

-> Article submitted to Ambio, Swedish Academy of Sciences

The effect of fire on woodlands in Namibia

Antje Burke

EnviroScience

P.O. Box 90230 , Klein Windhoek, Namibia

Tel/Fax: +264-61-223739

e-mail: enviroscience@iafrica.com.na

ABSTRACT

Today savannas around the globe bear the brunt of fire almost on an annual basis. Most savanna fires are lit by humans. It has been suggested that this has largely transformed savanna landscapes and is associated with a multitude of cascading effects that have altered obvious features such as vegetation structure and composition, but also resulted in more subtle changes affecting soil formation, nutrient cycling and inconspicuous organisms. However, the clock cannot be turned back. On the African continent a pragmatic approach linking fire management and control with traditional farming practises is thus desired. This in the long-term may sustain savanna ecosystems while at the same time providing people with the vital goods and services that comprise their livelihoods. This article reviews the impacts of fire on savanna ecosystems with particular reference to woodlands on Kalahari sands in Namibia. A shift in species composition to more fire-tolerant species and a degradation of structural diversity to largely bimodal size structure are perhaps marked signs of a change in fire regime and can be observed in many Namibian woodlands on Kalahari sands.

INTRODUCTION

Fire is one fundamental driver of the dynamics of tropical savannas around the world (1). Although a substantial amount of research on the effect of fire on savannas has been undertaken over the past century, some underlying principles and particularly the effects on different savanna types are poorly understood. It is evident that, in addition to fire, a combination of environmental drivers, such as rainfall, herbivory and other human activities (e.g. shifting cultivation, timber extraction and other resource use) play an important role in African savannas.

There is considerable debate whether or not present burning patterns resemble natural fire regimes and how these perceived changes may have affected and are presently affecting savanna vegetation and ecological processes (2, 3).

The main objective of this article is to give an account of the impact of fire on Namibian woodlands by reviewing fire research in savanna ecosystems worldwide, and drawing parallels to the Namibian situation where applicable. This paper does not attempt to do justice to all savanna and fire research that has been undertaken during the past few decades. Instead it focuses on providing adequate background to understand the basic principles of savanna dynamics and highlights those aspects for which some information of direct relevance to Namibian woodlands is available. I will here further focus on the semi-arid woodlands on Kalahari sands, as these are the most severely affected by fire in Namibia (Fig. 1). For more thorough reviews on the subject the reader is referred to in-depth treatments, e.g. by Booysen & Tainton (4) and Goldammer (5).

Fire is only one of many variables affecting savanna ecosystems. In order to gain an understanding of the complex variables driving savanna dynamics, some basic principles are introduced. This review hence broadly covers the following aspects:

- drivers of savanna dynamics
- fire research
- fire and ecological processes

- fire and vegetation
- fire and other biota and
- the management of fire.

DRIVERS OF SAVANNA DYNAMICS

Savannas are defined as tropical vegetation composed largely of woody plants and grasses (6). This includes the woodlands and shrublands of Namibia which cover nearly two thirds of the country. Savanna ecosystems around the globe are shaped by climate, substrate and the overriding factors fire and herbivory (1). Savannas in southern Africa are generally classified into broad-leaved, fine-leaved, mixed and mopane savanna, based on the physiognomy of their dominant components (6).

The Tree – Grass Debate

A basic assumption of savanna ecology is that there is intense competition between grasses and trees. The balance between the tree and grass component of savannas and the factors that determine the dominance of one or the other component, have been debated amongst savanna ecologists for many decades. One classical hypothesis postulates an equilibrium of tree-grass ratio attributed to root competition. This theory suggests that grasses largely obtain moisture from the upper layers of the soil, while trees draw their moisture from deeper sources (7). Depending on the nature and timing of rains, as well as grazing pressure, either one or the other component would gain an advantage. This simple concept has today been revised, with other factors such as season of water use, competition between trees and particularly disturbance (such as fire and herbivory) being recognised as important variables influencing the tree-grass relationship (8, 9).

FIRE RESEARCH

Because of its often detrimental impact fire research has received increasing attention over the past few decades. The large-scale burning of African savannas, for example, is believed to

contribute significantly to atmospheric pollution and as such also to global climate change. Various international research programmes currently investigate these aspects (10). On a local level, fire has been extensively applied as a management tool in Australia (11), South Africa (12) and other parts of the globe. A vast body of literature exists dealing with various aspects of fire regime, intensity, fuel loads and other fire parameters and their effect on different vegetation types (for review see e.g. 4, 2). For the purpose of this paper only the main points will be summarised.

Of critical importance determining the effect of a fire are the fire regime, i.e.:

- type of fire (e.g. surface or crown fire)
- fire season (timing and duration of burning)
- fire intensity (which depends on type of fuel and fuel load available) and
- frequency of fires.

Other major determinants are the type of vegetation affected and previous site history. Site history relates to the impacts of fire, rain, grazing and perhaps other activities, such as timber extraction and shifting cultivation during present and previous years. All these comprise a vast array of environmental factors pointing towards the difficult task of unravelling the effect of one particular parameter (Fig. 2).

The History of Fire in Namibia

Human-induced fires have been documented on the southern African continent for at least 1.5 million years (13). Due to low population pressure in the savanna areas, impacts, however, were likely localised. Hunter-gatherers of later periods, in turn, such as the San bushmen in Namibia and Botswana used fire extensively to hunt, improve grass growth and maintain diverse ecosystems which would enable them to obtain a wide array of veld products (14). More recently farmers in Namibian commercial rangelands use fire to control bush encroachment (15). There have also been suggestions that fires were intensively used for strategic purposes during war-time activities in the 1980ties, particularly in the north-eastern parts of the country.

Today various initiatives in Namibia have recognised the need for fire control and the use of fire as a management tool. The Directorate of Forestry has embarked on various projects creating fire awareness to help suppressing fires and developing appropriate burning techniques (16, 17). Pilot projects in eastern Caprivi have now been extended to other fire prone regions in the country. The Ministry of Environment and Tourism employs an on-going burning strategy in one of its prime wildlife areas, the Etosha National Park (18).

The major difference between naturally ignited, e.g. through thunderstorms, and human-induced fire relates to the season of burning. Thunderstorms in the early rainy season have been named the major cause of natural fires, thus restricting the burning season to this period. Humans light fires mainly during the dry season when plant material and atmospheric conditions are dry. Fire frequency has likely also been altered. Recent analyses of satellite images revealed that the majority of woodland in Namibia's north-east is presently burned on an annual basis (19). Whether or not the same short intervals could be maintained by natural fires is questionable.

FIRE AND ECOLOGICAL PROCESSES

The availability of nutrients and water in the largely infertile, sandy soils of the Kalahari basin, which form the substrate of large parts of southern African savanna, is an important determinant of savanna vegetation in Namibia (20). Particularly the movement and deposition of clay and organic matter is a crucial factor. Fire contributes to nutrient release and likely nutrient loss, as some elements, for example nitrogen and sulphur are released to the atmosphere during burning. This further depletes the nutrient stores of savanna soils which are inherently poor in nitrogen and phosphorous (6). In Australian savannas initial observations showed that also magnesium and potassium stores in the soil are depleted by annual fires (21). Studies in the Kalahari sands of the Kavango Region in Namibia indicated that soil formation may perhaps be altered by fires, resulting in impermeable layers in the soil which disrupt water infiltration and may limit plant rooting depth (22). This, in turn, directly

affects the productivity and, in the long-term, the composition of the vegetation. All these processes may result eventually in major nutrient losses from savanna ecosystems.

Another often heavily impacted or even eliminated component is the protective layer of the soil surface. Litter and other dead plant material as well as microphytic crusts help to stabilise the soil and hence prevent erosion. The removal of the organic soil stabilising matter could so result in erosion. However, the quantity and quality of available litter (23), existing vegetation, fire regime, rainfall and topography determine whether or not erosion becomes a problem.

THE IMPACTS OF FIRE ON NAMIBIAN WOODLAND VEGETATION

It will be beyond the scope of this brief review to summarise the wealth of information that has been assembled over the past century on the effect of fire on vegetation (see for example 2). Fire can affect all stages of a plants' life cycle, from seed dispersal, germination to growth, flowering and seed production. Plants' in fire-prone environments show an amazing array of adaptations to fire. There are also many indirect effects, for example via impacts on pollinators, herbivores and symbiotic relationships (e.g. mycorrhiza). I will here focus on two aspects only, namely vegetation structure and species composition, with particular reference to aspects relevant to broad-leaved savanna on Kalahari sands in Namibia.

Vegetation Structure

Fire is likely one of the key factors preventing trees to become dominant in savannas. Fire regime and existing vegetation (and associated fuel load) are two important variables determining how fires affect a particular woodland. In southern African savannas surface fire is the most common type of fire, while crown fires are rare. Surface fires are fuelled largely by grass and damage vegetation in flame height, normally below 2 metres (24). Due to the vigorous resprouting and regrowth that can be observed after fires, most woodland vegetation appears well-adapted. This does not mean, however, that there are no impacts on the vegetation. Most changes will be subtle and may only emerge after several seasons, such as a

change in species composition or a gradual degradation of vegetation structure. The vegetation structure of a particular woodland, in turn, is a good indicator of past and present fire regimes.

The most evident impact on vegetation structure is the suppression of tree recruitment. Hot, frequent fires, for example on an annual basis, prevent most trees from reaching the critical 2 m threshold which would allow them to escape the flame zone. Although the trees are not necessarily killed by the fire, most above ground parts will likely be defoliated or burned off and the young tree has to start sprouting from the base again. Depending on growth rate, very few trees manage to grow tall enough in one season to lift their canopies beyond the reach of the flames. Hence a pronounced two-layered structure of tall trees and low shrubs in many woodlands likely indicates a high fire frequency.

The amount of fuel, i.e. grass, is an important determinant of fire intensity. Grass, in turn, is often substantially reduced through grazing pressure. All things being equal (i.e. same vegetation type, substrate, rainfall, no other disturbances), the interplay between grazing and fire has been observed of critical importance in determining vegetation structure in *Baikiaea plurijuga* – *Burkea africana* dominated woodlands of the East Caprivi (16). Illustrated in a simplified diagram, heavy livestock grazing and total suppression of fires has been suggested by Trollope (16) to result in bush encroachment in this woodland type (Fig. 3). Minor or no grazing results in dense and tall swards of grass. Thus more frequent and hot fires occur and transform the woodland into open woodland with few tall trees and a dense cover of shrubs and grasses (Fig. 4). Under this scenario the abundance of grass facilitates hot and frequent fires, maintaining resprouting trees and shrubs in the flame zone and so hindering their ability to escape the damaging effect of the flames. Recruitment of trees is severely hampered under this scenario. Moderate to heavy grazing pressure in combination with fires would result in open to closed woodland, showing a more even size distribution of trees (Fig. 5). Here low availability of fuelling grasses results in cool, and likely less frequent fires, thus enabling some trees to escape the flame zone.

This suggests that livestock grazing can be used as a convenient method to control fires, a practise that has also been adopted in tropical savannas of Australia (25). However, considering the negative effects of overgrazing (e.g. 26) this strategy has to be evaluated on a case-by-case basis and with clear management objectives in mind. In ecologically relatively intact areas, such as parts of Australian savannas for example, high grazing intensities had a negative impact on insect diversity, and the richness of understorey vegetation, likely more so than fire *per se* (25).

Species Composition

Fire tolerance thresholds of individual species and the development stage of individual plants during the fire impact are two fundamental aspects determining the response to fires on species level.

Seasonal timing of fires is likely to show a marked impact on species composition. Plants are most susceptible during their early growing season, and there are differences between species in response to climatic cues. Under “natural” fire regimes, i.e. in the early rainy season, species that sprout early, before the onset of rains, (a) are either in their most vulnerable stage, or (b) are sufficiently developed to withstand fires that are associated with thunderstorms in the early rainy season. Those that start growing only after rains (and after the fires have swept through the woodlands), escape fire entirely during their early growth. However, their growth periods are remarkably shorter which may result in trade-offs regarding other aspects. Today most fires occur during the dry season. While in the early dry season most species are dormant, many tree and shrub species in Namibian woodlands start sprouting in early spring (i.e. late dry season). Fires during that period could have a detrimental effect on young growth of these species (e.g. *Baikiaea plurijuga* and *Guibourtia coleosperma*).

Fire tolerance is species specific. Many savanna plants show some form of adaptation to fire. There are woody plants with below-ground stems, such as *Dichapetalum cymosum*, *Diospyros chamaethammus*, *Lannea discolor* and *Salacia luebbertii*. These are

virtually unaffected by fires, unless a very hot fire penetrates below the surface. Others protect their stems with thick, sometimes corky bark, e.g. *Strychnos cocculoides* and *Pterocarpus angolensis*. Many shrubs are amazingly resilient to burns and resprout readily after fires have destroyed their above-ground branches. Examples are *Grewia flavescens* and *Ochma pulchra* (23). Grasses either protect their growth buds in dense tufts or develop extensive stolons (e.g. *Digitaria seriata*). The ability to grow vegetatively is relatively high amongst savanna plants, compared to plants in other biomes. Those with adaptations to fire have an evident advantage over species without such adaptations. Amongst woody plants those with no special adaptations or tolerance are the first to disappear, if too frequent fires prevent (a) their establishment altogether or (b) escape out of the flame zone. In Namibian woodlands *Baikiaea plurijuga*, *Guibourtia coleosperma* and *Commiphora* species are believed to be fire-sensitive, while *Pterocarpus angolensis* (27), *Ochma pulchra*, *Burkea africana* and *Terminalia sericea* (23) are comparatively resilient. The prevalence of fire-tolerant tree species over less fire-tolerant species in the Kavango Region of Namibia today speaks for itself.

FIRE AND OTHER BIOTA

Fire affects organisms of savanna ecosystems in two ways: it can result in direct mortality or through change of habitat, i.e. vegetation structure and composition. Like savanna plants, animals and other biota have also adapted to fires to some extent (28). Mortalities can likely be borne by adequately high reproduction, but change in habitat is more difficult to counteract. This is particularly true for highly specialised and range restricted species, such as insects feeding on a particular plant species. Not only the direct impacts of fire causing mortalities are a concern, but also indirect impacts through the animals' interaction with other components of the ecosystem. This can have a cascading effect influencing nutrient cycling, herbivory patterns and other ecological processes.

FIRE AS A MANAGEMENT TOOL

Both, controlling fire and the use of fire as a management tool are activities practised in Namibian woodlands. Although rural fire control is presently under the mandate of the Ministry of Local Government and Housing, Namibia's Ministry of Environment and Tourism is the most active agency in fire control. The Directorate of Forestry has recently extended their successful programme in community fire control in Caprivi to other parts of the country. Active burning is planned to be implemented to improve the structure of woodlands, reduce fire hazards and control bush encroachment. Exemplary practical tools to determine the correct burning regimes have recently been developed by Trollope and his colleagues for this purpose (17).

Burning regimes and practices need to be adapted for different objectives. The improvement of wood lots for timber production, for example, requires a very different burning regime than the improvement of rangeland for livestock production, e.g. by controlling bush encroachment. Often conflicting burning regimes arise from these objectives, and appropriate burning practises will also differ between vegetation types and under different environmental conditions.

Because of these conflicting objectives there is considerable controversy over fire management strategies. In tropical northern Australia, for example, intensive prescribed burning is practised early in the dry season, but there are voices questioning the approach and pleading for a less scorching method, not last to avoid presenting vast expanses of burned landscapes to the astonished tourists (29).

CONCLUSION

Fire season and fire frequency have likely been altered dramatically by humans in African savannas over the past centuries. A shift in species composition to more fire-tolerant species and a degradation of structural diversity to largely bimodal size structure are marked signs of this change and can be observed in many Namibian woodlands on Kalahari sands.

William Bond, one of South Africa's great fire ecologists summarised the *status quo* of the savanna-tree-grass-fire dilemma very fittingly:

“The reason for grasses failing to eliminate tree seedlings through competition or fire, and for trees failing to exclude grasslands and form non-flammable thickets, except in local part of the landscape, remains an intriguing and economically important puzzle for savanna ecologists.” (2, pp. 435)

However, even if the mechanisms are not entirely understood, where appropriate, adaptive livestock grazing may offer a useful management tool to help reducing excessive fuel loads and so the frequency and intensity of fires.

REFERENCES

1. Huntley, B.J. and Walker, B.H. (ed.) 1982. *The ecology of tropical savannas*. Ecological Studies 42, Springer-Verlag, Berlin.
2. Bond, W.J. 1997. Fire. In: *Vegetation of Southern Africa*. Cowling R.M, Richardson, D.M. and Pierce, S.M. (eds), Cambridge University Press, Cambridge p. 421-446.
3. Williams, R.J. and Griffiths, A.D. 1999. Fire regimes and biodiversity in the wet-dry tropical savanna landscapes of northern Australia. Conference Proceedings, *Australian Bushfire Conference*, Albury, p. 1093.
4. Booysen, P. de V. and Tainton, N.M. (eds). 1984. *Ecological effects of fire in South African ecosystems*, Springer-Verlag, Berlin.
5. Goldammer, J.G. 1990. *Fire in the tropical biota - Ecosystem Processes and global challenges*. Ecological Studies 84, Springer-Verlag, Berlin, 497 pp.
6. Scholes, R.J. 1997. Savanna. In: *Vegetation of southern Africa*. Cowling, R.M., Richardson, D.M. and Pierce, S.M. (eds.), Cambridge University Press, Cambridge, p. 258-277.
7. Walter, H. 1971. *The ecology of tropical and subtropical vegetation*. Oliver and Boyd, London.
8. Smith, T.M. and Goodman, P.S. 1986. The effect of competition on the structure and dynamics of Acacia savannas in southern Africa. *J. Ecol.* 74, 1031-1044.
9. Scholes, R.J. and Walker, B.H. 1993. *An African savanna: Synthesis of the Nylsvley Study*. Cambridge University Press, Cambridge.
10. Goldammer, J.G. 1999. *Development of a national fire policy and guidelines on fire management in Namibia*. Namibia-Finland Forestry Programme, Directorate of Forestry, Windhoek.
11. Morton, S.R. and Andrew, M.J. 1987. Ecological impacts and management of fire in northern Australia. *Search* 18, 77-82.
12. Trollope, W.S.W. and Tainton, N.M. 1986. Effect of fire intensity on the grass and bush components of Eastern Cape thornveld. *J. Grassl. Soc. south. Afr.* 2, 27-42.
13. Brain, C.K. and Sillen, A. 1988. Evidence from the Swartkrans cave for the earliest use of fire. *Nature* 336, 464-466.
14. Powell, N. 1998. *Co-management in non-equilibrium systems*. Doctoral thesis. Swedish University of Agricultural Sciences, Uppsala.
15. Strohbach, B.J. 1996. The effect of season and treatment on the survival rate and coppicing ability of five encroaching woody species. II. the effect for fire-girdling.

- Agricola* November 1996, 61-65.
16. Trollope, W.S.W. and Trollope, L.A. 1999. *Technical review of the Integrated Forest Fire Management component of the Namibia-Finland Forestry programme in the East Caprivi Region of Namibia*. University of Fort Hare, Department of Livestock and Pasture Science, South Africa, 40 pp.
 17. Trollope, W.S.W., Hines, C.J.H. and Trollope, L.A. 2000. *Simplified techniques for assessing range condition in the East Caprivi Region of Namibia*. Directorate of Forestry, Namibia-Finland Forestry Programme, Windhoek 68 pp.
 18. du Plessis, W.P. 1997. Refinements of the burning strategy in the Etosha National Park, Namibia. *Koedoe* 40, 63-77.
 19. Trigg, S. 1998. *Fire scar mapping in Northern Namibia*. A report on the forest fire control component of the Namibia-Finland Forestry Programme, Directorate of Forestry, Windhoek.
 20. De Sousa Correia, R.J. & Bredenkamp, G.J. 1986. A reconnaissance survey of the vegetation of the Kavango, South West Africa. *J. SWA Sci. Soc.* 41, 29-45.
 21. Cook, G.D. 1994. The fate of nutrients during fires in a tropical savanna. *Aust. J. Ecol.* 19, 359-365.
 22. Simmonds, E.B. 2000. *Soils of Kavango Region*. Report for Ministry of Environment and Tourism, Windhoek.
 23. Rutherford, M. 1981. Survival, regeneration and leaf biomass changes in woody plants following spring burns in *Burkea africana* - *Ochna pulchra* savanna. *Bothalia* 13, 531-552.
 24. Trollope, W.S.W. 1984. Fire in savanna. In: *Ecological effects of fire in south African ecosystems*. Booysen, P.de V. and Tainton, N.M. (eds.), Springer-Verlag, Berlin p. 149-176.
 25. York, A. and Britton, D. 1999. Impacts of grazing and burning on forest biodiversity. Conference Proceedings, *Australian Bushfire Conference*, Albury, p. 1095.
 26. Hoffman, M.T., Bond, W.J. and Stock, W.D. 1995. Desertification of the eastern Karoo, South Africa: conflicting palaeo-ecological, historical and soil isotopic evidence. *J. Env. Mon. Assessm.* 37, 159-177.
 27. Geldenhuys, C.J. 1977. The effect of different regimes of annual burning on two woodland communities in Kavango. *S.A. Forestry J.* 103, 32-42.
 28. Norris, P. and Conroy, B. 1999. Fire ecology of soil and litter invertebrates. Conference Proceedings, *Australian Bushfire Conference*, Albury, p. 1069.
 29. Andersen, A.N., Braithwaite, R.W., Cook, G.D., Corbett, L.K., Williams, R.J., Douglas, M.M., Gill, A.M., Stterfield, S.A. and Muller, W.J. 1998. Fire research for conservation management in tropical savannas: introducing the Kapalga fire experiment. *Aust. J. Ecol.* 23, 95-110.

Acknowledgements. The initial research for this review was stimulated and financially supported by the Environmental Profile of the Kavango Region Project of the Ministry of Environment and Tourism, Namibia. I would like to give credit to Chris Hines and Winston Trollope for their outstanding practical approach and earlier discussions on the fire issue in Namibian woodlands. Discussions with Moses Chakanga enabled me to incorporate the latest developments at the Directorate of Forestry.

Captions to figures and photographs

Figure 1. Extent of Namibian forests and woodlands (grey) and most fire-prone areas (hatched). Internal boundaries show administrative regions.

Figure 2. Simple diagram of the main factors controlling savanna dynamics. Other aspects such as climate, substrate and topography also have to be taken into account.

Figure 3. Simple model of interaction between grazing and fire regime in Kalahari woodlands of East Caprivi, Namibia. Maintaining all other variables constant, heavy livestock grazing and long-term suppression of fire is believed to result in bush encroachment (derived from observations in East Caprivi by Trollope and Trollope 1999).

Figure 4. Simple model of the effect of light or no grazing in combination with hot and frequent fires on Kalahari woodlands of East Caprivi, Namibia. Open woodland with a bimodal structure is the result (derived from observations in East Caprivi by Trollope and Trollope 1999).

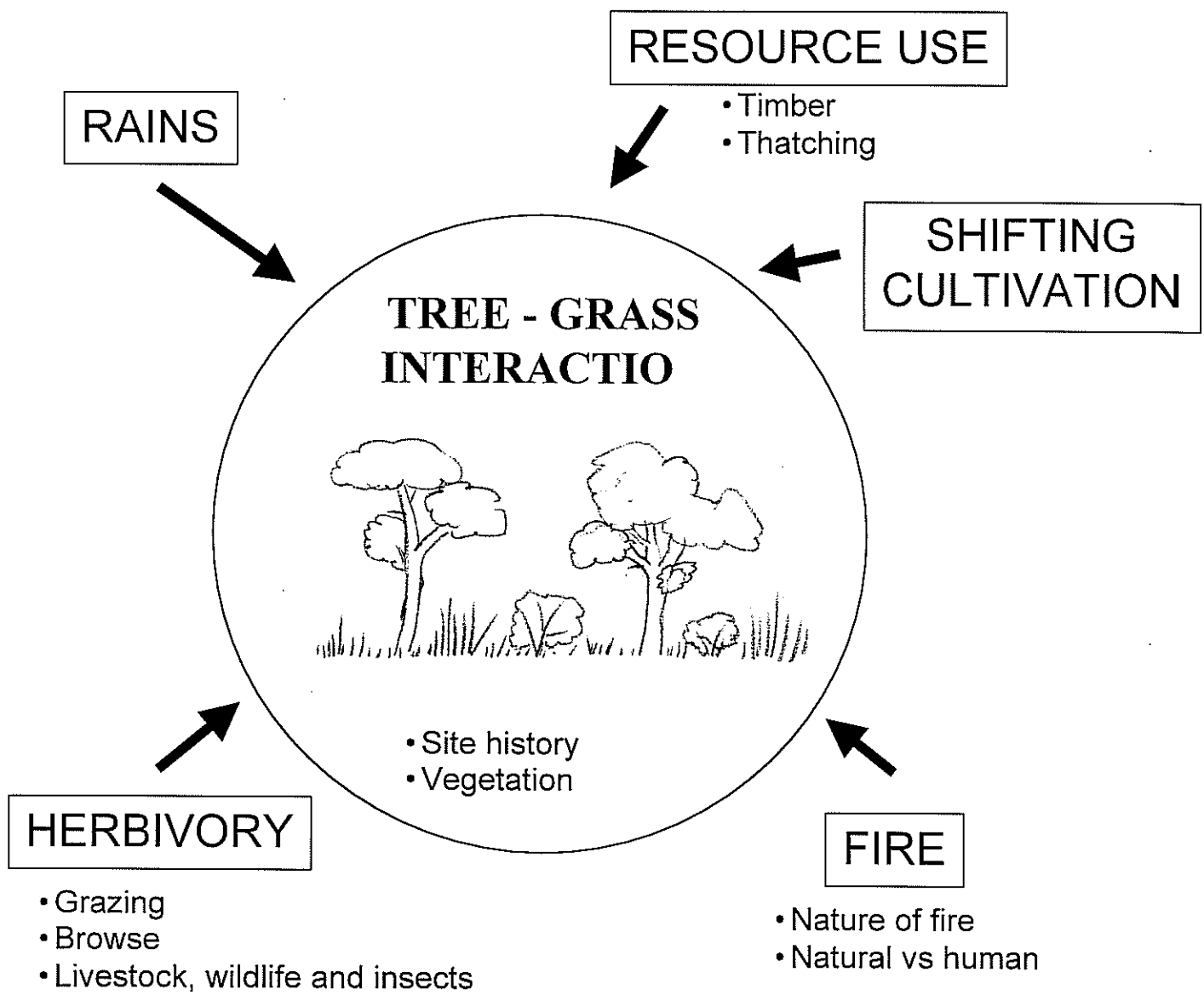
Figure 5. Simple model of the effect of moderate to heavy grazing and fires on Kalahari woodlands of East Caprivi, Namibia. Open to closed woodland with a more diverse structure is expected to develop (derived from observations in East Caprivi by Trollope and Trollope 1999).

Photo 1. Frequent fires in *Burkea africana* woodland in the Kavango Region of Namibia maintain a virtually undergrowth free habitat (Photo by A. Burke).

Photo 2. The bark of the local fruit tree *Strychnos cocculoides* almost resembles that of mediterranean oaks grown for commercial cork production. This is a very effective adaptation to fire (Photo by A. Burke).

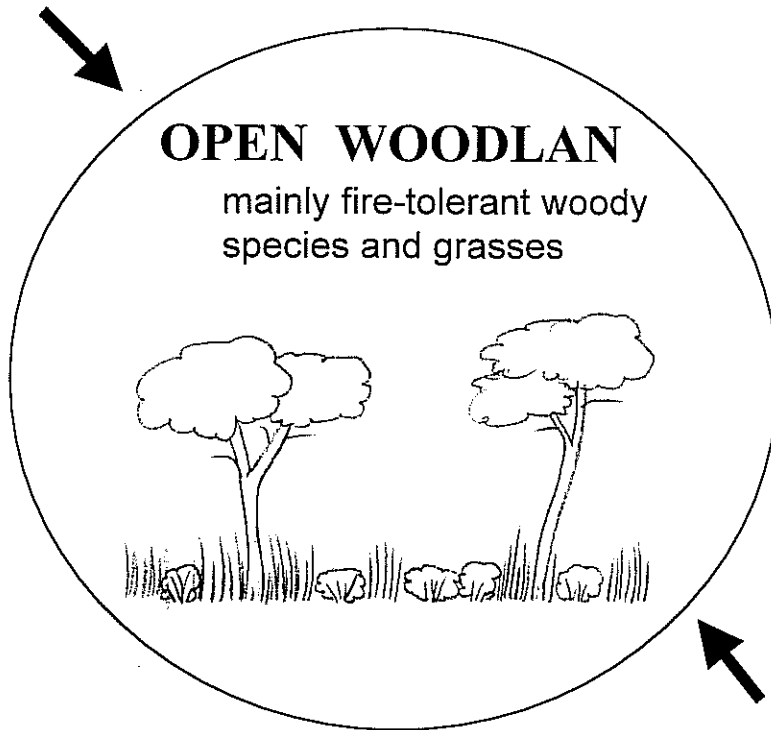
Photo 3. Bush fires in Kalahari woodlands in Namibia are largely restricted to surface fires with a typical flame height up to 2 metres (Photo by J. Burke).

Photo 4. Geophytes, such as the flame lily (*Gloriosa superba*) escape most fires by restricting their active periods to a few months after the rains and remaining dormant below ground for the remainder of the year (Photo by A. Burke).



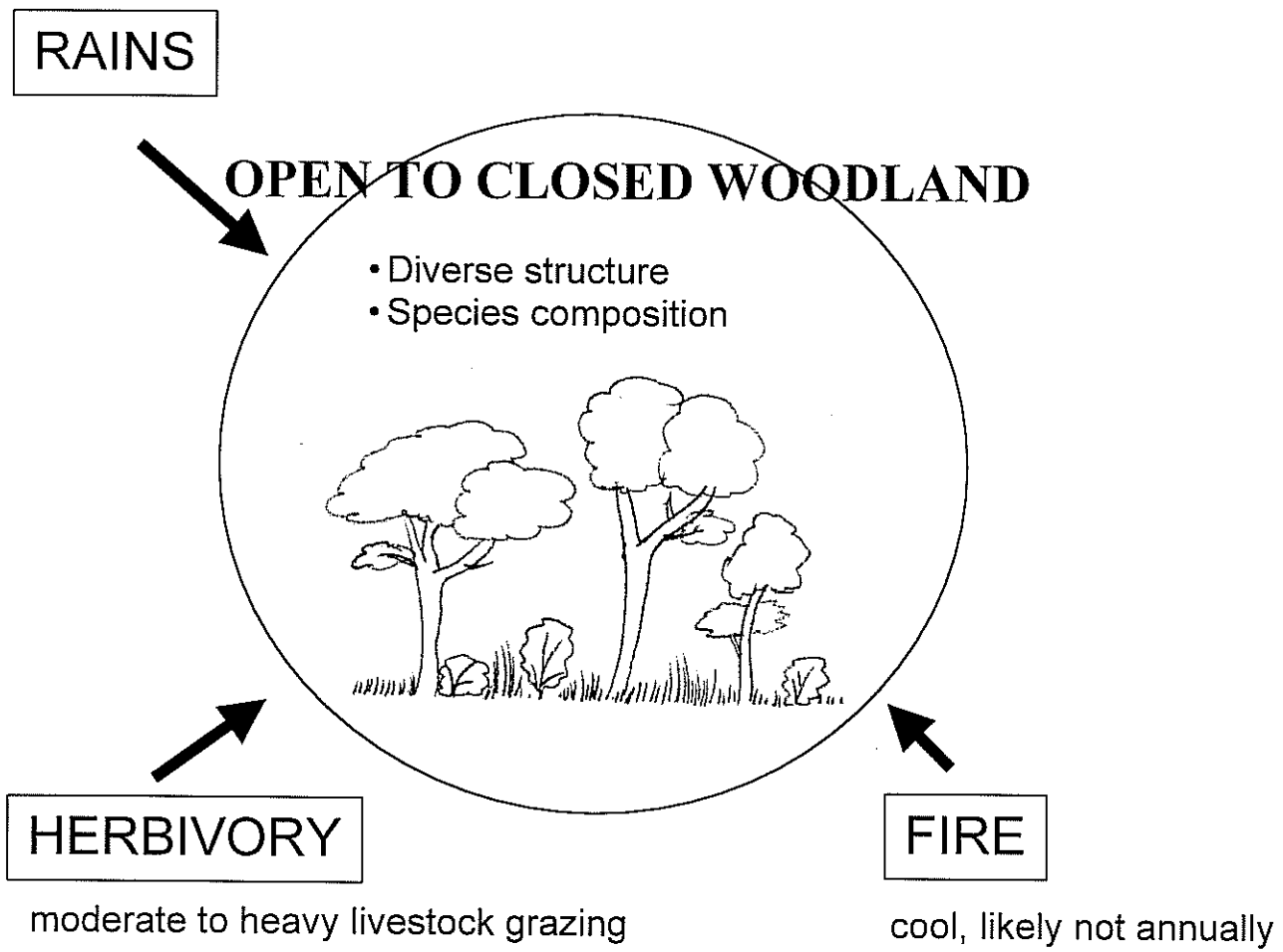
LIGHT OR NOR GRAZING AND FIRES

RAINS



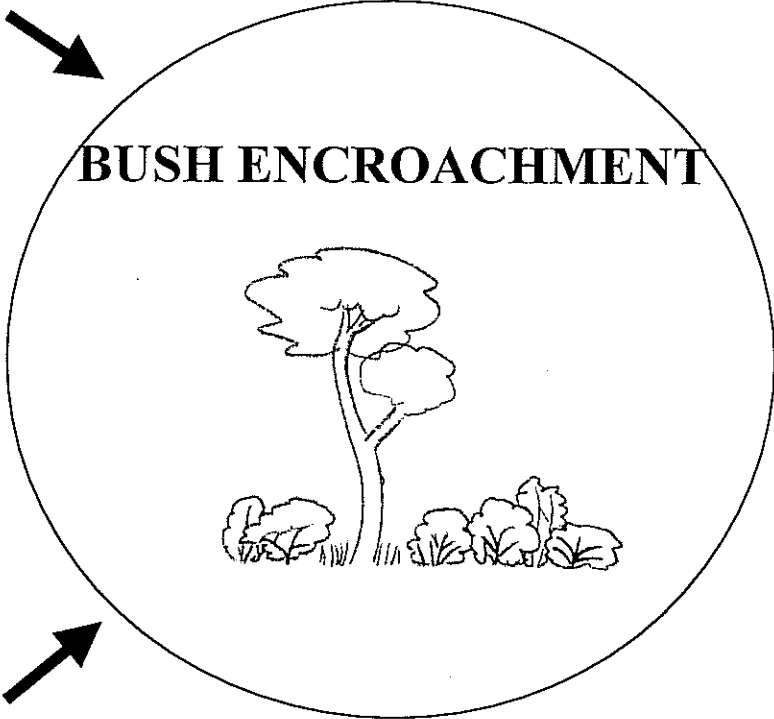
FIRE
hot and

MODERATE TO HEAVY GRAZING AND FIRES



NO FIRE, HEAVY GRAZING

RAINS



BUSH ENCROACHMENT

HERBIVORY

- Intense livestock grazing

