# Effects of Changes In Elephant Densities On the Environment and Other Species—How Much Do We Know?

**Jonas Chafota**

WWF Regional Programme Office, P.O. Box CY1409, Causeway, Harare, Zimbabwe. Email jchafota@wwf.org.zw

## Introduction

The basic problems of elephant management are due to a fundamental change in land use and life styles that have taken place in Africa since the last century. Most conservation areas in Africa form "ecological islands" (Martin and Taylor, 1983) because they are surrounded by human settlements. Factors which caused elephants to increase within the conservation areas are removal of hunting pressure and compression of range (Spinage, 1973; Laws et al., 1975; Jachmann and Bell, 1984; Martin et al., 1996).

The term environment as defined by Bailey will be used here to include all the materials and processes in the surrounding of elephant and emphasis is placed on abundance, diversity and complexity of materials and processes many of which influence managed populations and other species. Owen-Smith (1988) outlined the possible dimensions of the elephant problem as follows (a) radical modification of certain habitat types leading to perhaps the loss of species which depend upon them (b) elimination of certain sensitive plant species (c) reduced vegetation cover leading to accelerated erosion and decline in the overall productivity of the ecosystem (d) depression of the resource base for megaherbivores themselves and (e) loss of aesthetic features of landscape, such as mature trees.

Despite many years of research, the dynamic impact of elephant on the environment is poorly understood. Defining management policies to deal with the elephant over-abundance has been problematic because of lack of scientific facts. The purpose of this paper is to review the current state of knowledge pertaining to the impact of elephant on the associated environment, with emphasis on how changes in elephant densities may cause changes in biodiversity with particular reference to southern Africa ecosystems. The term biodiversity is a concept used to describe the variety of life forms and can be measured in terms of biomes, ecosystems, species and genetic varieties (Biodiversity Support Program).

An estimated 160 000 elephants, which constitutes about 40% of the African continental elephant population, is found in Zimbabwe, Namibia, South Africa and Botswana (Craig, 1996). Of this population, about 50% is found in Botswana, 40% in Zimbabwe and 10% in Namibia and South Africa. The largest contiguous area of elephant concentration with a population size of about 120 000 elephant and contained in a range of about 110 000 $km^2$ extends through northern Botswana, the Caprivi Strip of Namibia and northwest Matebeleland in Zimbabwe (Craig, 1996), Fig. 1. This translates to an elephant density of about 1.03 $km^{-2}$ although in Botswana, elephant densities of 3 to 12 $km^{-2}$ have been reported in the Kwando/Linyanti dry season concentration areas (Melton; Work; Craig, 1990; Spinage, 1990; Calef).

## Impacts on Woody Vegetation

The impact of elephant on woody vegetation and its consequences is well documented. The severity of impact of elephant on vegetation depend largely on the type of impact suffered by a plant species and its response to the impact. Elephant impacts which are likely to kill a woody species include uprooting, tree felling and bark stripping. Susceptible genera have been found to be *Acacia*, *Commiphora* and *Adansonia* (Bell, 1985). Elephant impacts in woodlands dominated by these genera have been known to be major factors in the conversion of woodlands to grassland, with the conversion accelerated by fire in some cases in Murchison Falls National Park, Uganda (Buechner and Dawkins; Buss; Laws and Parker, 1968; Laws, 1970; Laws et. al, 1970), Tsavo National Park (East), Kenya (Bax and Sheldrick; Glover; Laws, 1970).

The probability of tree death on elephant impact has been found to be related to aridity, soil type, size of tree, nutrient status and the response of woody species to elephant damage. *Brachystegia, Julbernadia, Isoberlinia, Colophospermum*, some *Combretum*, *Terminalia*, and a range of other shrub species have a higher probability of coppicing. In well drained sandy soils of low nutrient status, the response of woody species to elephant damage is shrub coppice regrowth as observed in the *Brachystegia* woodlands of Kasungu National Park, Malawi (Jachmann and Bell, 1985), in Vwaza Marsh Game Reserve, Malawi (McShane), in Chobe National Park, Botswana (Chafota and Owen-Smith) and in the Kalahari sand woodland of Hwange National Park, Zimbabwe (Childes; Rushworth). In the Luangwa Valley, coppicing of *C. mopane* woodlands in response to elephant browsing occurred on clayey soils with an impervious B horizon and a nutrient rich A horizon (Lewis).

The conversion of woodlands to open grasslands is unlikely in southern Africa ecosystems due to the ability of woody vegetation to regenerate by coppice regrowth. Lindsay indicated that the likelihood was the conversion of woody vegetation to open, patchy mosaics. Vegetation associations in the high density elephant ranges in Southern Africa (Fig. 1) are dominated by the genera *Colophospermum*, Miombo (*Brachystegia, Julbernadia*), *Baikiaea* and *Acacia* mostly in the canopy layer. *Colophospermum*, Miombo (*Brachystegia, Julbernadia*) and *Baikiaea* have a potential to coppice follwing impacts by elephant and other agents. The vegetation associations in high elephant ranges can briefly be described as follws:

***(a) Northern Botswana***

The elephant ranges described as northern Botswana covers an area of about 80 km$^2$ includes Chobe National Park, Nxai Pan National Park, Moremi Game Reserve, Forest Reserves and Wildlife Management Areas. Based on studies by Child; Simpson; Sommerlatte; Moroka; Ben-Shahar (1993) and Chafota (*in prep.*) the dominant vegetation types in the canopy layer of the Kalahari sandveld include *Baikiaea plurijuga, Burkea africana* and *Colophospermum mopane*. The *C. mopane* woodland extends into western Kaprivi in Namibia. The shrub layer which also includes the regeneration of the canopy layer is dominated by *Ochna pulchra*, *Diplorhynchus condylocarpon, Terminalia sericea, Bauhinia petersiana, Baphia massaiensis, Combretum apiculatum, Combretum fragrans, Combretum collinum* and *Combretum zeyheri*. The *B. plurijuga* woodland is usually found on deep Kalahari sands while mopane occurs on clayey soils. The riverine woodlands of the Linyanti and Chobe river fronts were dominated by *Acacia* species which, have now been destroyed by elephants. The Kalahari sands were described as having poor nutrients with high infiltration rates (Conybeare)

**(*b) Northwest Matebeleland, Zimbabwe***

The elephant range in northwest Matebeleland covers an area of about 19 400 km$^2$ and incluse the Matetsi Wildlife Complex, Hwange National Park, Forestry Areas, Intensive Conservation Areas and 2 Communal Lands (Price Waterhouse). The soil types range from deep the Kalahari sand woodlands to, grey loamy-clay soils, and soils derived from deep basaltic soils (Rushworth; Williamson; Childes; Conybeare). The woody vegetation is related to soil types. The dominant woody species in the canopy tree layer include *C. mopane*, *B. plurijuga*, *Guibourtia coleosperma*, *Pterocarpus angolensis* and some *Acacia* associations. The shrub layer composition is similar to that found in northern Botswana.

**(c) *The Sebungwe, Zimbabwe***

The Sebungwe region covers an area of about 15 000 km$^2$ and is comprised of Binga, Gokwe and part of Kariba Districts covering an area of 40 000 km2, however, the elephant concentration area lies within an area of 15 000 km$^2$ with landuse categories of 49% communal lands, 20%, 20% Safari Areas, 28% National Parks and 3% Forest Areas (Taylor, 1978). The vegetation is related to soils which are mainly sands of various textures, derived from numerous sandstone beds (ADA, 1973). The soils are generally low in plant nutrients, frequently shallow and sandy with low moisture retention capacity; some are sodic, and many of them, particularly on steeper land, will erode easily (Brunt et al.). On Kalahari sands, deep soils of low fertility and low water holding capacity have developed. Soils derived from mudstones and shales are grey heavy clays with very unfavourable and unstable structure. The area is comprised of a variety of vegetation associations which were described by ADA; Taylor (1978) and Anderson et al. to include in the tree layer *Julbernadia globiflora*, *Brachystegia boehmii*, *B. plurijuga*, *Erythrophleum africanum, P. angolensis, B. africana* and *C. mopane*. Other woody species commonly found in the tree layer include *Kirkia acuminata, Adansonia digitata* and *Screrocarya birrea*. Woody species commonly found in the shrub layer include *B. massaiensis, D. condylocarpon, T. sericea* and *Combretum* species.

***(d) The Zambezi Valley, Zimbabwe***

The vegetation types of the Zambezi Valley were described by Anderson et al. Major woodland types include *C. mopane*, *Brachystegia allenii*, *J. globiflora* a with associated woody species such as *C. apiculatum, Terminali stuhlmannii, Diospyros kirkii* and *Acacia tortlis* on alluvial soils near rivers.

**(e) *Gonarezhou National Park, Zimbabwe***

The vegetation of the Gonarezhou is related to soil types which has been described as regosols, fertile and unleached, formed from the Crataceous sandstone deposits; vertisols which are derived from the Karoo basalts and siallitic soils derived from the Limpopo mobile belt paragneiss (Nyamapfene, quoted by Cunliffe). The most extensive vegetation type is *C. mopane* with associated woody species which include *Grewia spp.*, *C. apiculatum*, *K. acuminata, Terminalia prunioides, S. birrea, Commiphora spp., A. nigrescence, A. digitata*, and *T. sericea.*

***(f) Kruger National Park*, *South Africa***

Geologically, the Kruger National park is divided into two almost two equal sections of predominantly granitic formations in the western half and basalts in the eastern half. A summary of vegetation types based on previous studies was provided by Mills et al. Five main vegetation zones correlated with soil types were described as large leaved deciduous bush, mixed *C.*

*apiculatum* on granitic soils, *Acacia nigrescence*-*Sclerocarya birrea* on basalt soils and *C. mopane* on the sandveld.

***(g) Etosha National Park*, *Namibia***

The vegetation of Etosha National Park has been described as predominantly *C. mopane* (Lindeque and Lindeque).

## Interaction With Other Agents

Studies of feeding habits of elephant in Sengwa Wildlife Area, Zimbabwe (Guy), Luangwa Valley (Caughley), Kasungu National Park, Malawi (Jachmann and Bell, 1985) and Chobe National Park, Botswana (Chafota, *in prep.)* revealed that the feeding level preference of woody species lies in the range 1 and 2.5 m. Restricting utilization to the shrub layer confirms the finding of Laws et al. (1975) and Barnes (1979,1980) that small size classes were preferred and its only when they were depleted that large trees were utilized.

Observations in Chobe National Parks (Chafota, *in prep*) suggest that tree felling may occur episodically in association with events such as drought, frost and fire. Elephants may have severe impacts on canopy trees in localized zones particularly near permanent water sources as observed in the Chobe river front (Child; Sommerlatte; Moroka) or near artificial water sources as observed in Hwange National Park (Conybeare). Localized severe impacts on canopy trees may also occur if movement of elephant is restricted by human beings (Thompson) or movement restricted by physical barriers such as game fences and impassable terrain (Cumming et al., 1997).

Fire and frost and drought may cause a high mortality on young trees up to the height of 3 m (Rushworth; Childes; Conybeare; *pers obs*.). As observed by Chafota and Owen-Smith in Chobe National park, northern Botswana, the impacts of fire, frost and drought may be as great as that of elephants, and more extensive and these agents may affects trees little utilized by elephant. As the canopy layer is opened up, the increase in the growth of the herb layer will be enhanced thus increasing the frequency and intensity of fires.

## Can an Equilibrium Be Attained?

It is unlikely that the stable limit cycle of elephant vegetation interaction hypothesized by Caughley is attainable in southern Africa. What is most likely to happen in the absence of management intervention is the continued increase of elephant resulting in the destruction of canopy trees to the extend that woody vegetation will be maintained at shrub or coppice level. A number of factors particularly fire, frost and drought as discussed above may interact with elephant impacts to maintain woodlands at coppice or shrub state. But elephant alone may prevent woodland regeneration and recruitment into larger size classes by feeding on small size classes especially when no larger size classes are not available (Dublin; Caughley).

The transformation of woodlands to a stable shrub coppice seems to be a feature in savanna woodlands growing in sandy soils or other soils where woody shrubs have a large fraction of their biomass underground (Rushworth; Childes)

## Can an Irreversible Vegetation Change be Attained?

The elephant problem in east Africa was perceived to result in permanent habitat change for example in Tsavo National Park, Kenya (Buechner and Dawkins; Laws, 1970) and in Ruaha

National Park, Tanzania (Barnes, 1982, 1983). To contain the increase in elephant populations, culling was adopted as a low risk strategy until more was learnt about the system dynamics of national parks. Examples where culling took place are Murchison Falls, Uganda (Laws and Parker, 1968), Luangwa Valley, Zambia (Hanks), Kruger, South Africa (de Vos et al.; Hall-Martin), Hwange and other parks in Zimbabwe (Cumming, 1981, 1983). In Tsavo, the non-interference was adopted and this, resulted in habitat destruction followed by catastrophic mortality during 2 years of drought (Corfield; Parker).

To reduce loss of canopy cover, the management objective was to keep elephant densities at _1 $km^{-2}$ in protected areas in Zimbabwe (Martin et al. 1996; Taylor and Cumming, 1993; Cumming et al., 1997) and at_ 0.75 $km^{-2}$, in Kruger National Park, South Africa (Mills et al.). Management decisions were thus influenced by culturally-based value judgements and aesthetic decisions (Bell, 1983; Taylor and Cumming, 1993).

Controlling elephant populations by culling has been an unfortunate management strategy because not much can be learned about systems dynamics of national parks if populations are kept at low levels. There has been lack monitoring and experimental baseline controls to test predictions or evaluate the effectiveness of adopted management strategies (Arcese and Sinclair). The effectiveness of culling was rarely monitored and as agued by Taylor and Cumming (1993) the adaptive approach would require considerable effort in both in manpower and financial resources to carry out research, design of monitoring programmes and implementation to ensure rigorous assessment of whether the prediction or original objective has been met. Furthermore, the desired state of vegetation particularly loss of canopy trees was not attained in practice in Zimbabwe because the number of elephant culled was not sufficiently large due to the underestimation of population sizes (Price Waterhouse; Martin et al., 1996). Despite high levels of elephant reduction exercises, vegetation changes perceived as detrimental have not been prevented by keeping elephants at relatively low levels in South Africa (Viljoen) and little is known about elephant-fire-vegetation dynamics despite a long term research programme of spanning over two decades (Mills et al.). This could have been cause by confounding factors of climatic changes, fire and herbivory.

The Tsavo experience has demonstrated that irreversible habitat change did not occur contrary to predictions (Leuthold; Arcese and Sinclair). Vegetation recovery was attributed to reduction in elephant numbers by drought in 1970-71 (Corfield) and heavy poaching in the late 1970's (Leuthold; Waithaka). But (Arcese and Sinclair) argued that habitats in the Tsavo began to regenerate before elephant reductions due to drought and poaching took place and suggested that changes that occurred could have been due to human or other influences.

The major lesson learned from the Tsavo experience is that if the non-interference or the *laissez- fare* management option is adopted there may be environmental degradation and elephant mortality in time due to food restriction. The Tsavo experience has not yet occurred in the southern African elephant range and is unlikely to occur for the forceable future due to a combination of the following factors:

**1.** The issue of whether elephant impact is negative or positive upon their environment depends on whether they are free-ranging or compressed by human pressures (Western). The southern African elephant range is fairly large and elephant have opportunities of cross- border movement in the contiguous concentration area which extends across international boundaries of Botswana, the Caprivi Strip in Namibia and northwest Matebeleland in Zimbabwe (Craig, 1996; Price Waterhouse). Elephant movement occurs in response to changing food and water availability and protection from poaching, thus reducing the likelihood of localized population crashes. There is a likelihood of maintenance or expansion of the elephant range outside protected areas as human-elephant conflict may be reduced as a result of community based conservation programmes in the region which directly benefit the local people. But the community based conservation programmes are being threatened by increased demand and overuse of on natural resources by human beings in the prevailing poor macroeconomic environment in southern Africa. An analysis of the changing patterns of settlement after the 1980's revealed that land was being cleared for human settlement and cultivation at the rate of 8-9% per annum in community based conservation areas of the mid-Zambezi Valley (Cumming and Lynam, 1997). This may lead to habitat fragmentation, loss of range of elephant and increased elephant densities in protected areas due to compression. The elephant range may be extended if the Transfrontier Conservation Area Concept takes off the ground. Transfrontier conservation areas are defined as relatively large conservation areas, which straddle frontiers between two or more countries and cover large scale natural systems encompassing one or more protected areas (The World Bank).

**2.** Seasonal movements of elephant between wet and dry season ranges as observed in Chobe National Park (Craig, 1990; Calef) as well as transborder movements (Craig, 1996, Price Waterhouse) could have alleviated all year round impacts on localized and sensitive vegetation types.

**3.** Elephant seasonally subsist largely on plant parts of different and abundantly available woody species in the shrub layer which include *Brachystegia, Colophospermum, Terminalia, Diplorhynchus, Bauhinia, Combretum* and *Bauhinia.* These species are resilient to elephant impact and may show profuse seasonal regrowth following elephant use (Thompson; Jachmann and Bell, 1985; McShane; Ben-Shahar, 1997; Cumming et al., 1997; Chafota, *in prep.*) or destruction by fire or frost (Rushworth; Childes). The opening up of canopy trees may promote growth of grass, coppicing of impacted trees and seedling regeneration thus providing more food for elephant and other vertebrates.

## Effects on Other Species

The effects of elephant on other species has not been well monitored and documented and much of what is available in the literature is speculative or predictive with respect to the likely effects of too many or too few elephant and its effects on biodiversity changes. Loss of biodiversity was expected to result from too many elephant, none or too few elephant (Owen-Smith, 1989; Western). The elephant is viewed as one of the keystone herbivores (Owen-Smith, 1987) species responsible for influencing ecosystem structure, woodland dynamics and accelerated nutrient cycling through its feeding habits which may or may not be beneficial to other species.

Owen-Smith (1989) indicated that pleistocene megaherbivore extinction in north America could have contributed to the extinction of lesser large mammal species. In recent times, the extermination of elephant in Hluhluwe Game Reserve, South Africa is believed to have resulted in the encroachment of forests and thickets which among other factors could have contributed to the decline of (a) grazers such as wildebeest, zebra, waterbuck and reedbuck and (b) browsers such as bushbuck, kudu and black rhino with the exception of mixed feeders impala and nyala (Owen-Smith, 1989). In Tsavo, Kenya, browsers e.g. the black rhinoceros, dikdik, giraffe and lesser kudu declined due to the conversion of woodland thickets to open grassland by elephant while grazing angulates such as oryx, gazelle, warthog and zebra increased (Parker).

Similar observations were reported by Western  for Amboseli National Park, Kenya, where there was an increase in grazers and decline in browsers and mixed feeders and vice versa where woodlands proliferated outside the park.

While the above changes in large mammal population has been linked changes in elephant densities, it was recognised (Pachydem) that elephant habitat interactions are complex and poorly understood, both in the long and short term, and that establishing cause and effect relationships is therefore difficult.  Hence, the need to measure change in biodivesity using indicators such as birds, other vertebrates and invertebrate in terms of both species richness and abundance.   A study by Cumming et al. (1997) and  Fenton et al. of differences in species richness of woodland birds, birds, bats, mantices and ants between reserves where elephants had destroyed the miombo woodland and adjacent but intact miombo woodlands outside the reserves revealed  that (a) species richness of woodland birds and ants were significantly lower where elephants had removed tree canopy (b) no clear pattern was evident for ants and mantices and (c) bats were little affected by loss of canopy trees.   These studies suggest that  woodland disturbance may have no effect on some species while others may be affected positively or negatively.

In Chobe National Park, Botswana, Addy confirmed that the bushbuck, inhabiting the riverine woodland of the  Chobe river had declined in areas most severely impacted by elephants. However, the bushbuck was not likely to go extinct since adequate cover remained in the form of woody species not favoured by elephant.

## Effects on Elephants Themselves

Elephant populations in the contiguous concentration area have been reported to be growing at the rate of about 5% per annum (Spinage, 1990; Calef; Price Waterhouse). Theoretically, increases in populations of megahebivores should respond to varying food abundance by lengthening birth intervals and delays in attainment of sexual maturity (Laws, 1968). But there are time lags in the responses of these mechanisms to vegetation change further elephant increase may ultimately be restricted by nutritional deficiencies which may be associated with prolonged periods of droughts. Usually, severe impact on elephant fall on juveniles and females through reduced calf survival, deferred conceptions or catastrophic elephant mortality as observed in Tsavo, Kenya (Corfield; Parker). The only adjustment that can prevent or reduce localized overexploitation of food resources is dispersal. Recent distributions of elephant from aerial survey data in northern Botswana show that there is continued elephant movement further west to the Okavango delta (Derby Gibson, *pers comm*.).

## Effect on Nutrient Retention and Cycling

The quality of vegetation upon which herbivores depend is a function of precipitation, nutrients in the soils and nutrients in the biomass of vegetation (Botkin et al.) but there is little or no information on how elephants might influence productivity of savannas Cumming (1982). There is evidence from studies in East Africa (Botkin et al.) that both higher plants and mammalian herbivores as well as activities of fire, soil microorganisms and arthropods are involved in nutrient cycling particularly in areas of moderate to high rainfall. Higher plants conserve nutrients (a) directly by rapid uptake of available soil nutrients and their incorporation into plant tissue and (b) indirectly by exerting control on the systems's hydrological cycle and channelling precipitation through transpiration rather that runoff. Herbivores influence nutrient cycling and retention by (a) flux vegetative nutrients through their digestive systems (b) providing control mechanism for nutrient retention and availability near the surface of the soil for easy uptake by plants within the ecosystems and (c) stimulating uptake of nutrients through the consumption of vegetation resulting in rapid turnover in various elements.

The implication of the above scenario with respect to elephant vegetation interaction is that at very low elephant densities the vegetative contribution of nutrient cycling may diminish as much of the vegetation may be locked in one state.

## Summary and Conclusions

The future outlook on elephant-vegetation interaction with respect to biodiversity conservation has to be considered in terms of the following issues (see also Taylor and Cumming, 1993; Cumming, 1993; Cumming et al., 1997).

- There is a need to explore the effects of elephant disturbance on biodiversity and particularly their effects on spatial and temporal heterogeneity of habitats.
- There is a need to establish the limit of woodland change below which there is an adverse effect on biodiversity on sensitive species. But the dilemma is that management intervention to stop further biodiversity erosion through elephant culling has been shelved due to prohibitive operational costs, and cost recovery through the sale of elephant products is not feasible due to CITES ban. However, this could be an opportune time, to undertake long term studies of elephant habitat-interactions in the southern Africa ecosystems.
- As the elephant population is allowed to increase without management intervention, there

will be increase dispersal of elephant into the surrounding communal areas. The human elephant conflict will therefore be acute and this may result in restricting elephant movement thus confining them in protected areas resulting in adverse impact on biodiversity.

- Biodiversity conservation inside and outside protected areas should be integrated through ways which will make wildlife conservation an economically viable landuse option on local communities residing and living with wildlife in marginal areas. This could be done by taking a step much further than the current community based conservation approaches by focussing more on multispecies animal production systems which integrates wildlife and livestock production systems.

## Acknowledgements

I would like to thank the organizers, particularly Lovell Jarvis of the Department of Agricultural and Resource Economics at the University of California, Davis, for inviting me to present this paper and for support to attend the workshop; WWF for giving me time to prepare the paper and to attend the workshop, and Norman-Owen Smith for reviewing the first draft of the paper.

## References

Addy, J. E. 1993. Impact of elephant induced vegetation change on the Chobe bushbuck along the Chobe River, northern Botswana. Unpublished M.Sc. Thesis. University of the Witwatersrand.

Agricultural Development Authority. 1973. Agro- economic survey of northern Matebeleland. Ministry of Agriculture, Salisbury.

Anderson, I.P., P.J. Brinn, M. Moyo, and B. Nyamwanza. 1993. Physical resource inventory of the communal lands of Zimbabwe - an overview. *Natural Resources Inistitute Bulletin* 60: 1- 186 pp.

Arcese, P., and A.R.E. Sinclair. 1997. The role of protected areas as ecological baselines. *J. Wildli. Manage*. 61: 587-602.

Bailey, J.A. 1984. *Principles of wildlife management.* John Wiley & Sons.

Barnes R.F.W. 1979. Elephant ecology in the Ruaha National Park, Tanzania. Unpublished Ph.D. Thesis. Cambridge University.

_____. 1980. The decline of baobab tree in Ruaha National Park, Tanzania. *Afr. J. Ecol*. 18: 243-52.

_____. 1982. Elephant feeding behaviour in Ruaha National Park, Tanzania. *Afr. J. Ecol*. 20: 123-36.

_____. 1983. The elephant problem in Ruaha National Park, Tanzania. *Biol. Cons*. 26: 127-148.

Bax, N.P., and D.L.W. Sheldrick. 1963. Some preliminary observations on the food of elephants in the Tsavo Royal National Park (East) of Kenya. *E. Afr. Wildl. J*. 1: 40-35.

Bell, R.H.V. 1983. Decision-making in wildlife management with reference to problems of overpopulation. R.N. Owen-Smith ed. pp. 145-186. *Management of Large mammals in African Conservation Areas*. Pretoria: Haum.

_____. 1985. Elephants and woodland - a reply. *Pachyderm* 5: 17-18.

Ben-Shahar, R. 1993. Patterns of elephant damage in northern Botswana. *Biol. Cons*. 65: 249-256.

_____. 1997. Elephants and woodlands in northern Botswana: how many elephants should be there? *Pachydem* 23: 41-43

Biodiversity Support Program. 1993. *African biodiversity: foundation for the future*. Beltsville, Maryland: Professional Printing, Inc.

Botkin, D.B., J.M. Mellilo, and L.S.-Y. Wu. 1981. How ecosystems processes are linked to large mammal population dynamics. Fowler, C.W. and T.D. Smith, eds. pp. 373-388. *Dynamics of large mammal populations*. New York: Wiley.

Brunt, M.A., V.J. Clarke, and C. Greling. 1986. *Tsetse area development and land use planning in the Zambezi Valley, Zimbabwe*. FAO Consultant Report.

Buechner, H.K., and H.C. Dawkins. 1961. Vegetation change induced by elephants and fire in Murchison Falls National Park, Uganda. *Ecology* 42: 752-766.

Buss, I.O. 1961. Some observations of the food habits and behaviour of the African elephant. *J. Wildl. Manage*. 25: 131-148.

Calef, G. W. 1991. Elephant numbers and distribution in Botswana and northwestern Zimbabwe. Paper presented at a workshop on Management of the Hwange Ecosystem. Hwange Safari Lodge, 9-13 July, 1991.

Caughley, G. 1976. The elephant problem - an alternative hypothesis. *E. Afr. J*. 14: 265-283.

Chafota, J., and N. Owen-Smith. 1996. Options for the management of elephant in northern Botswana. *Pachyderm* 22: 67-72.

Child, G. 1968. *An ecological survey of northeastern Botswana*. Report to the Government of Botswana. FAO Report No. TA 2563.

Childes, S.L. 1984. The population dynamics of some woody species in the Kalahari sand vegetation of Hwange National Park. Unpublished M.Sc Dissertation, University of the Witwatersrand, Johannesburg.

Conybeare, A.M. 1991. Elephant occupance and vegetation change in relation to artificial water points in a Kalahari sand area of Hwange National Park. Unpublished D. Phil. Thesis, University of Zimbabwe.

Corfield, T. F. 1973. Elephant mortality in Tsavo National Park, Kenya. *E. Afr. Wildl. J*. 11: 339-68.

Craig, G.C. 1990. Present population and distribution of elephants in northern Botswana. Hancock, P. ed. pp. 16-18. *The Future of Botswana's Elephants.* Gaborone: Kalahari Conservation Society.

Craig, G.C. 1996. Elesmap Project final technical report. CEC Project No. B7-5040. Namibia Nature Foundation.

Cumming, D.H.M. 1981. The management of elephant and other large mammals in Zimbabwe. P.A. Jewel, and S. Holt eds. pp 91-118. *Problems in management of locally abundant wild mammals*. New York: Academic Press.

Cumming, D.H.M. 1982. The influence of large herbivores on savanna structure in Africa. Huntley, B.J., and B.H. Walker eds. pp. 217-245. *Ecology of Tropical Savannas*. Berlin: Springer-Verlag.

Cumming, D.H.M. 1983. The decision-making framework with regard to the culling of large mammals in Zimbabwe. R.N. Owen-Smith ed. pp. 173-186. *Management of Large mammals in African Conservation Areas*. Pretoria: Haum.

Cumming, D.H.M. 1993. Multispecies systems: Progress, prospects and challenges in sustaining range animal production and biodiversity in East and Southern Africa. *Proceedings of the VII World Conference on Animal Production*, Vol. 1: 145-159.

Cumming, D.H.M., M.S. Cumming, J.M. Dunlop, A.G. Ford, M.D. Hovorka, D.S. Johnston, M. Falcounis, Z. Mahlangu, and C.V.R. Portfors. 1997. Elephants, woodlands and biodiversity in southern Africa. *Sth. Afr. J. Sci*. 93: 231-236.

Cumming, D.H.M., and T.J.P. Lynam. 1997. *Landuse changes, wildlife conservation and utilization, and the sustainability of agro-ecosystems in the Zambezi Valley: Final Technical Report, Vol. 1.* WWF Programme Office, Zimbabwe. Project ZW0024.

Cunliffe, R.N. 1993. *Landuse in the southern lowveld of Zimbabwe*. Harare, Zimbabwe: Department of National Parks and Wildlife Management.

de Vos, V., R.G. Bengis, and H.J. Coetzee. 1983. Population control of large mammals in the Kruger National Park." R.N. Owen-Smith ed. pp. 213-231. *Management of Large mammals in African Conservation Areas*. Pretoria: Haum.

Dublin, H.T. A.R.E. Sinclair, J. McGlade. 1997. Elephants, fire as causes of multiple stable states in the Serengeti-Mara woodlands. *J. Animal Ecol*. 59: 1147-1164.

Fenton, M.B., D.H.M. Cumming, I.L. Rautenbach, G. Cumming, M.S. Cumming, G. Ford, R.D. Taylor, J. Dunlop, M.D. Hovorka, D.J. Johnston, C.V. Portfors, M.C. Kalcounis, and Z. Mahlangu. 1997. Bats and the loss of tree canopy in African Woodlands. *Conservation Biology* 12: 399-407.

Glover, J. 1963. The elephant problem at Tsavo. *E. Afr. Wildl. J.* 1: 30-39.

Guy, P.R. 1976. The feeding behaviour of elephant (*Loxodonta africana*) in the Sengwa Area, Rhodesia. *Sth. Afr. J. Wildl. Res*. 6: 55-63.

Hall-Martin, A. 1984. Conservation and management of elephants in the Kruger National Park, South Africa. Cumming, D.H.M., and P. Jackson eds. pp. 104-115. *The Status and Conservation of Africa's Elephants and Rhinos*. IUCN, Switzerland.

Hanks, J. 1971. Reproduction of the elephant (*Loxodonta africana*) in the Luangwa Valley, Zambia. *J. Repr. Fert*. 30: 13-26.

Hough, J. 1986. Management alternatives for increasing dry season base flow in the miombo woodlands of southern Africa." *Ambio* 15: 341-346.

Jachmann, H., and R.H.V. Bell. 1984. Why do elephants destroy woodlands? *African Elephant and Rhino Group Newsletter* 3: 9-10.

Jachmann, H., and R.H.V. Bell. 1985. Utilization of *Brachystegia* woodlands of the Kasungu National Park, Malawi. *Afr. J. Ecol*. 23: 245-58.

Laws, R.M., and I.S.C. Parker. 1968. Recent studies of elephant population in East Africa. *Symp. Zool. Soc. Lond.* 21: 319-359.

Laws, R.M. 1970. Elephants as agents of habitat and landscape change in East Africa. *Oikos* 21: 1-15.

Laws, R.M., I.S.C. Parker, and R.C.B. Johnstone. 1970. Elephants and habitats in North Bunyoro, Uganda. *E. Afr. Wildl. J.* 8: 163-180.

Laws, R.M., I.S.C. Parker, and R.C.B. Johnstone. 1975. *Elephants and their habitats. The Ecology of Elephants in North Bunyoro, Uganda*. Oxford: Clarendon Press.

Leuthold, W. 1996. Recovery of woodland in Tsavo national Park, Kenya, 1970-94. *Afr. J. Ecol*. 34: 101-112.

Lewis, D.L. 1991. Observations of tree growth, woodland structure and elephant damage on Colophospermum mopane in Luangwa Valley, Zambia. *Afr. J. Ecol. 29*: 207-221.

Lindeque, M., and P.M. Lindeque. 1991. Satellite tracking of elephants in northwestern Namibia. *Afr. J. Ecol*. 29: 196-206.

Lindsay, W.K. 1990. Elephant/habitat interactions. Hancock, P. ed. pp. 19-23. *The Future of Botswana's Elephants*. Gaborone, Botswana: Kalahari Conservation Society.

Martin, R.B. G.C. Craig, and V.R. Booth. 1996. *Elephant management in Zimbabwe*. Harare, Zimbabwe: Dept. of National Parks and Wildlife Management, Zimbabwe. Third Edition.

Martin, R.B., and R.D. Taylor. 1983.Wildlife conservation in a regional land use context: The Sebungwe region of Zimbabwe. R.N. Owen-Smith ed. pp. 249-268. *Management of Large mammals in African Conservation Areas*. Pretoria: Haum.

McShane, T.O. 1989. Some preliminary results of the relationship between soils and tree response to elephant damage. *Pachyderm* 11: 21-31.

Melton, D.A. 1985. The status of elephant in northern Botswana. *Biol. Cons*. 31: 317-334.

Mills, M.G.L., I.L. Wyte, A.J. Viljoen, N. Zambatis, and A.L.F. Potgieter. 1996. *Background information for the National Parks Board’s review of the Kruger National Park’s elephant management policy*. South Africa: National Parks Board, Scientific Report 1/96.

Moroka, D.N. 1984. *Elephant - habitat relationships in northern Botswana*. Gaborone, Botswana: Department of Wildlife and National Parks.

Nyamapfene, K. 1991. *Soils of Zimbabwe*. Harare: Nehanda Publishers.

Owen-Smith, N. 1987. Pleistocene extinctions. The pivotal role of megaherbivores. *Paleobiology* 13: 351-362.

Owen-Smith, R.N. 1988. *Megaherbivores: The influence of very large body size on ecology*. Cambridge University Press.

Owen-Smith, N. 1989. Megafaunal extinctions: The conservation message from 11 000 years B.P. *Cons. Biol*. 3: 405-412.

Pachydem. 1993. Elephant and biodiversity working group. *Pachyderm* 17.

Parker, I.S.C. 1983. The Tsavo story : An ecological case history. R.N. Owen-Smith ed. pp. 249-268. *Management of Large mammals in African Conservation Areas*. Pretoria: Haum.

Price Waterhouse. 1996. *Elephant focus in Zimbabwe, 1980-1995 - an analysis and review*. Harare, Zimbabwe: Price Waterhouse.

Rushworth, J.E. 1975. *The floristic, physiognomic and biomass structure of Kalahari sand shrub vegetation in relation to fire and frost in Wankie national Park, Rhodesia*. Unpublished M.Sc. Thesis. University of Zimbabwe.

Simpson, C.D. 1975. A detailed vegetation study on the ChobeRiver in the northeast Botswana. *Kirkia* 10: 185-227.

Sommerlatte, M.W. 1976. *A survey of elephant populations in north-eastern Botswana*. Gaborone, Botswana: Dept. of Wildlife and National Parks and UNDP/FAO Project 72/020, Wildlife Management and Utilization in Botswana.

Spinage, C.A. 1973. A review of ivory exploitation and population trends in Africa. *E. Afr. Wildl. J*. 11: 281-9.

Spinage, C.A. 1990. Botswana's problem elephants. *Pachyderm* 13: 15-19.

Taylor, R.D. 1978. *Regional planning for the Sebungwe: An outline description and evaluation of natural resources within the Sebungwe Region in relation to rural development*. Harare, Zimbabwe: Department of National Parks and Wildlife Management.

Taylor, R.D., and D.H.M. Cumming. 1993. Elephant Management in southern Africa. Harare, Zimbabwe: *WWF Multispecies Project Paper No*. 40.

The World Bank. 1996. *Mozambique: the transfrontier conservation areas pilot and institutionalstrengthening project*. GEF Project No. 15534-MOZ.

Thompson, P.J. 1975. The role of elephants, fire and other agents in the decline of a Brachystegia boehmii woodland. *J. Sth. Afr. Magmt. Ass.* 5: 11-18.

Timberlake, J., N. Nobanda and I. Mapaure. 1993. Vegetation survey in Zimbabwe. *Kirkia* 14: 24-48.

Viljoen, A.J. 1988. Long-term changes in the tree component of the vegetation in the Kruger National Park. Macdonald I.A.W, and R.J.M. Crawford eds. pp. 310-315. *Long Term Data Series Relating to Southern Africa's Renewable Natural Resources*. South African National Scientific Report No. 157.

Waithaka, J. 1997. Management of elephant in Kenya - what have we learned so far? *Pachydem* 24: 33-36.

Western, D. 1989. The ecological role of elephant in Africa. *Pachyderm*, 12: 42-45.

Williamson, B.R. 1975. The condition and nutrition of elephant in Wankie National Park. *Arnoldia* 7: 1-16.

Work, D.R. 1986. *Summary report of aerial surveys conducted in 1983, 1984 and 1985*. Johannesburg: University of the Witwatersrand.