, grass accumulation does not appear to affect the growth rates of *A. sieberiana*. Earlier studies, (e.g., Jachmann et al. 1989), observed variation in rates of sprouting in relation to time of burn among different species, but concluded that at Nazinga

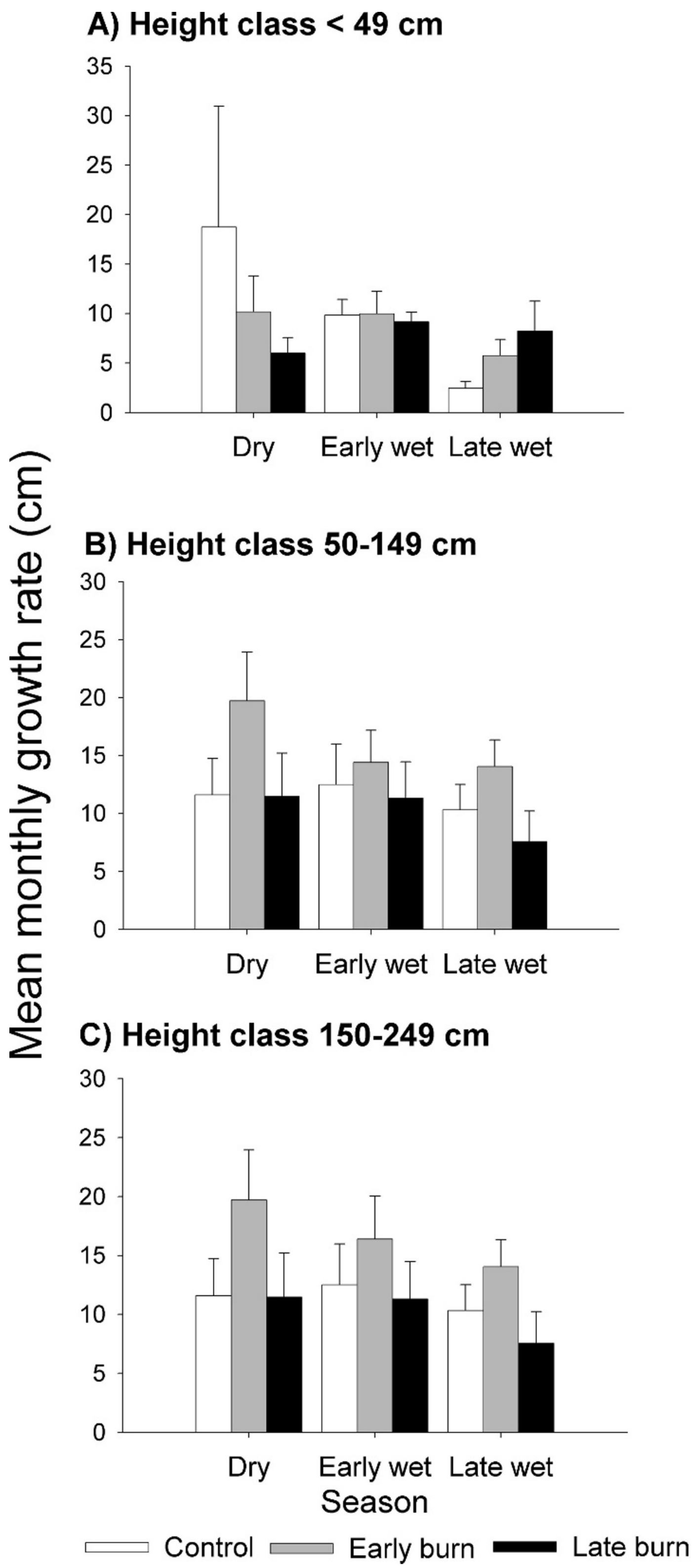

Figure 3. Mean monthly growth rates of *Acacia sieberiana* height classes, **A,** < 49 cm; **B,** 50–149 cm; and **C,** 150–249 cm, during different seasons and treatments in Kidepo Valley National Park, Uganda. Error bars (SE) show variation among individuals of different height classes in 14 replicate blocks for each treatment. No significant treatment differences were found (one-way ANOVA tests). Seasons: dry (November–February), early wet (March–June), and late wet (July–October).

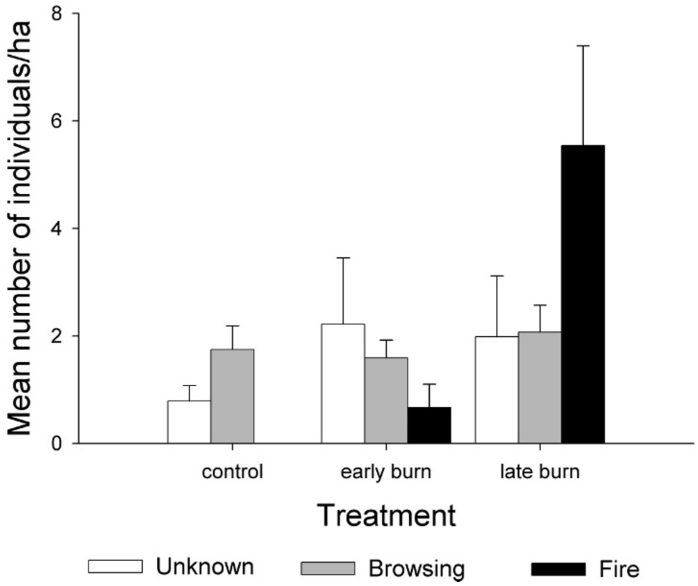

Figure 4. Causes of *Acacia sieberiana* mortality during 3 yr of experimental burning in Kidepo Valley National Park, Uganda. Error bars (SE) show variation among 14 replicate blocks for each treatment.

ranch in Burkina Faso, West Africa, trees within the midseason late-burnt areas resprout more rapidly than those within early burnt areas.

Fire contributed substantially to mortality in the late dry season, whereas mortality caused by browsing was important in all treatments. A substantial amount of mortality could not be attributed to any particular cause. Late dry season burning led to significant mortality among the < 49 cm and among the big trees (> 250 cm); however, recruitment of small trees surpassed mortality among < 49-cm height class in the second year.

In Queen Elizabeth National Park, Sabiiti and Wein (1988) reported that after 2 yr of no burning, seedlings of *A. sieberiana* attained heights of up to 1.5 m and 2.8 m in 2 and 3.5 yr, respectively. They concluded that following 2 to 3 yr without burning, and in the absence of browsers, *A. sieberiana* would survive fire mortality. Although fire return interval was not varied in this study, other savanna vegetation studies have documented that high fire frequencies prevent seedlings and woody sprouts from entering the canopy and reaching reproductive maturity (Higgins et al. 2000; Peterson and Reich 2001). Also previous studies have found low survival of large trees following fire (e.g., Williams et al. 2002; Andersen et al. 2005) and have emphasized the importance of considering the fire-return interval in the use of fire for woodland management (e.g., Bradstock et al. 2002; Goldammer and de Ronde 2004; Woinarski et al. 2004).

Diseases such as heart rot of trunks and larger branches have been reported to occur on savanna trees (Lonsdale and Braithwaite 1991). Such diseases may have rendered large trees more vulnerable to elephant breakage. Elephants prefer to feed on 1–2-m trees but also feed on and push over trees higher than 2 m (Jachmann and Bell 1985). The elephant population in Kidepo has been relatively low, but it has congregated in the Narus Valley area (ca. 500 km^2) of the park, because this area harbors the only sources of water in the dry season, and because of poaching elsewhere in the park (Aleper and Moe 2006). Interaction between tree diseases, elephant browsing, and fire may account for some of the unknown high mortality recorded in the late burn.

As in many other savanna areas (Russell-Smith 1995), park managers in Kidepo commonly burn areas early in each dry season, in order to promote patchiness, stimulate fresh forage to retain herbivores in the park, and reduce intensity of late dry season fires. Despite such use of fire early in the dry season, park managers in Kidepo have little control over the area burnt each year, because of the high incidence of unauthorized burning in the late dry season.

CONCLUSION AND MANAGEMENT IMPLICATIONS

In this study, the mortality due to fire on *A. sieberiana* was lower for trees above 50 cm compared to smaller trees. However, although fire stimulated seedling and sprout recruitment after 2 yr, the numbers of large trees were reduced after consecutive years of burning and in the presence of browsers. In order to control fires, Chandler et al. (1983) recommended fires of low intensity (approximately 400–425 kW $\cdot$ m^{-1})—a range at which suppression with hand tools is possible. This is particularly important in protected areas like Kidepo where no sophisticated fire extinguishing tools are available. Prefire intensity parameters (e.g., fuel moisture content) should be developed and used to guide in deciding the appropriate time of season to accomplish a safe prescribed burn. In conclusion, fire can be used as a management tool to promote the recruitment of *A. sieberiana*. However, repeated annual burning tends to reduce the number of larger trees. If the objective is to promote *A. sieberiana* woodland, more than 2 yr of consecutive late dry season burning should be avoided.

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