1a. Evolution and behaviour

Summary Table

Theme	Brief Description
1. Social Behavior	1a. Cooperation - advantages and examples of herd member assistance. 1b. Allomothering - reasons females take care of calves other than their own. 1c. Communication - behavior to call recognition (matriarch), with a brief list of elephant cues.
2. Reproductive Behavior	2a. Female Reproduction - facts surrounding offspring. 2b. Musth - a state of heightened sexual and aggressive activity. 2.b.i. Identification of - the main ways to distinguish musth. 2.b.ii. Adaptive Strategy - younger males can drop out of musth voluntarily. 2.b.iii. Calls - studies done with playback calls.
3. Diet	3a. General - what they eat. 3b. Isotope Studies - focusing on browse:grass ratios to determine grass and browse consumed over time by elephants. 3c. Tree felling/bark stripping - hypotheses as to why. 3d. Geophagy - consumption of soil thought to be due to a low sodium level available in vegetation.
4. Ranging	4a. General with Definitions 4b. Home Range Extent - variance in extent. 4.b.i. Seasonal - there are changes in wet vs. dry. 4.b.ii. Sexual Segregation - related with season, the observed variation between family groups and males. 4c. Park Size - specific example of Addo Elephant Park. 4d. Implications for Kruger's New Management - concerns with zoning and true elephant home ranges.

Theme	Brief Description
5. Human Interaction	5a. Pressures of Humans on Elephants - example of colonization of elephants before and after the Ruaha became a National Park around water sources. 5b. Encroachment of Elephant on Humans - effects of elephants entering human villages. 5.b.i. Crops - the percent of loss and cost due to mainly male perpetration. 5.b.ii. Cattle - one study comparing the effects of zebra, elephants and cattle on vegetation and one another. 5c. Poaching
6. Anomalies	6a. Delinquents - young male elephants responsible for much havoc on people and rhinos. 6b. Solution to Delinquents - introduction of older male bulls.

Introduction

Our paper focuses on research done in the field of elephant behavior dealing with a general overview of social, reproductive, and ranging behavior of elephants describing social structure and seasonal changes in interactions. We then also elaborate on feeding behavior over different time scales, and the reasons behind this foraging behavior. On a different level we take a look at how humans interfere with the relationship between elephants and their environment by limiting the amount of water the elephants have access to. Inversely, consequences of close quarters with humans has lead to such complications as crop raiding by elephants, juvenile delinquents, and the changes in elephant movements.

Methods

We used free databases and those provided by our universities (Emory, UCT, NCSU) online, the library at Skukuza, and the OTS provided library. Our search was limited by availability of papers due to age, for example most papers prior to 1990 had limited online accessibility, limited access to symposiums, veterinarian journals, and books.

Literature review

Social Behavior

Female elephants live in herds of 8 to 12 individuals, which revolve around a matriarch and consist of several generations of female calves. Males live alone or in small groups and only come in contact with female herds for mating opportunities, leaving the rearing of the offspring solely to females. Offspring live under the matriarchs care for 10-15 years, and at this point males disperse and females stay with the herd. Cooperation of adults, most commonly in female family groups, is essential to elephant's social structure and reproductive success in deterring predators and finding quality food or water. In addition, elephants demonstrate aid to ailing and dying elephants. Sikes (1971, pg. 272) describes the reaction of a herd to a dying member.

"In a case where the animal is mortally wounded and cannot rise the other members of the herd cluster round in an attempt to raise it. Failing to do so, they circle it disconsolately several times, and if it is still motionless they come to an uncertain halt. They then face outwards, their trunks hanging limply down to the ground. After a while they may prod and circle again, and then again

stand, facing outwards. Eventually, if the fallen animal is dead, they move aside and just hang around'." (Sikes 1971 cited by Schulte 2000)

Allomothering, defined as a female caring and nurturing a calf other than her own, is essential in female herd survival (Schulte 2000). The reason for allomothering can be found in the direct and indirect advantages to the all mother, helping female, such as access to higher quality food (if caring for a dominant female's young), experience in offspring rearing, and kin selection (ensuring the survival of related elephants). Another benefit of allomothering is reduced aggression amongst the herd since this phenomenon creates strong social bonds (Schulte 2000).

Elephants have a vast repertoire of acoustic vocal calls with 31 being described (Langbauer 2000). Matriarch females can recognize the call of over 12 family groups or 100 individuals. Playback call experiments over the last twenty years in Amboseli National Park have shown that the recognition of familiar and non-familiar calls is dependent on the matriarch. A family group with an older matriarch (age 55) is several thousand times more likely to bunch, form a defensive circle around calves, in response to calls from unfamiliar family groups than family groups with younger matriarchs (see Appendix A-Graph 1). The significance in older matriarchal family groups call recognition is more efficient in their use of time and energy, since bunching only occurs when necessary, and allows for more opportunities for cooperation with familiar family groups (McComb 2001). The vocal calls of elephants also have an infrasonic structure (15-25 Hz), which allows the vibrations to travel up to four kilometers in distance. African elephants can detect infrasonic calls up to 2.5 km away from the source and can distinguish social recognition 1-1.5 km from the source (McComb *et al*. 2003) (see Appendix A-Table 1). A case study has shown that a matriarch can maintain the memory of a familiar call for up to 12 years (McComb 2000). The infrasonic calls may also be linked to coordinated elephant movements in order to minimize competition of resources while simultaneously maintaining enough proximity to protect themselves from predators (Langbauer 2000).

Elephants use chemical signals, usually found in urine, to advertise physiological conditions and kin (see Appendix A-Table 2). Visual displays are utilized to convey dominance, threats, aggression, musth, greeting, submission, and apprehension (Langbauer 2000) (see Appendix A-Table 3).

Further research should be conducted in the field of elephant cognitive abilities because there is a lack of understanding the underlying reasons behind elephant social interactions.

Reproductive Behavior

Conception in African elephants peaks during the mid-wet season so that births occur during the start of the wet season when resources are at their highest abundance. The mean calving interval of elephants in Kenya is five years, which may be the result of the 22 month gestation period and two years of weaning. Females prefer to mate with males older than 35 years in an effort to secure longevity genes (Owen-Smith 1988). Female elephants usually start ovulation during their early teenage years but ovulation can range from 7 to 23 years (Ganswindt 2005).

Musth is the annual state in male elephants characterized by increased aggression, heightened interest in females, elevated testosterone, and increased travel (Langbauer 2000). The energy requirements for musth is so great that non-musthing elephants spend most of their time resting, feeding and regaining strength (Poole 1999). The time interval males spend in musth has a positive correlation to age with males 30–35 years old spending several weeks, males 35–40 years old spending 1–2 months, and older males 2–4 months in musth per year.

The evolutionary advantage for musth is that it identifies sexually active males to other males since conflicts over the rare estrous females occasionally leading to the death of a male and enables even small males to dominant any non-musthing male regardless of size. Musth has two individual characteristics: temporal gland secretions and urine dribbling. Those animals that exhibit both have highest levels of androgen and are therefore the most aggressive. Only elephants with urine dribbling show an increase in epiandrosterone, a steroid representative of gonad functioning. The urine dribbling is the main identifier of sexually active and musthing elephants. The musth state is now perceived as a competitive mating strategy (Ganswindt 2005).

A study conducted at Pilanesberg shows that young males in musth drop out of musth when confronted with aggressive more dominant musthing males. This adaptation ensures immediate survival and long-term reproductive fitness due to the lessened likelihood of death in mating conflicts. The occurrence and duration of musth is dependent upon the energy required to find females with small areas containing many females showing the longest musthing period in males (Slotow 2000).

In playback experiments, dominant male musth calls caused aggressive behavior in other musthing males and avoidance of the area by non-musthing males (see Appendix B-Table 1). It also attracted vocal displays by estrous females. The estrous calls of females attracted musthing males and deterred non-musthing males (Poole 1999).

Diet

African elephants are mixed feeders as they are known to eat both grass and browse material, but there is much variation in the grass:browse ratio across the elephant populations of Africa (Owen-Smith 1992). Contrasting elephants in open grassland, such as Queen Elizabeth National Park in Uganda, with those found in wooded savannas, such as those of Kenya and Zambia, you see grass comprises 60-95% of elephant's diet throughout the year, and only 40-70% in the wet and only 2-40% in the dry (Field 1971; Lewis 1986; Napier Bax &Sheldrick 1963 all cited in Owen-Smith 1992).

An isotopic study was used to determine the grass:browse ratios for elephants in Amboseli National Park, Kenya (Koch *et al.* 1995). This study examined the carbon isotope ratios in elephant hair and teeth to determine the amount of C4 grass and C3 browse consumed over time (Koch *et al.* 1995). Nitrogen (varies with rainfall) and strontium (high levels indicate foraging in old granitic areas) isotope compositions were looked at in the teeth and bones to show changes in the habitat use of elephants in the Amboseli from 1974-1990 (Koch *et al.* 1995). Results concluded that elephants that died in the early 1970s were migrants between grassland and bush land, while those dying in the late 1970s and 1980s had grass-rich diets as a result of the parks diminishing woodlands and disrupted seasonal migrations (Koch *et al.* 1995). Knowledge of these dietary patterns is important for understanding the role that elephants play in the ecological transformations of woodlands to grassland, which is the current concern of the Kruger Park management.

One of the major concerns in the KNP is the effect elephants have on biodiversity through their destruction of trees, since elephants seem to consume very little browse from the trees they push over. Hypotheses looked at other than direct nutrition are the "farming" and other social and sexual hypotheses. The "farming" hypothesis includes the idea that elephants are stripping bark and knocking down trees in order to destroy adult tress and promote the growth of accessible low shrubs that resprout from the felled tree bases (Guy 1967; Jachman & Bell 1985; Owen-Smith 1992 all cited in Midgley & Balfour, in prep). Opposing views to this hypothesis should be looked at in the further reading of Midgley and Balfour (Appendix C). Social and sexual hypotheses suggested by Guy (1967 cited in Midgley & Balfour, in prep) that tree felling may be a form of social display to attract females and ward off competing males. Opposing views to be looked at in further reading (Appendix C).

Elephants have been observed to regularly consume soil. In a test done in Zimbabwe it was suggested that elephants may resort to geophagy to make up for the low sodium levels available from vegetation and water in the dry season (Hold *et al.* 2002). This idea is supported by the negative correlation between quantity of soil consumed and faucal sodium levels, assuming faucal sodium levels are a valid indicator of sodium balance (Hold *et al.* 2002). Females were also found to consume more soil than males, which is possibly explained by their greater nutritional demands due to pregnancy and lactation (Hold *et al*. 2002). It was also found in Tanzania that soil eaten by elephants also contained 35% kaolin clay, which is known to absorb toxic substances from the alimentary tract and increase the bulk of faeces (Wade 1977 cited in Houston, Gilardi, & Hall 2001). It was suggested that kaolin my be useful in neutralizing the activity of plant secondary compounds allowing elephants to feed on a wider variety of plants by forming a long lasting protective lining in the gut by binding to the mucous layer (Houston *et al*. 2001).

Further research in the areas of tree-felling and geophagy would be in the interest of the scientific community. If the reasons behind tree-felling are socially linked, conservation practices such as culling that alter hierarchies may add to the situation by promoting aggression, and therefore more tree-felling among young bulls. Van Wyk and Fairall (1969) point out that pushing over *Combretum spp.*, which continue living, perform a useful function in providing food for smaller browsers and protection for grass seedbeds, thus increasing biodiversity. Geophagy habits are also important to consider when dividing the park into distinct management areas because if the elephants are lacking important resources in the area they are restricted to, management may have to provide mineral licks or some generated way for the elephants to get what they need.

Ranging Behavior

Elephants are known to restrict their movements to specific areas in their habitat known as their home-range (Owen-Smith 1992). This it the area in which activities such as feeding, resting, reproduction and shelter seeking take place. Females are found in matriarchal, or family groups, that often have overlapping home-ranges, because they are not territorial and therefore may be found in large aggregations where there is a great source of nutrition (Western & Lindsey 1984 cited in Whitehouse & Schoeman 2003). Male elephants on the contrary, leave these groups when they reach sexual maturity and are subsequently found alone or in small bachelor groups (Whitehouse & Schoeman 2003).

Throughout the elephant population of Africa, there is great variance in the extent of elephant home-ranges. See Table 1in Appendix D for differences in home-ranges across different countries within Africa. Dry season home-ranges are thought to cover 10% less area than those in the wet season, with water resources being the restricting factor (Owen-Smith 1992). Valleys in Zambezi and Luangwa showed elephants seldom moved more than 50km from permanent water sources (Caughley and Goddard 1975; Dunham 1986 both cited in Owen-Smith 1992). Sexual segregation was seen in the Chobe National Park, Botswana. Family units were more restricted in their range than solitary bulls in the dry season, remaining closer to the Chobe River while bulls roamed further from the river (Stokke & du Toit 2002). The opposite was true during the wet season, family units being found to use a much greater range while the bulls remained near the water source (Stokke & du Toit 2002). Reasons for these behaviors should be looked at in Appendices D.

Movements of elephants were studied in the Addo Elephant Park using radio tracking, in order to determine whether the small size of the elephant enclosure forced the elephants into abnormal ranging patterns (Whitehouse & Schoeman 2003). Whitehouse and Schoeman found that although the area is much small than some elephant ranges (Table 1, Appendix B), the recorded home-ranges were smaller than the total area and that the small area of the park did not allow for an isolated 'retirement area' for the non-musth males, an area which normally facilitates a refuge for the non-musth males from the aggressive musth males (Whitehouse & Schoeman 2003). Further reading can be done in Appendix C.

- The ranging behaviors and patterns discussed above should be of concern to the Kruger Park management when dividing the park into specific management areas.
- Questions that need to be addressed are: will the elephants in the high impact zone abandon their home-range in the high impact zone and move to the low impact zone if the area becomes too saturated?; and how will the culling schemes accommodate for this movement from one zone to another? Further study is needed to take account for the movements within in home-ranges.

Anomalies in Elephant Delinquency

Elephants have been cause for concern in two parks in Africa, Pilanesburg and Hluhluwe Umfolozi Park (Time 1997). It has been noted that young aggressive bull elephants have killed several rhinoceros, specifically white, charging tourists, and even killing a professional hunter (Koch, 1996). It has been hypothesized that all these young elephants are from a group that was translocated from Kruger National Park (KNP) in the early 1980s after the culling of their parents, as part of the KNP's policy of the time to reduce numbers of elephants in their park (Koch 1996). Since 1978, approximately 1500 orphaned calves, 600 being males, were moved to unfamiliar locations and raised with no control by adult elephants or the hierarchical social structure that defines elephant structure (Time 1997). It is believed that this lack of discipline from older animals led to the delinquency of these young elephants (Koch 1996).

The delinquents, being male, were observed experiencing musth, a state of heightened sexual and aggressive activity, at much earlier ages than would be normal and last longer than previously observed. It was observed that these young elephants were coming into musth at age 20 instead of 30 and instead of lasting a few days, it has been as long as three months (Time 1997). A proposed solution to the young elephants delinquency is the deployment of elder adult bulls to sort out the young (Gaisford 2004). With older bulls present it is much more likely that the young bulls will settle down. Kruger introduced six of their older males into the Pilanesburg population in 1998 (Slowtow 2000). They were to be added to the 85 elephants that they currently had in the park including 17 young bulls between 15 and 25 (Slowtow 2000). It was seen that musth duration was severely shortened and the number and age of males entering musth for the first time was also significantly reduced after the introduction of these older bulls (Slowtow 2000). This translocation of the older bulls was noted to have completely ended the deaths of rhinoceros by young bull elephants (Slowtow 2000). It is proposed that other parks having the same problem of introduced young elephants that grew up without social structure provided by older animals may employ this method of solving similar problems (Slowtow 2000). It is also proposed that poaching of the older larger animals may present this same problem of leaving orphaned animals (Slowtow 2000).

Human Interaction

Human interaction includes the pressures of humans on elephants and the encroachment of elephants on human agriculture and cattle farming. The increase in elephant population is thought to be specifically attributed to human pressure and rainfall which was later found to have little affect (Barnes 1983). In the Ruaha National Park before 1946, settlements were scattered throughout the area close to water sources (Barnes 1983). During the dry season, elephants were denied access to the potential water sources due to human presence (Barnes 1983). After Ruaha National Park was established in 1946 the human pressure was resituated around the edges of the ecosystem which encouraged elephants into the park (Barnes 1983). This sudden unrestricted access to water may have resulted in a positive change in juvenile survival rates as was suggested when the population quickly increased (Barnes 1983).

Encroachment of elephants on human society has been mostly through crop raiding. These elephants have been known to feed on cultivated food, damage food stores, water installations, fences/barriers, and occasionally injuring or killing people (Hoare 1999). It has been noted that there is a seasonal peak to the raiding of crops corresponding to the wet season and seems to be a nocturnal behavior apparently to minimize risk (Hoare 1999). In Zimbabwe it was observed that elephant damage to food crops accounted for 75-90% of all incidents by large mammal pests, 79% perpetrated by male groups or lone males, 9% by mixed herds, and 12% by cow groups (Hoare 1999). Mature crops were selected in 62% of all cases, intermediate growth crops 35%, and early growth crops only 3% (Hoare 1999). Looking at Asian elephants we can postulate that African elephants, are attracted to food crops because they are more palatable, more nutritious, and have lower secondary defenses than wild browse plants (Hoare 1999). Another reason is that some crops when ripe have high sodium and low silica and fiber content, which is very attractive in the late wet season (Hoare 1999) - reference soil and geophagy papers in diet about sodium intake. Again looking at Asian elephants, in India elephant raiding and damage accounts for $20.5mill/year (Sukumar 1991). It is proposed that being polygymous animals displaying sexual dimorphism, males have greater variance in reproductive success than females which would lead them to favor a “high risk-high gain” strategy which promotes their reproductive success (Sukumar 1991). This high risk strategy brings them into greater conflict with people (Sukumar 1991). Adult males have been observed to enter crops six times more frequently than a member of a female led herd and eat two times the amount a female member (Sukumar 1991). The solution proposed for the problem males was either culling or relocating, however, this can quickly lead to a female-biased sex-ratio, easily resulting in a decline in fertility (Sukumar 1991).

Looking at the ways cattle affect wildlife and wildlife affect cattle, it was found that despite widespread belief that grazing wildlife compete with cattle for grass in Africa that resource partitioning minimizes this competition (Young 2005). Cattle and zebra have considerable overlap in habitat use and diet, whereas elephants eat both grass and forbs, and may compete differentially with cattle (which eat both) and zebras (which eat only grass) (Young 2005). In conclusion this study showed that the presence of cattle and elephants appear to increase grass cover and increase numbers of zebra present, however cattle feed significantly less in plots with elephants than those without (Young 2005). This should be looked at further because of the beginnings of a transfrontier park and the effects this may have on the bordering countries.

Appendices

Appendix A

Table 1. Responses to experimental trials, when subjects were played calls of family or bond group members at 2.5–0.5 km

Family (call played)	2.5 km	2.0 km	1.5 km	1.0 km	0.5 km
EAs (Esme)	No response	–	Listening, streaming, calling	–	
SBs (Ysolde)		Listening, smelling	–	Listening, smelling, calling, approach	–
JAs (Ysolde)		Listening	–	Listening, smelling, calling, approach	–
RAs (Remedios)		Listening	Listening, streaming, calling	–	–
EBs (Echo)	No response	Listening	Listening	Listening	Listening, smelling, calling, approach
1st section KBs (Kleo)	Listening, smelling, streaming	Listening, smelling	Listening, smelling, calling, approach	–	–
2nd section KBs (Kora)	Listening, smelling, streaming, calling, approach	–	–	–	–

Diagnostic response in each trial is shown in bold. Calling=contact calling.

after McComb et al. (2003)

TABLE 3. Some chemical cues used by elephants

General context	Specific context	Behaviorally active compounds	Released through
Advertisement of hormonal state	Estrus		
	Female–male	(Z)-7-dodoecenyl acetate	Urine
	Female–female	???	Urine
	Musth		
	Non-musth	—	
	Pre-musth	↑ Testosterone; non-methane hydrocarbons	TGS
	Early-mid musth	↑ Testosterone; cyclohexanone; a mixture of 7-ketone, an alcohol, a cyclic ketone, and frontalin	TGS, urine
	Mid-late musth	↑ Testosterone; 2-nonanone	TGS, urine
	Kin recognition		
Group cohesion	Maternal identity	???	Urine

TGS, temporal gland secretions; ???, unknown; —, none.
See Rasmussen and Krishnamurthy [2000] for a fuller discussion.

Table 2

After LANGBAUER (2000)

Table 3

TABLE 1. Acoustic calls of African elephants

General context	Narrower context	Call type (range)	AM	AF	J	C	I	Ref.	Playback?
Advertisement of hormonal state	—	Estrous rumble (L)	—	X	—	—	—	2, 3	Yes
	Dominance	Musth rumble (S/L)	X	—	—	—	—	2, 3	Yes
Advertisement of emotional state	Sexual excitement	Female chorus (S/L[ab])	—	X	XF	X?	?	2, 3	
		Genital testing (S)	—	X	X	—	—	3	
	Social excitement	Social rumble (S/L[ab])	—	X	X	X	X?	3	
		Roar (S/L[ab])	—	X	X	X?	—	1,2,3	
		Mating pandemonium (S/L[ab])	—	X	X	X	?	2,3	
		Play trumpet (S)	X	X	X	X	—	1,3	
		Social trumpet (S/L[a])	—	X	X	X	—	1,3	
	Social fear	Scream (S/L[a])	—	X	X	X	—	1,2,3	
		Bellow (S/L[a])	X	X	X	X	X?	1,2,3	
		Groan (S)	X	—	—	—	—	3	
	Fear, surprise	Trumpet blast (S/L[a])	X	X	X	X	—	1,2,3	
		Snort (S)	?	X	X	X	—	1,2,3	
Group cohesion and coordination	Coordination	Let's go rumble (S)	—	X	X?	—	—	2,3	
	Cohesion	Contact call (L)	—	X	X	X?	—	2,3	
		Contact answer (L[b])	—	X	X	X	?	2,3	
		Greeting rumble (S/L[ab])	—	X	X	X	X?	2,3	
		Coalition rumble (S)	—	X	—?	—	—	3	
		Discussion rumble (S)	—	X	?	?	—	3	
		Infrasonic alarm? (S/L?)	?	?	?	?	?	3	
		Lost call (L)	—	—	X	X	X	3	
Agonistic	Cohesion	Attack rumble (S[b])	—	X	X	?	?	3	
	Dominance	Female–female (S)	—	X	X	X	—?	3	
		Male–male (S)	X	—	—	—	—	3	
Affiliative	Distress	Suckle rumble (s)	—	—	—	X	X	3	
	Comfort	Suckle cry (S)	—	—	—	X	X?	2,3	
		Distress call (S)	—	—	—?	X	X	3	
		Reassurance rumble (S[b])	—	X	X	X	—	3	
		Calf response (S)	—	—	—	X	X	3	
		Suckle distress scream (S)	—	—	—	X	X	3	

S, apparently intended for short-distance audience; L, apparently intended for long-distance audience; L[a], although apparently intended for a short-distance audience powerful enough to be percieved over long distances; [b]Often or always given as a group call.

AM, adult male; AF, adult female; J, juvenile; C, calf; I, infant; X, occurs; XF, occurs in females only; —, does not occur; ?, unknown.

1, reported in Berg [1983]; 2, reported in Poole, et al. [1988]; 3, reported in Poole [1994].

Modified from Poole [1996].

after Langbauer (2000)

Graph 1

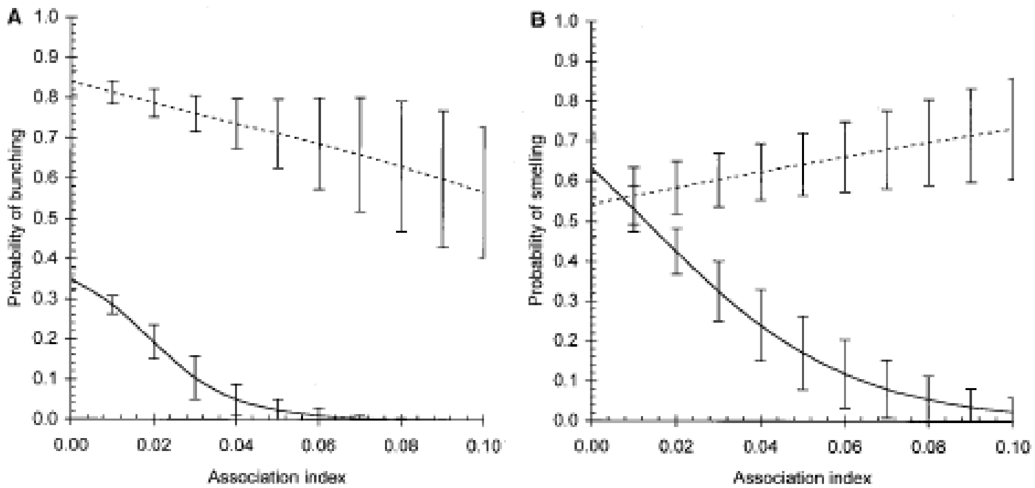

Fig. 1. The variation of response to playback calls as a function of the association index for families with matriarchs of differing ages. Values depicted are those from a logistic regression model (as described in Table 1) for families with matriarchs of 35 years (young matriarchs; dashed line) and matriarchs of 55 years (old matriarchs; solid line). Although age was a continuous variable throughout our analyses (the range of ages in our sample was 27 to 67 years), here we focus on two age groups that are representative of young and old matriarchs in order to clearly illustrate the interaction between the age of the matriarch and the association index with the caller. Standard error bars predicted from the models are depicted as a guide. The graphs describe probabilities of (A) bunching and (B) smelling.

after McComb *et al.* (2001)

Appendix B

Table 1

Table 1: Published range size estimates for African elephants. In all cases, home range sizes were calculated using the minimum convex polygon (MCP) method.

Population	MCP range and size (km2) mean ± S.E	No. of elephants tracked	Reference
Northwest Namibia	5860 ± 1342	9	Lindique & Lindique 1991
Kruger National Park, South Africa	625 ± 80	20	Whyte 1993
Norther Cameroon	2775 ± 291	2	Tchambe et al 1995
Northern Botswana	1450 ± 407	18	Verlinden & Gavor 1998
Amboseli, Kenya	2756 (Total Range)	6	Western & Linsday 1984

Table 4. Percentage of playbacks during which specific behaviours were observed when the musth rumble stimulus of male 119 was played to musth and nonmusth males that were larger or smaller than male 119

	Musth		Nonmusth	
	Smaller *N*=8	Larger *N*=2	Smaller *N*=3	Larger *N*=5
Walks away	0	0	33	80
Walks towards speaker	100	100	33	0
Apprehensive behaviour	25	0	67	60
Aggressive behaviour	50	50	0	0

after Poole (1999)

Appendix C

Tree-felling and Bark Stripping

One of the major concerns in the Kruger Park is the elephants effect on the biodiversity of the reserve through their destruction of trees. Since elephants seem to consume very little browse from the trees they push over, many hypotheses have been developed giving alternate reasons, other than direct nutrition, for pushing down trees.

"Farming" hypotheses include the idea that elephants are stripping bark and knocking down trees in order to destroy adult trees and promote the growth of accessible low shrubs that resprout from the felled tree bases. Elephants may also be promoting the growth of preferred grass lawns. (Guy 1967; Jachman & Bell 1985. Owen-Smith 1992 all cited in Midgley & Balfour unpublished). Midgley and Balfour (unpublished) refute these hypotheses on the basis that they are not evolutionary stable strategies, as elephants cannot ensure exclusive benefits from the trees they push down and those who do not push over trees (i.e. cheaters) will also benefit.

Other social and sexual hypotheses have also been proposed. Guy (1967 cited in Midgley & Balfour unpublished) suggests that tree felling may be a form of social display to attract females and ward off competing males. This hypothesis is also suggested to be unlikely by Midgley & Balfour (unpublished) as both solitary male and females have been noted to push over trees. Tree felling, as well as bark stripping, may serve as training for physical conflicts and tusk contests, a hypothesis that predicts elephants would try push over trees that are very large and that males would predominate in these activities (Midgley & Balfour unpublished).

Further research in this area will greatly inform conservation policies. If the reasons behind tree felling are socially linked, conservation practices such as culling that alter hierarchies may worsen the situation by promoting aggression, and therefore more tree felling, among young bulls. Management should also consider the benefits of tree felling. Van Wyk and Fairall (1969) point out that pushed over *Combretum spp.*, which continue living, perform a useful function in providing food for smaller browsers and protection for grass seedbeds, thus increasing biodiversity. They also note that elephants perform a useful role by uprooting species such as *Dalbergia melonoxylon*, which are prone to bush encroachment if not burned by regular fires. Another consideration is that the persistence and accumulation of dead trees, in the absence of fire, may over-emphasise the browsing and destruction rates (Van Wyk & Fairall 1969).

~Dorit Hochman

Appendix D

Seasonal Variation and Sexual Segregation in Home-ranges

Wet season ranges change in response to local rainfall and resultant areas of new growth. Dry season home ranges are thought to cover 10% less area than those in the wet season, with water resources being the restricting factor (Owen-Smith 1992). However, in the Zambezi and Luangwa Valleys, elephants seldom moved more than 50km from permanent water sources (Caughley and Goddard 1975; Dunham 1986 both cited in Owen-Smith 1992).

Research by Stokke and du Toit (2002) in the Chobe National Park, Botswana, shows that there is sexual segregation in the seasonal variation of elephant home-ranges. Family units, consisting of mature female elephants and their young, were more restricted in their range than the solitary bulls in the dry season, remaining closer to the Chobe River. Bulls on the other hand, roamed the furthest from the river during the dry season. The opposite is true for the wet season. The family units were found to use a much greater range of habitats, while the bulls remained near the water sources.

The restricted range of the family units in the dry season could be due to the greater rate of water turnover experienced by the young elephants, as they have higher rates of respiratory and evaporative water loss than large bulls (Gordon 1977 cited in Stokke and du Toit 2002). Though the bulls expend energy roaming far in the dry season, pay-off may be found in the form of isolated nutritional hotspots. It is also likely that non-musth bulls would be roaming far in order to avoid conflict with musth bulls which are more likely to be found closer to the family units.

The family units are able to range further in the wet season as they are no longer restricted by water. Pregnant and lactating females may need to range further to satisfy their greater nutritional requirements for higher quality food. Most elephants, especially bulls, are largely grazers in the wet season (Owen-Smith 1998 sited in Stokke and du Toit 2002). Bulls would not need to range far in the wet season as enough nutritional graze is found near the rivers (Stokke and du Toit 2002). Their greater size also ensures that they are able to get more nutrition from their food due to their large gut size.

A question that Stokke and du Toit (2002) do no not address is whether there are more conflicting encounters between musth and non-musth bulls in the dry season since they are not roaming far from one another. However, they do raise an important management consideration concerning the taking of census in the dry season when tree foliage is low, allowing greater visibility. It is likely that these counts may undercount the roaming males.

~Dorit Hochman

Appendix E

Further Suggested Readings

There were many articles having to do with rogue elephants, disease, reproduction, translocation, musth, tranquilization, and sensitive points that may be pertinent in the 2002 Journal of Indian Veterinarian Association Kerala 7(3): 1-64.

A Research Update on Elephants and Rhinos; Proceedings of the International Elephant and Rhino Research Symposium, Vienna, June 7-11, 2001. Vienna, Austria, Schuling Verlag. This symposium discusses several topics relevant to this chapter and others.

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1B: Natural agents influencing elephant populations

Barthram Krishnamoorthy, Andrea Romero, & Alexis K. Vaughan

Summary Table

Theme	Brief Description
1. Habitat	
1.1 Home Ranges	Seasonal Habitat Variations:
	Bulls occupy more types of habitats than family units in the dry season, but fewer in the wet season.
1.2 Determining Factors	Water and Nutrients:
	Water and nutrients are essential factors in the establishment of feeding ranges
1.3 Landscape Heterogeneity	Vegetation Patch Composition:
	Home range size decreases for bulls and family units when species richness increases in vegetation patches.
2. Nutrition	
2.1 Diet	Typical Diet:
	Elephants' diet consists of over 80 plant species. They have a specialized digestive system adapted for the digestion of cellulose.
2.2 Seasonal Feeding Patterns	Forage Quality:
	Poorer forage quality in the dry season increases the use of fat reserves.
2.3 Nutrient Distribution	Nutrients in Vegetation :
	Some mopane woodlands are over-utilized while other similar areas are not.
3. Social Structure	
3.1 Social Organization	Hierarchical Tiers:
	Social groupings are categorized into six tiers. Tiers are affected by ecological factors seasonally as well as by gender and age.
3.2 Dominant Females	Role of Matriarch:
	Group dynamics form around the matriarch. Upon her death, other females distance themselves from one another.
4. Mortality and Disease	Causes of Natural Death
	Elephants die naturally due to heat stress, various diseases, and violent confrontations with each other.

Introduction

Kruger National Park, located in South Africa, currently faces important decisions concerning the management of African elephant (*Loxodonta africana*) populations. Historically, elephant populations suffered significantly due to the effects of heavy poaching and habitat loss. These populations began to recover in Kruger National Park the late 1940's with the most significant increase between the mid-1960's and mid-1970's[1] (Whyte *et al*. 2003). The population increased by approximately 8,000 individuals within about ten years (Whyte *et al*. 2003). From 1967 to 1994 Kruger National Park employed culling as a management tool in order to control elephant populations, at what they considered acceptable boundaries. However, culling stopped after 1994, and the current management must now decide if/how elephant populations should be regulated (Whyte *et al.* 2003).

There are currently two prominent schools of thought regarding elephant population management. The first believes that elephant populations will stabilize and reach equilibrium naturally, and adopts a laissez-faire policy (Whyte pers. comm.). The second hypothesizes that far before this natural equilibrium stabilizes, elephant populations will irreversibly decimate the environment and compromise biodiversity within the park, and thus, elephant populations should be actively controlled. The study of ecological factors influencing elephants is crucial in order to better understand population dynamics. Our aim in this section is to investigate and summarize ecological factors that affect elephants. In particular, we are interested in presenting information that can be useful in future managerial decisions concerning elephant population control in Kruger. This section is organized into four areas: nutrition, habitat, social structure, and mortality and disease. In each of these sections we present the main ecological factors influencing elephant population dynamics and investigate the implications of these factors in terms of management. We will not focus on the subsequent implications of elephant behavior due to these ecological factors, and water, as an ecological factor, is being reviewed in a separate section.

Methods

We mainly employed the Internet for our article and data collection. We used several internet sites to find scholarly works: Google Scholar, J-Stor, and Galileo (an Emory University scholarly search engine). We searched for "African elephant ecology," "African elephant population dynamics," and similar headings. We also utilized two books: The Kruger Experience (du Toit *et al.* 2003) and Megaherbivors (Owen-Smith 1988) in order to grasp a better understanding of our subject. In addition, we consulted with various people associated with Kruger National Park. The following people helped us and provided important resources and information essential for this topic: Dr. Ian Whyte, Dr. Rina Grant , Angela Gaylard,, Laurence Kruger, Dr. Julie Coetzee, and Dr. Deedra McClearn. In addition, Angela Gaylard provided access to her library of elephant scientific papers at the Shingwedzi field station.

Literature Review

Habitat

Habitat preference for the African elephant is influenced by several ecological factors. Home ranges vary from six to 580 square miles depending on whether an area is used by females or males and the availability of nutrients and water (http//library.sandiegozoo.org/fact%20sheets/elephant_african/af_elephant.htm). Home ranges can overlap among herds as little territoriality is exhibited (http//library.sandiegozoo.org/fact%20sheets/elephant_african/af_elephant.htm). Habitat ranges can vary extensively with climatic and breeding seasons.

Seasons affect habitat ranges between family units and solitary bulls. During the dry season, bulls occupy a larger number of habitat types and travel further from perennial water sources in comparison to family units (Stokke & du Toit 2002). In contrast, during the wet season family units occupy a greater number of habitat types than bulls (Stokke & du Toit 2002). The seasonal difference in habitat use among family units and bulls appears to be correlated with water and nutrient requirements. Lactating females and infants have a higher water turnover and thus, have higher water consumption needs.

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[1] See appendix

Lactating cows also require more water in order to produce adequate amounts of milk. Infants have a high water turnover due to basic physiological processes such as growth (Gordon 1977; Beuchat 1990; as cited in Stokke & du Toit 2002). However, bulls are able to travel further from water because their large size allows them to withstand longer periods of time without water (Owen-Smith 1988; as cited in Stokke & du Toit, 2002). During the wet season, water sources are more abundant and not a limiting ecological factor for family units allowing them to pick feeding areas based on nutrient concentrations. Thus, male and female habitat ranges vary seasonally, as social groups containing lactating cows and infants are more dependent on perennial water sources during the dry season.

Land heterogeneity is another important ecological factor that impacts habitat ranges. This impact is not determined by seasonal fluctuations or gender but related to the size, shape, and dispersal of patches of various types of vegetation across the landscape in Kruger National Park (Grainger *et al.* in print). Water is the strongest determinant of home range size in both the bull and family unit groups; however nutrient requirements, vegetation, and cover are also important determinants (Bertrand *et al.* 1996; Tufto *et al.* 1996; Stokke & du Toit 2002; as cited in Grainger *et al.* in print). Habitat ranges of both bull and family units decreased exponentially with the increase in patch richness density and number of water sources (Grainger *et al.* in print). Contrary to Stokke & du Toit (2002), no significant difference in home range size was observed between bulls and cows (Grainger *et al.* in print).

Further studies need to explore the hypothesis that this behavior may be due to the elephants consciously spacing themselves out to avoid conflict with musth bulls and to take advantage of dispersed vegetation hotspots. In addition, more insight is needed to determine the effect of musth in bulls, which could have significant influence on home range size, in that size may increase dramatically as bulls spread out in search of oestrus cows (Barnes 1983 as cited in Stokke & du Toit 2002). Another suggested study would involve the removal of artificial water sources so that a clear relationship between landscape heterogeneity and home range size could be accurately assessed.

Nutrition

The African elephants' diverse diet consists of over 80 plant species including grasses, forbs, and woody vegetation which vary with availability and season (Owen-Smith 1988). During the wet season, elephants favor grass, however, they become more dependent on woody browse during the dry season (Owen-Smith 1988). This shift of vegetation leads to a diet with increased fibrous plant tissues such as twigs, bark, and roots in the dry season. Elephants have a digestive system that contains cellulase-producing protozoans and bacteria. The presence of cellulase is necessary to aid in digestion by fermentation of their high-cellulose diet, a substance indigestible to mammals (http//library.sandiegozoo.org/fact%20sheets/elephant_african/af_elephant.htm). Even with the presence of cellulase, 66% of the consumed diet is undigested and eliminated (http//library.sandiegozoo.org/fact%20sheets/elephant_african/af_elephant.htm). Due to the high amounts of undigested material, African elephants consume four to six percent of their bodyweight daily (approximately 75-150 kg of food per day) (http//library.sandiegozoo.org/fact%20sheets/elephant_african/af_elephant.htm). Thus, the constant need to forage in order to achieve daily nutritional requirements dictates much of their day-to-day activities.

Foraging is essential for the accumulation of nutrients. Diet quality should inversely affect consumption. In other words, as the quality of the diet deteriorates consumption should increase, as elephants would need to consume more in order to maintain the same levels of nutrient uptake (Malpas 1977). Larger stomach fills in lactating females (Laws *et al.* 1975 as cited in Malpas 1977) and higher dry season stomach fills (Malpas 1977) support this theory. Thus, seasonal fluctuations impact elephant consumption rates as rich diets (higher crude protein content in vegetation) are available in the wet season and, comparatively, poorer diets (lower crude protein content vegetation) in the dry season (Bredon & Horrell 1961; 1962; Bax & Sheldrick 1963; Karue 1975; Field 1971;1975, as cited in Malpas 1977).

The effect of seasons on diet quality also affects elephant growth. Kidney fat index (KFI) (weight of kidney fat/weight of kidney) measures fat reserves (Malpas 1977). Data supporting higher dry season KFI values seem counterintuitive since elephants are exposed to poorer diets during this period. Nonetheless, these data are used to suggest that African elephants with reduced growth rates in the dry season, due to poor diets, make use of the improved resources at the start of the wet season for growth and not fat storage reserves. Towards the end of the wet season, when diet quality declines, elephants begin to build up fat reserves to utilize during the dry season. Thus, KFI levels are low during the majority of the wet season, high towards the end of the wet season, and decline as reserves are used up in the dry season (Albl 1971 as cited in Malpas 1977). Therefore, seasonal variation affects diet quality which, in turn, can affect growth, physiological processes, and feeding patterns.

Feeding patterns are not only affected by seasonal fluctuations but elephant age-and-sex related differences also. Adult males have distinct feeding patterns from females and young individuals (Naiman *et al.* 2003). Bulls have the least diverse diet (in terms of woody plants), consume more plant parts, feed comparatively longer at each browsing site before moving on, and engage in more root consumption, branch breaking, and tree felling in comparison to females and sub-adults. Females and sub-adults feed more frequently by defoliating and appear to be more selective for high-quality plant parts (Stokke & du Toit 2000). Family units position themselves in foraging areas with more plant species diversity than adult males. In addition, most elephant browsing occurs on trees lower than 4 m in height, possibly due to the tendency of elephants to forage on previously browsed areas (Stokke & du Toit 2000). Bulls do not feed higher in the canopy than females and sub-adults, however, females browse at higher levels in the canopy when feeding in close proximity to sub-adults (Stokke & du Toit 2000). Thus, natural feeding patterns are variable between sexes as well as age.

Several factors contribute to the establishment of feeding areas. First, the distribution of nutrients influences plant productivity, and in turn, affects animal distribution (Naiman *et al.* 2003). Wild herbivores select the highest-quality forage present (Owen-Smith & Novillie 1982 as cited in Naiman *et al.* 2003), however, elephant over-utilization of certain mopane woodlands over similar woodlands is not correlated to soil properties, shrub and tree densities, and protein levels in mopane leaves (Ben-Shahar & Macdonald 2002). It appears that the differences in protein levels in mopane leaves between two research sites in northern Botswana are negligible and do not offset other factors such as distances to water and other food sources which are important in the establishment of feeding areas (Ben-Shahar & Macdonald 2002). It is imperative, however, to better understand the intricate relationship among ecological factors and the relative importance of each factor in contributing to the establishment of feeding areas.

The impact of nutrient distribution on elephant feeding preferences of similar vegetation areas is an important area of study which should be investigated further. If, in fact, elephants do not preferentially feed on higher protein and nutrient areas, the results indicate a certain component of stability in this ecosystem as it appears unlikely that elephants will concentrate feeding in a high protein area until they deplete the resources and vegetation (Ben-Shahar & Macdonald 2002). In fact, areas that currently sustain high levels of utilization are unlikely to be further decimated. However, a proper analysis of the factors that influence feeding area choice (concerning nutritional content of areas as well as distances from water and other food sources) would be beneficial to properly assess high risk foraging areas and fully comprehend the ecological factors that lead to over-utilization of certain areas and not other similar areas.

Social Structure

Elephants have highly developed multi-tiered social structures that are affected by ecological factors. These societies are matriarchal, with males leaving the family unit in their adolescence and either forming small dynamic groups or becoming solitary (http//library.sandiegozoo.org/fact%20sheets/elephant_african/af_elephant.htm). Elephant populations are arranged into six hierarchal tiers of organization: mother-calf (tier 1), families (tier 2), bond/kinship groups (tier 3), clans (tier 4), subpopulations (tier 5), and populations (tier 6) (Buss 1963; Laws 1970; Douglas-Hamilton 1972; Moss & Poole 1983, as cited by Wittemyer *et al.* in print). Ecological factors, mainly season and age of matriarch, affect the social structuring and cohesion levels of social units (Wittemyer *et al.* in print). Families (tier 2) are the most stable while larger groups (tier 3 and 4) are more sensitive to ecological factors (Wittemyer *et al.* in print).

Seasonal fluctuations affect the social dynamics of African elephants. Families (tier 2) are stable across season. On the other hand, bond/kinship groups (tier 3) and clans (tier 4) show less cohesion during the dry season. The data suggest that tier 3 and 4 units are affected by ecological factors such as increased resource competition during the dry season. Nonetheless, there are benefits, such as predatory defense, associated with social living (Wittemyer *et al.* in print). The balance of benefits and costs associated with social grouping changes seasonally and thus, social tier structures are very dynamic and vary with season and resource availability (Wittemyer *et al.* in print).

Another ecological factor affecting composition of social groups in African elephants is the age of the dominant female. Grandmothers lead larger families than younger matriarchs (Wittemyer *et al.* in print). Reproductively active daughters stay with their mothers while their offspring are reproductively immature, leading to an overlap of three generations in the same social group (Wittemyer *et al.* in print). Social groups disperse and maintain informal contact (tier 3 and 4) after the death of the matriarch. Thus, the presence of older dominant matriarchs increases social group size.

Matriarch age not only affects group size, but also group reproductive success. Dominant females are responsible for evaluating the threat level of non-related individuals encountered (McComb *et al.* 2001). In turn, matriarchs signal to the rest of the group whether defensive behaviors are necessary in response to foreign individuals. Older matriarchs exhibit superior discriminatory abilities of threat levels, which translate into more efficient time allocation and opportunities for cooperation with foreign individuals (McComb *et al.* 2001). Therefore, the effective discriminatory ability of older females subsequently translates into higher reproductive success for the family unit (McComb *et al.* 2001).

Social grouping provides limited fitness benefits to individuals within the group (McComb *et al.* 2001). The study of the cost and benefits associated with social grouping can help elucidate the ecological factors that affect fitness. In other words, it is important to recognize what ecological changes influence the relative costs and benefits of group living, and consequently the formation or disassembly of social groups. The investigation of ecological factors that affect the elephant population in a small scale (group dynamics) can provide clues as to which factors most affect the populations in a large scale.

Mortality and Disease

Little is known about elephant diseases and causes of mortality in the wild. Due to their relative immunity to predation, elephants suffer from diseases related to old age such as cardiovascular disease, blocked arteries, aneurysms, and arthritis (http//library.sandiegozoo.org/fact%20sheets/elephant_african/af_elephant.htm). They are also vulnerable to heat stress, anthrax, tuberculosis, foot & mouth disease, elephant pox, rabies, tetanus, encephalomyocarditis virus, pneumonia, and dysentery. Furthermore, young females are vulnerable to septicemia, a blood disease. Other major causes of death include drought, accidental slips and falls, bulls fighting during musth, and human interactions (defense of crops and poaching) (http//library.sandiegozoo.org/fact%20sheets/elephant_african/af_elephant.htm). In addition, elephants are limited by teeth replacement because once the last tooth is worn down, the elephant will be unable to eat properly (http//library.sandiegozoo.org/fact%20sheets/elephant_african/af_elephant.htm). However, few studies have focused on rates of mortality and natural death.

Conclusion

Ecological factors highly impact elephant population dynamics. In our study, we have shown how habitat, nutrition, social structure, and mortality and disease are all affected by seasonal fluctuations, gender, and age. Seasonal fluctuations, through their impact on vegetation and water availability, have direct impacts on elephant populations. The change in the availability of important resources during the dry and wet seasons creates seasonal dependent changes in all areas explored in this section. Gender and age differences also impact elephant population dynamics, creating distinct behavioral and ecological patterns based on sex and maturity. Thus, better understanding of basic ecological factors and their effects on elephant populations is essential for the comprehension of natural population controls.

The topics covered in this section must be considered for future management policies concerning elephant population control. However, there are still areas that must be further investigated in order to provide a more complete analysis of the current situation. In the areas of habitat and nutrition, further comparative studies that explore the relationship among nutrient deposition and habitat choice would be useful to help target areas that could be over-utilized and possibly decimated by elephants. In addition, further studies dealing with age and gender differences of habitat use and feeding patterns are crucial in order to explore which groups within the population are, if at all, affecting vegetation patterns.

Nonetheless, the areas of habitat, nutrition, and social structure, in terms of ecological factors, have been addressed. However, little focus has been put on the ecological factors affecting birth rates, mortality, and natural diseases. The investigation of these areas is imperative to the fundamental knowledge of ecological factors that directly affect population dynamics. All of these areas are important for the implementation of proper management policies concerning the necessity of elephant population control in order to maintain certain levels of biodiversity within the park.

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2. VEGETATION

Vernon Visser and Jacob Cram

Theme	Subtheme	Risk	Description (Conflicting hypotheses listed)
Effects on different vegetation types	Baobab	Moderate risk	Damage historically observed.
	Acacia spp.	Moderate-low risk.	1) Damage concentrated on large trees→Low overall impact on forest 2) Damage significant
	Combretum spp.	Moderate-low risk.	1) Elephant effect not serious. 2) Elephants affect woodland. Recommended population density of 0.5-0.6ele/km^2.
	Mopane	Low risk.	Mopane regenerate.
	Marula	Low risk.	Marula populations sustainable.
Factors affecting elephant impacts on vegetation	Water	Very important	See relevant section elsewhere in report
	Fire	Extremely important	See relevant section elsewhere in report
	Other herbivores	Very important	Other herbivores (e.g. giraffe, impala etc.) prevent regeneration of woodlands Other browsers cause tree damage (e.g. porcupines, kudu, rhino etc.).
	Soils	Important	Soils influential in determining elephant impacts in W. Zimbabwe but not in N. Botswana Mopane.
Elephant-Vegetation Dynamics	Stable limit cycle hypothesis	Further research required to determine relative importance of differing hypotheses and in different ecosystems.	Elephants cause a decline in woodlands, which in turn leads to a decline in elephant numbers, woodland able to recover and cycle continues.
	Hypotheses including effects of ungulates and pastoralists		Similar to the above except that ungulates important in preventing regeneration and therefore woodlands only recover when ungulate populations decline.
	Equilibrium hypotheses		Elephants cause changes in structure and composition of vegetation but able to survive at some sort of equilibrium population.
	Elephant-vegetation incompatibility	No known models	Elephant population increases and woodland declines could be construed as being unsustainable, but fairly subjective as to what unsustainable is. In addition other herbivores contribute to woodland decline.

Introduction

Central to any discussion of elephants' environmental effects is their relationship to vegetation. Elephants directly interact with their environment by browsing and through destroying trees. Indirectly, elephants' impacts on vegetation are strengthened by interaction with fire, and elephants may promote woody vegetation by triggering plant growth and regeneration. Perhaps one of the most important elements of the debate of the impacts of elephants in Kruger Park is their tendency to convert woodlands to grasslands. There is debate both about the extent of this phenomenon, and upon the benefits and detriments of such an environmental shift. It is our aim in this literature review to summarise available information of the effects of elephants on vegetation.

We look first at the traditional generalization of elephant effects, and then move on to a discussion of the effects of elephants upon different woodland vegetation types. Where possible we identify, or speculate on, or the likely impacts of elephants on the vegetation types within the park. We then move on to a discussion of other important cofactors, which interact with elephants, thereby acting indirectly upon the vegetation. Examples of these factors include water and fire, which are discussed in greater depth in other chapters of this report, as well as soil types and impacts of other herbivores. Lastly, we will discuss some hypotheses on elephant-vegetation interactions, with emphasis on whether current effects on vegetation are part of a long-term natural cycle.

Methods

We conducted a review of published literature pertaining to elephants and their effects on vegetation. We used JSTORE through Tufts University, Google Scholar, and the personal archives of Angela Gaylard. We summarized key points from each article. From these points, we compiled a report describing the effects of elephants on vegetation. We cooperated with other students in order to integrate this section into a larger report on elephants.

Literature review

THE TRADITIONAL MODEL

Since the late 1960's and early 1970's many policy makers and managers have traditionally viewed elephants as agents that act to the detriment of woodlands. Although this view has come under criticism recently, it continues to be an important paradigm in the understanding of elephant in many habitats. Perhaps the most influential early discussion of this paradigm was brought forward by Van Wyk & Fairall in 1969. The authors observed that elephants browse vegetation and push over trees. Furthermore, elephant impact is substantially greater than that of other herbivores. They recognized that the degree of elephant effect varies with other environmental circumstances, for instance that distance from watering points lessens the damage that elephants cause to a given patch of vegetation. From their analysis of many different habitats within the park, they concluded that Kruger Park is particularly sensitive to elephant damage. While we recognize that this paper contained many important observations, much new knowledge about elephant effects on vegetation has been gathered since. Researchers have identified additional types of elephant impacts, especially in habitat specific studies. Frequently the warnings appear to be less dire than those sounded by Van Wyk & Fairall (1969), although many woody species do appear particularly susceptible to elephant damage. In many cases studies on similar woodlands, sometimes even the same woodland, there have been differences in the level of concern about elephant effects on vegetation. It is the object of the following section to summarise the heterogeneity of potential elephant impacts on a range of vegetation types. We will focus upon those vegetation types present in Kruger Park about which we found sufficient information. We recognize that many of the woodland types within Kruger are not discussed here, while many of those that are discussed may differ in important ways from those in the park. Information about elephants and vegetation is still being collected, and it is important to keep an eye on research progress especially that conducted within the park itself, in order that management strategies may be adapted accordingly. Following is a list of five important and researched vegetation types and a discussion of the impacts of elephants upon them.

ELEPHANT IMPACT ON FIVE IMPORTANT WOODY VEGETATION TYPES

*Baobab (***Adansonia digitata)**

Baobabs in Kruger National Park experienced a great deal of mortality between 1991 and 1994 during an extended drought. Elephant damage does increase mortality risk during drought. However, many of the trees that died in the mid '90s drought died with no signs of elephant damage. Recruitment in baobab populations is higher in areas without elephants. Until recently, elephant densities have been low for about the previous 1000 years, allowing for greater recruitment rates (Whyte *et al.* 1996).

Barnes *et al.* (1994) identified in a ten-year study that baobab populations declined as elephant numbers increased; conversely the baobabs recovered when elephant populations declined due to over-poaching. The patterns of elephant effects on baobabs appear to be inconsistent across space. Weyerhaeuser (1985) found that in Lake Manyara National Park in Tanzania, smaller trees tended to have highest mortality. Barnes (1985), also in Tanzania, suggested that elephants select against the smallest baobab trees. Swanepool (1993), in Zimbabwe, observed that elephants did not harm any size class disproportionately. Chazan and Harris (2004) suggested that the Kruger Park baobab population was stable. Most baobabs in the Kreuger park are large and able to withstand substantial amounts of elephant damage (Chazan & Harris 2004).

It is unlikely that elephants can remove all baobabs from a park like Kruger, since many Baobabs, such as those growing on cliff faces, are inaccessible to elephants (Whyte *et al*. 1996; Chazan & Harris 2004). Nevertheless, since most Baobabs are accessible to elephants, and with elephant populations on the rise, the possibility of negative effects of elephants on Kruger National Park's baobab populations remains.

ACACIA *SPP.*

Elephants damage many species of *Acacia* to a greater degree than they harm nearby trees of other genera (Callange *et al*. 2002). However, this damage does not appear to affect *Acacia* populations overall. Studies on *Acacia tortilis* and *A. seya* showed that elephants damage mostly the larger, mature, trees. Meanwhile, elephants tend to ignore early stage and regenerating trees. Thus, although elephants decrease the number of mature acacias, their propensity to ignore growing trees allows *Acacia* forests to regenerate. Accordingly most reports indicated that *A. tortilis* forests are unlikely to be seriously harmed by elephants (Okula & Sise 1986, Mwalosi 1987, Mwalosi 1990, Rillew 1983, Calenge *et al.* 2002). In the Serengeti, giraffes and fire have been shown to repress *Acacia* populations more significantly than do elephants because they predominately kill regenerating or small trees (Pellew 1983). In Kruger National Park, elephants have been shown to inflict small amounts of damage upon *A. nigrescens,* which appear to recover readily. (Buckley *et al.* 2004).

A contrasting study recently conducted on *A. xanthrophloea* woodlands in Kenya (Western & Maitumo 2004), however, indicated that that elephants did have a strong effect on woodlands in that particular system, more so even than fire. The authors deduce that early pastoralists kept elephants away. Furthermore, livestock grazing controls grasses, which compete with *Acacia* seedlings, thereby promoting to acacia growth. The authors suggested the existence of a previously prevalent dynamic mosaic interaction between human and elephant populations.

With a few exceptions, we suggest here that most acacia populations studied appear able to withstand a good deal of damage by elephants. We suggest that there is little reason to fear for the survival of acacias, even under high elephant densities.

COMBRETUM *SSP.*

We found conflicting information about elephant effects on C*ombretum* spp. *Combretum*, which co-dominated with *Acacia*, in a woodland community in Chad, was not seriously affected by elephants (Callenge 2002). A separate study conducted in a game ranch in West Africa, in a *Combretum-Terminalia* woodland, indicated that elephants did affect the woodland. The latter authors recommended keeping elephants at 0.5-0.6 elephants/km^2 to minimize vegetation loss at that particular site (Jachmann & Croes 1991). Whether elephants will have a neutral effect on Kruger's or South Africa's *Combretum* specifically remains an unstudied issue. As *Combretum imberbe* has been proposed as a protected South African tree (Herrmann 2003), it would be wise to monitor changes in Kruger's *Combretum* populations.

MARULA (SDEROCARYEA BIRREA)

Elephant impacts upon Marula appear sustainable, according to a study on woodlands near Kruger National Park (Gadd 2002). While elephants damage the bark of Marula trees, the trees are able to regenerate their bark and recover from the elephant damage (Buckley *et al*. 2004)

*MOPANE (*COLOPHOSPERMUM MOPANE)

Elephants do browse mopane trees, and prefer mopane to many other trees. However mopane are well suited to regenerate after elephant browsing; elephants rarely kill the mopane trees they browse. Browsed mopane tend to appear more hedgelike, while unbrowsed mopene have treelike morphologies. Elephant browsing on studied mopane forests appears to be sustainable (Ben-Shahar 1996).

Several factors appeared to affect the degree of elephant damage on mopanes. Proximity to water sources appears, as in many other systems, to have the greatest effect on elephant damage (Styles & Skinner 2000). Soil type also appears important: soils that promote shrub-like mopane yield less stable woodlands than do soils that promote tree-like growth of mopane (Lewis 1991). Elephant browsing intensity also tends to fluctuate with time of year. Browsing is greatest in the winter when twigs are the most palatable. However, elephants frequently exert less browsing on mopane than do other large herbivores, such as eland (Styles & Skinner 2000).

OTHER FACTORS INFLUENCING VEGETATION DYNAMICS

A number of factors are known to influence fluctuations in vegetation cover and composition. These include water (precipitation, proximity to water sources etc.), fire, soils, and herbivores other than elephants. In this section we will not focus on water and fire because these are covered in other sections of this document. As far as our literature search revealed herbivores other than elephants may have a profound impact on vegetation dynamics and often work in concert, or may even be more important than elephants in influencing vegetation changes.

Giraffe have been implicated in preventing the regeneration of woodlands, particularly *Acacia* woodlands. They have been shown to reduce the growth rates of saplings (Birkett 2002) and to prevent saplings reaching a height at which they are no longer vulnerable to fire (Pellew 1983). It has also been suggested that porcupines, through ring barking, and buffalo and kudu, through debarking, all contribute to changes in woodlands (Mapaure & Campbell 2002). Rhinos have also been shown to have effects on woodlands similar to elephants by damaging trees smaller than 2m tall. However rhino browsing and damage is limited to trees smaller than 6m, but elephants are capable of toppling trees taller than 6m whereas rhinos are not (Birkett 2002). In mopane woodlands elephants seem to utilise this vegetation type mostly in winter when twigs are most edible. Eland, however, browse mopane throughout the year and it has been suggested that the smaller, shrub mopane morph is as a result of continuous eland browsing (Styles & Skinner 2000). Another herbivore which has been implicated in preventing regeneration of trees is the impala. It was suggested that impala along with other herbivores were preventing the regeneration of riparian vegetation along the Chobe river in Botswana (Mosugelo *et al* 2002), as well as of *Acacia tortilis* woodland in northern Tanzania (Prins & van der Jeugd, 1993). In northern Tanzania it was also shown that most woodland regeneration occurs when ungulate populations crash as a result of some disease epidemic; the result is an even-aged stand of trees from a burst of new recruits. Thus ungulates are, at least in that situation, more important in controlling *Acacia* woodland regeneration than elephants (Prins & van der Jeugd 1993). Smaller animals, such as birds, rodents and primates, may also affect woodland regeneration through seed removal (Mosugelo *et al.* 2002).

Elephants may facilitate insect and fungal attacks in *Brachystegia boehmii* woodlands in northern Zimbabwe through the damage they inflict on trees. In this case elephants would be critical contributors to tree mortality as they facilitate the entry of borers and fungi thereby making the tree susceptible to being killed in a fire or being blown over (Thomson 1975).

We did not focus on the influence of soils on elephant food selection and vegetation impacts, but it should be noted that soils may play an important role in this regard. In western Zimbabwe it was found that elephants tended to avoid species growing on more nutrient-poor sandy soils and, that plants growing in these areas had lower nutrient concentrations (Holdo 2003). However in another study conducted in a northern Botswana mopane woodland it was found that elephant impacts did not vary across different nutrient levels in soils and in the plants themselves (Ben-Shahar & MacDonald 2002).

ELEPHANT AND VEGETATION DYNAMICS

The interactions between elephants and the surrounding vegetation are very complex and it is often difficult to determine which one is influencing which. There is also the added difficulty of other confounding factors such as fire, rainfall, and other herbivores that may be equally or even more important in regulating changes in the vegetation and elephant populations. Over the years a number of models have been proposed to explain observed changes in elephant populations and vegetation. Duffy *et al.* in 1999 suggested that there are three different types of hypotheses regarding elephant-tree population dynamics: (1) Elephants and trees interact with one another resulting in cycles of high and low populations.

(2) Elephants and trees can exist in equilibrium. (3) Elephants and trees are unable to survive together for any extended period of time. Below we outline some of the different models developed over the years, highlighting the evidence given for and against these models.

Caughley (1976) proposed a stable limit cycle hypothesis for elephants and vegetation whereby elephants will increase in numbers and cause a decline in woodland cover which in turn will lead to a decline in elephant numbers once tree numbers become too low to support the elephant population. Thus the woodlands are able to regenerate and so the cycle continues. Caughley (1976) provided three different lines of evidence for his hypothesis from the Luangwa valley in Zambia: firstly he suggested that the frequency of forking in mopane trees could give an indication of the relative abundance of elephants. This is because if saplings between 0.5 and 2 m tall have their terminal shoot broken off, the tree will produce forked terminal branches which are still present in a mature tree and can thus be used as an indicator of relative amounts of elephant impacts. Comparing the degree of mopane forking with the circumference of the trees gives one an idea of relative elephant abundance over time. Secondly Caughley (1976) examined age frequency distribution of baobabs and found that this was in concordance with his findings regarding the forking of mopane trees. Baobabs were much more common before 140 years ago and since those times have been in steady decline (baobab seedlings are heavily browsed by elephants). Caughley's (1976) second line of evidence was to show that his observations in the Luangwa valley did not fit any other hypotheses (equilibrium, compression and intrinsic eruption hypotheses). Thirdly Caughley (1976) showed that theoretically his hypothesis was sound and that in certain instances a stable equilibrium point may in fact be achieved, it all depending upon the value of the parameters. At the end of his paper Caughley (1976) cautions readers that his hypothesis may in fact only be partly true or may in fact be false but that viewing high elephant densities as a 'problem' may be too narrow a view and that high and low elephant densities may be part of some 'single process'.

Support for a stable equilibrium hypothesis can be found in a study by Pellew (1983). He looked at the reduction of *Acacia tortilis* woodlands in Kenya and proposed that elephants were causing the decline of mature trees, but that giraffes and fire were preventing the regeneration of a mature woody canopy. He thus suggested that these woodlands were being held in the regeneration phase by giraffes but that with either a lower giraffe population and/or less frequent fires the woodlands would recover to mature dense-canopy woodland. Pellew (1983) suggested that the evidence needed to demonstrate a woodland cycle would be the presence of even-aged stands of *A. tortilis* trees, however at the time this evidence was unavailable. Ten years later Prins & van der Jeugd (1993) presented evidence of even-aged *A. tortilis* stands existing in northern Tanzania but rather than proposing a stable limit cycle hypothesis involving just the interaction of elephants and vegetation, they suggested that regeneration of these woodlands takes place infrequently due to random disease epidemics among the local ungulate populations. They also acknowledge the importance of taking into consideration the local factors of particular areas. For example they suggest that fires were uncommon in their research area, allowing for the re-establishment of the woodlands during low ungulate populations. In the Serengeti, where fires are more frequent, the woodland was unable to regenerate and so when ungulate populations recovered there was still no opportunity for woodland regeneration.

Van de Koppel & Prins (1998) claim that elephants are inferior competitors in grazing compared to smaller herbivores such as buffalo and impala. They are forced to utilise woody vegetation and ultimately cause a decline in the woody vegetation. They thus deplete their own food resource and are must then migrate or starve. Van de Koppel & Prins (1998) propose that the multiple stable states model (Dublin *et al.* 1990) in which elephants convert woodlands to grasslands and maintain them as such is flawed because elephants are unable to maintain high populations in pure grasslands and it is rather the smaller ungulates which maintain the grasslands.

Owen-Smith (1988) asks the question of whether elephants actually cause a decline in their own food resources, which is the question that underpins most of the above hypotheses. He ultimately seems to support the view of a stable equilibrium of elephant populations stating that "megaherbivore populations tend to reach saturation densities at which nutritional limitations restrict further increase." It is suggested that megaherbivore populations are able to regulate themselves through a change in the age at which animals become sexually mature and the time period between births of individual females. Elephants are able to change the structure and composition of the vegetation even at relatively low densities and in so doing may in fact actually increase the nutritional value of the food available to them (by converting tall woodlands to shrublands, promoting the growth of more nutritious species in canopy gaps and also suppressing the production of secondary chemicals in plants through heavy browsing). In changing the vegetation the elephants may limit the availability of reserve food sources for themselves during future periods of drought. It was suggested that elephants could move to more favourable areas during droughts, but that in areas where they are unable to migrate they will have large impacts on the vegetation during dry periods, being forced to utilise taller woody vegetation and that elephant populations may in fact decline markedly during these periods. Such utilisation by elephants during drought periods might lead to greater patchiness of the landscape with the areas that were favoured during the droughts being heavily damaged during these periods and then being abandoned when rainfall improves and the population is able to move elsewhere. Finally Owen-Smith suggested that elephant populations in such circumstances would only show slight increases and decreases as climatic conditions varied.

Western & Maitumo (2004) proposed yet another model of elephant-tree interactions that included the presence of pastoralists. They suggest that livestock depress the growth of grass, which leads to a decrease in fire frequency and thus an increase in woodlands. Elephants then move in and cause a decline in the woody cover and allow grass to grow again and so the cycle repeats itself.

No model, to the best of our knowledge, has been produced that specifically deals with the hypothesis that elephants and vegetation cannot exist together for an extended period of time. However a study conducted in a small Kenyan game reserve revealed that the rate at which elephant, giraffe and rhino populations were increasing, and the rate at which tree densities were declining was unsustainable in the long term (Birkett 2002). Unsustainable used in this context is however a fairly subjective term, depending on what the author regards as being unsustainable. As part of a stable limit cycle hypothesis woodland declines are not unsustainable but part of a natural cycle. From an equilibrium hypothesis point of view woodland declines as seen in this study could be regarded as being unsustainable, but the blame cannot be placed squarely upon the elephants as both giraffes and rhinos in this particular study contributed substantially to the woodland's decline.

In South Africa, and the Kruger National Park in particular, it is unlikely that elephants could convert woodlands to grasslands as most of the woody species in the park such as mopane (*Colophospermum mopane*), *Terminalia* spp. and some *Combretum* spp. are coppicing and heavy elephant utilisation of these trees would more likely result in a change of vegetation structure from a woodland of mature trees to one dominated by shrubby trees (Chafota 1996).In addition to this, evidence from Duffy *et al.* (1999) seems to suggest that elephant populations will actually reach an equilibrium with their environment as long as they depend largely on a single species as a source of food which in the northern KNP would probably be mopane. Elephant population changes in the KNP have been shown to be density dependent above 0.37 elephants.km^{-2} (van Aarde *et al.* 1999), which suggests that elephant populations may have been nearing some sort of equilibrium point or may have passed some threshold and were on the verge of beginning to decline.

It is not known with certainty how elephant populations in the KNP interact with the local vegetation and whether there is any degree of cyclicity or fluctuation in their relationship or whether elephants may attain some sort of equilibrium level with the vegetation. Evidence does seem to exist that elephant populations will not increase as rapidly above densities of 0.37 elephants.km^{-2} (van Aarde *et al.* 1999), supporting some idea of equilibrium with the local vegetation or maybe even some sort of stable limit cycle or fluctuation type interaction. Gillson & Lindsay (2002) in a CITES briefing document contend that savannas are systems that inherently fluctuate and that over the last 1500 years savannas in east Africa have fluctuated between grassland and woodland numerous times. The major problem though is that elephant densities have never been allowed to get high enough in the KNP to test these hypotheses because of the previous culling policies of the park. The greatest fear however is that the elephants may cause some sort of irreversible change if they were given free rein and in that process a large number of other species would be lost from the park. Further research therefore is urgently needed to determine how elephant populations will interact with the vegetation of the park at high elephant densities and what sort of implications this will have for other animals and plants in the park.

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3. Biodiversity

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Section	Main Points
3.3.1 - Direct Impacts of Elephants on Biodiversity	
3.3.1.1 - Vegetation	
3.3.1.1.1 - General Vegetation Structure	Elephant herbivory and damage cause changes in structural vegetation that increase heterogeneity and create a more diverse array of habitats.
3.3.1.1.2 - Woodlands	Elephants decrease the amount of woodland cover. There is controversy over whether the effects are positive or negative
3.3.1.2.3 - Succulent Thickets	Elephants pose a severe threat to the endemic species of succulent thickets.
3.3.1.2.4 - Termitarium Thickets	The introduction of elephants has increased biodiversity in the ecosystem.
3.3.1.2 - Plant Species	
3.3.1.2.1 - *Acacia spp.*	Elephant impacts on Acacia species vary widely. *Faidherbia albida* was greatly impacted by elephants with high mortality. Elephant damage was not the main cause of death in A*cacia senegal*.
3.3.1.2.2 - *Aloe marlothii, Elephantorrhiza burkei, Pappea capensis*	These species are severely affected by elephant presence and are likely to go extinct within ten years of elephant introduction into an area.
3.3.1.2.3 - *Adansonia digitata* (Baobab)	Baobabs are greatly impacted by elephants and are targets for aggressive behavior.
3.3.1.2.4 - *Colophospermum mopane*	Mopane is adapted to elephant damage and herbivory and is therefore more resilient.
3.3.1.2.5 - *Portulacaria afra*	*Portulacaria afra* is also adapted to elephant herbivory.
3.3.1.2.6 - *Sclerocarya birrea* (Marula)	Seed dispersal and regeneration is aided by elephant presence. They show low mortality even with high impact from elephants.
3.3.1.2.7 - *Scalaracarya caffra*	The mortality rate from elephant impact is extremely high.
3.3.1.3 - Animals	
3.3.1.3.1 - Rhino	Delinquency of orphaned elephants has led to rhino mortality.
3.3.1.2.2 - Buffalo	There is no evidence of direct competition between buffalo and elephants.
3.3.1.3.2 - Impala and Kudu	Impala and kudu are not in direct competition with elephants because of their vegetative preferences.

Section	Main Points
3.3.2 - Indirect Impacts of Elephants on Biodiversity	
3.3.2.1 - Ungulates	Grazing ungulates generally benefit from elephant induced structural change in vegetation. Browsing ungulate populations either benefit from or decline due to elephant induced structural change in vegetation depending on context.
3.3.2.2 - Frugavores	Frugivores might be negatively impacted by destruction of woodland by elephants. Further information is needed.
3.3.2.3 - Bats	Elephant impact has the potential to reduce bat species diversity. Particular effects are not straightforward and are often context dependent.
3.3.2.4 - Small Mammals	Small mammal diversity is generally correlated with the structural diversity of vegetation and amount of litter/low ground cover. More information is needed for savanna ecosystems.
3.3.2.5 - Birds	Bird diversity is reduced in elephant impacted woodlands. The destruction of raptor nesting sites by elephants is potentially a problem but scientific support is needed.
3.3.2.6 - Reptiles/Amphibians	Heterogeneity in vegetation cover and food availability are likely to be the most important factors in reptile species richness but no studies have examined this.
3.3.2.7 - Invertebrates	Ant species diversity is reduced in elephant impacted woodlands. Cicadas were found only in intact woodlands. There is much data lacking regarding invertebrate diversity.
3.4 - Discussion	The Pleistocene extinctions caused by the extermination of the mega-mammals might present an analog for the long-term effects of low elephant populations. The intermediate disturbance hypothesis might provide a framework to evaluate the effects of different densities of elephants. The most pressing issue is the severe lack of research on the impact of elephants on biodiversity.

3.1 - Introduction:

Kruger National Park (KNP) has scheduled an elephant workshop for the middle of March 2005, designed to address the issue of culling. A similar conference that met in October of 2004 called to attention the significant lack of scientific data to either support or refute the policy of elephant culling, which necessitated this second meeting. The students of the Organization for Tropical Studies undergraduate semester 2005 were asked to submit a literature review on the effects of elephants on biodiversity as part of a larger, multi-faceted submission that also addresses issues of ecology, vegetation, fire, water, behavior, and management as they pertain to elephants. This review is designed for use in the workshop to assess the impacts and interactions of elephants and the environment as well as the impacts of past human interventions.

It has been documented that elephants have a profound effect on the dominant vegetation type and are often cited as the main cause of shifts from woodlands to grasslands or shrublands (see above for more information). This shift and other associated impacts have potential implications for biodiversity in KNP. Before assessing the impacts of elephants on biodiversity, we must agree on a working definition of the term “biodiversity”. According to the publication *Pachyderm*, the prevailing definition is that of J. A. McNeely *et al.*: “[biodiversity] is an umbrella term for the degree of nature’s variety, including both the number and frequency of ecosystems, species, or genes in a given assemblage” (Taylor 1993).

By this definition, biodiversity includes a broad range of ecological characteristics, including not only number of species but ranges of biotic and abiotic factors at many ecological scales. But because of both time constraints and literature availability, we focused this analysis on the effects of elephants on individual species richness. In general, we found there to be an overall lack of direct scientific research on the effects of elephants on biodiversity, with most of the evidence being anecdotal or tangential from other studies. To fully understand the effects of elephants on the environment, there is a need for more scientific studies of elephant impacts to overall biodiversity, specific taxonomic groups, and individual species.

The impact of elephants on biodiversity can be direct or indirect; we address both in this review. Direct impacts, addressed first, concentrate on vegetation with some impact on animals that interact with or compete directly with elephants. Next, we discuss the indirect impacts of elephants, which mainly include the effects of vegetation changes on other species. We also address the potential relationship between the current elephant situation and the mammalian extinctions of the Pleistocene (Owen-Smith 1988). Lastly, we include a discussion of the intermediate disturbance hypothesis as it relates to elephant impacts on African ecosystems.

3.2 - Methods:

The literature for our review on elephant impact utilized an array of academic search engines and journal databases. Articles and citations were obtained from the Web of Science, IUCN, and Google scholar. We used the Emory University and University of North Carolina libraries to search for, and gain access to the articles using journal databases such as J-Store and EBSCO. This literature review is intended to provide a general overview; and is not fully comprehensive due to time and resource constraints. Although the topic of the section is "biodiversity," we focused this analysis specifically on the effects of elephants on species richness.

3.3 – Literature Review

3.3.1 – Direct Impacts of Elephants on Biodiversity

3.3.1.1 - Vegetation

3.3.1.1.1 - General Vegetation Structure

As the vegetation group stated in the previous section, elephants have various impacts on the vegetation structure of an ecosystem. Several points about vegetation structure need to be highlighted, as they are directly related to biodiversity. One of the main themes that comes to light throughout the literature is the theory of intermediate disturbance, especially with reference to vegetation. For example, moderate densities of both grazers and elephants seem to facilitate high plant species richness. This occurs when the recruitment of shrubs by the grazers and the creation of grasslands by elephants balance the vegetation changes in the environment (Western 1989). In some cases it is questionable whether or not elephants are the primary cause of changes in vegetation structure. Even in cases of elephant decline, ungulates such as impala can contribute to bush encroachment (Prins & Van de Jeugd 1993). Elephants remove little biomass and tend to target random sizes and types of vegetation (Ben-Shahar, 1993). This feeding behavior creates a patchy and varied effect, which preserves the diversity of the landscape. Various other studies also show that many types of vegetation, such as *Colophospermum mopane* and *Portulacaria afra* have become adapted to elephant herbivory (Ben-Shahar 1993; Stuart – Hill 1992).

3.3.1.1.2 - Woodlands

Elephant browsing and behavior affect the growth and regeneration of woody vegetation. Conflicting studies show that this disturbance can be both positive and negative for other species of organisms. The gaps in vegetation caused by elephant herbivory and damage create gaps in the forest canopy. These "light gaps" facilitate the growth of plant species that are usually hindered by the shade of the canopy (Campbell 1991). Other studies present evidence of the loss of woodlands due to elephant damage and herbivory. This loss also occurs at the microhabitat level, decreasing the biodiversity of the ecosystem (Bezuidenhout 2004). This contrast in results is due to the complexity of factors that influence change in woodland structure. It is almost impossible to attribute the change in structure to one sole cause (see figures 1 & 2).

3.3.1.1.3 - Succulent Thickets

Elephants cause severe damage to vegetation in succulent thickets. On the Eastern Cape, elephants have threatened many endemic species. The endemism in this area is very high and therefore, needs to be protected from the destruction and damage of elephants (Johnson *et al.* 1999).

3.3.1.1.4 - Termitarium Thickets

Bezuidnehout (2004) documented an increase in biodiversity in the Marakele National Park following the introduction of elephants to the area. The newly-introduced elephants created a boost in the density of light shrubs and decreased in the woody vegetation, thus increasing biodiversity and generating a more patchy habitat.

3.3.1.2 - Impacts on Individual Species of Plants

3.3.1.2.1 - Acacia

Several studies examined the effects of elephants on different species of Acacia trees. In the riverine acacia woodlands of Northern Botswana, elephants created a significant decrease in Acacia density (Fig. 3). Skarpe (2004) reasons that the general conception of what a savanna should look like is based on a time when the elephant population was very low due to over-exploitation by humans. Therefore, as the elephant population returns to its "normal" level, there should be a natural decrease in the woody vegetation (Skarpe *et al.* 2004). More work is needed on how the ecosystem functioned before the large-scale decline of the elephant population.

Faidherbia albida (Acacia albida) is greatly affected by elephant browsing. In the Ruaha National Park in Tanzania, forty percent of all *F. albida* died. This mortality rate is due to the damage of mature trees and herbivory on regenerative, young saplings. The proportion of trees killed increased with tree density. The effects on *F. albida* have implications for a variety of other organisms associated with the removal of shade and food sources (Barnes 1983).

Spinage & Guiness (1971) examined the cause of death on *Acacia senegal* in Akagera National Park, Rwanda. In addition to elephant-induced mortality, he cited lightening, root infection and old age as other causes of death. Spinage & Guiness (1971) determined that old age, not elephants, was the main cause of death for *A. senegal*, and that elephants are more likely to decrease regeneration through herbivory than to kill mature trees.

Acacia xanthophloea (fever trees) are highly tolerant to the herbivory of elephants. In a study by Botha *et al.* (2002), the population of fever trees in the Lowveld of South Africa declined in number. But, because of their resilience to elephant damage, the decline did not seem drastic or severe (Botha *et al.* 2002). Fever trees provide a useful example of co-evolution with elephant herbivory. The adaptation shows that the vegetation structure has been subjected to heavy elephant herbivory and over time, solutions to this pressure have been favored and have persisted in the environment.

3.3.1.2.2 - Aloe marlothii, Elephantorrhiza burkei, Pappea capensis

These three species are all heavily affected by elephant presence and are likely to go locally extinct within the first 10 years of elephant introduction. In these situations, it is important to determine the desired level of biodiversity protection.

3.3.1.2.3 - Adansonia digitata *(Baobab)*

Baobabs are probably the most common example of elephant destruction. The soft, pulpy wood is very attractive to elephants (Weyerhaeuser 1985). Elephant impact on baobabs is severe. Studies reveal that elephants cause up to a twenty-nine percent mortality in adult trees (Swanepoel 1993). The recruitment of baobabs may have been largely restricted to rocky hills, where elephants seldom forage. The regeneration of baobabs is infrequent in plains areas that are frequented by elephants. There is some evidence that elephant-free rocky hillsides might serve as seed banks for baobabs on lower plains (Owen-Smith 2003). Baobabs are an important cultural icon in South Africa. With the increase in the elephant population, the status of Baobabs must be closely monitored.

3.3.1.2.4 - Colophospermum mopane

Mopane is an integral and dominant part of many savanna vegetation structures in Africa. Multiple studies have shown that Mopane is tolerant to elephant herbivory. Even in area where Mopane is the major food source for elephants, browsing does not necessarily reduce the Mopane biomass (Figs 4 & 5) (Ben-Shahar 1996). A study, in Lake Kariba, Zimbabwe, found a low mortality rate despite a seventy-seven percent damage rate to Mopane. In this study regeneration of Mopane was not inhibited by elephants, but the recruitment into taller height classes was restricted (Mapaure & Mhlanga 2000).

3.3.1.2.5 - Portulacaria afra

A study by Stuart-Hill (1992) in the Eastern Cape of South Africa shows that the succulent tree, *Portulacaria afra*, is adapted to the herbivory of elephants (see figure-6). Stuart-Hill compares goat and elephant herbivory, demonstrating that *P. afra* is more tolerant of elephant herbivory than goat herbivory. The woody composition of the area did not change with elephant presence. Although, the study did find that the canopy cover decreased and the shrub density increased. This illustrates the idea that elephants create new habitats and patchiness in the ecosystem. It is also another example of the adaptation of plants to elephant herbivory.

3.3.1.2.6 - Sclerocarya birrea *(Marula)*

The fruit of Marula (*S. birrea*) is one of the favorite food sources of elephants. Because the tree is so attractive to elephants, it is well adapted to their herbivory. Marula seed germination is higher when the seeds are passed though an elephant's digestive track. Marula fruit has become selectively adapted to the herbivory of elephants, and elephants have become an integral part of the regeneration of marula trees. Seeds that have been stored in elephant dung have a higher success rate of germination (Lewis 1987). A study done in three reserves in South Africa shows that marula is the most highly favored species of tree relative to abundance (see figure-7). The trees have a high rate of elephant impact, but show low mortality. Small trees were not likely to be targeted (Gaad 2002). In contrast, newly introduced elephants significantly decreased the population of marula in small game reserves in South Africa. Out of all the trees in the reserves, marula was the most affected (Duffy *et al.* 2002). The differences in these contrasting findings may be the result of the differing size and type of the study areas. Smaller reserves are more highly impacted by elephants because of the more limited availability of resources. Patchiness and heterogeneity are less likely to occur in small reserves because of the inability of the elephant to move to different resources and types of vegetation.

3.3.1.2.7 - Scalaracarya caffra

A study in Kruger National park, shows that *S. caffra* is highly impacted by elephants (Coetzee *et al.* 1979). Coetzee shows that the mortality rate of the tree is extremely high, and that the impact is greater along population boundaries of *S. caffra*, roads and in areas of high elephant density.

3.3.1.3 – Animals

3.3.1.3.1 - Rhino

In the 1980's, elephants, whose family groups were culled in Kruger National Park, were translocated to various parks and game reserves around Africa. These orphaned elephants grew up with no guidance from mature elephants in their new homes. They consequently developed behavioral problems, resulting in some uncharacteristic acts, including the killing of rhino. Elephants have killed more than 20 rhinos in different locations across the continent (Koch 1996). Rhino deaths pose a direct effect on the population security of the endangered black rhino.

3.3.1.3.2 - Buffalo

There is no documented evidence of competition between the elephant and Cape buffalo (Skarpe *et al.* 2004).

3.3.1.3.3 - Impala and Kudu

When the resources are available, elephants generally prefer to browse. Since kudu and impala are also browsers, they have the potential to compete directly with elephants. But, in most cases, they are probably not competing with elephants because impala and kudu tend to browse species that are avoided by elephants. This relationship may differ according to geographic location and various elephant densities (Owen-Smith 2003).

3.3.2 - Indirect Impacts of Elephants on Biodiversity

The direct impacts of elephants on their surrounding environment are far-ranging and varied in nature. The impact of elephants, however, goes beyond these primary interactions. Many aspects of elephants' environments are affected: if not by elephants themselves, then by the primary changes that are induced by the elephants. These secondary (or indirect) effects are widespread and extremely variable across various taxa. There is not a comprehensive scientific literature examining secondary effects of elephants. However, with sufficient knowledge of the primary impacts of elephants, it is possible to extrapolate useful information from studies that deal with changing community compositions and do not directly investigate elephants. This information can then be used to enhance our understanding of the secondary and even tertiary impacts of elephants on the ecosystems in which they live. Secondary elephant impacts have been relatively well-documented in ungulates, and less-well documented for other taxa including smaller mammals and birds. The responses of reptiles, amphibians, and invertebrates to the impacts of elephants are poorly represented in the literature, and consequently in this analysis.

3.3.2.1 – Ungulates

Elephants are well-documented agents of structural shift in vegetation communities from more closed woodlands to open shrubby areas and grasslands. This often has important implications for ungulates that are specialized grass-feeders, as elephants in many cases promote the maintenance of open grassy areas. Western (1989) discusses the important role of elephants in East Africa in facilitating pasture for medium and small ungulates, including domestic livestock. In several documented cases, the decline and extirpation of grazing species has been linked to the encroachment of woody vegetation in the absence or relative absence of elephants (Owen-Smith, 1988). This was the case for several species including wildebeest, zebra, waterbuck, and reedbuck in Hluhluwe, South Africa (Chafota 1998). In Tsavo national park in Kenya, Chafota (1998) documented the increase in populations of several grazing species including oryx, gazelle, warthog, and zebra. Young (2004) found that by suppressing cattle resource extraction from a grassland area, elephants actually reduced the negative effects of competition between the livestock and zebra. The mechanism for this interaction is unknown, but it represents another secondary benefit of elephants for grazers. Grazing species, then, seem generally to benefit from cohabitation with elephants, provided that competition with elephants for grass does not become limiting.

The secondary impacts of elephants on specialist browsing ungulates, however, seem slightly more complex than those on grazers. Owen-Smith (2003) suggests that a vegetation shift from larger trees to shrubs actually benefits browsers by providing them with increased accessibility to smaller vegetation. This is an interesting idea that potentially has important implications for browsing species. However, for this to be the case, competition, between elephants and smaller browsers, must not occur. Skarpe *et al.* (2004) showed that the palatability of woody vegetation does not decrease with increased use by elephants. Thus, provided smaller browsers were not out-competed by elephants, a positive association between elephant density and browser diversity may well exist. Yet, Owen-Smith's (2003) conclusion also assumes that the woody and shrubby areas will retain woody species for browse, and not be converted, by further elephant impact, into grasslands that lack browse entirely. The loss of woodlands and shrublands was linked in several instances to a loss of browsing species, and it seems likely that in many cases the impact of elephants has a negative effect on browser diversity. Examples of this include the decline of the Chobe bushbuck due to the loss of *Acacia* woodlands along the Chobe River in Zimbabwe (Skarpe *et al.* 2004), the decline of bushbuck, kudu, and black rhino in Hluhluwe, South Africa (Chafota 1998), and the extinction of bushbuck and lesser kudu from Amboseli national park due to elephant impacts on vegetation (Cumming & Fenton 1997).

3.3.2.2 – Frugavores

The decline of fruit-bearing woody plant species is a potentially important consequence of elephant activity. A study by Barnes (1983) suggests that, in *F. albida* woodlands in Tanzania, fruit is an important component in the diets of baboons, vervet monkeys, and kudu. *F. albida* woodlands are declining due to increased elephant densities. It is likely that elephants affect fruit availability in other systems: elephant effects on the diversity of fruit-dependant species should be more closely examined.

3.3.2.3 - Bats

Fenton (1998) found a higher bat species richness in intact woodlands than in adjacent plots of elephant-impacted woodlands in central Africa. Plots that were non-adjacent (greater than 5km apart) did not show significant differences in bat species richness, even between intact and impacted plots. Cumming & Fenton (1997) found that bat species richness did not differ significantly between intact and impacted woodlands in a savanna ecosystem. Yet, they found fruit bats (*Epomophorus* sp.) to be absent from elephant-impacted woodlands. These varied findings suggest that the loss of canopy cover, due to elephant impact, has the potential to reduce diversity of bat species. But, the particular effects of elephants on bats are not straightforward and should be considered in the specific context of localized areas. Also of interest, Fenton (1998) found no significant effect of elephant impact on the availability and composition of insectivorous bat prey species (from insect trapping data).

3.3.2.4 - Small mammals

No studies have explicitly examined the effects of elephants on small mammals. It is useful, however, to examine the relationship between vegetation and small mammal diversity. It seems likely that small mammal species composition and richness are closely tied to vegetation type and structure, as small mammals are dependant directly on vegetation to provide cover, food, and general habitat. A small mammal census, by Williams *et al.* (2002), in the tropical forest of Australia found that the richness of mammals in this particular ecosystem is largely a product of spatial variability in assemblage/vegetation structure. Giuliano & Homyack (2004) found that mammal species richness was greater on riparian sites in the United States where livestock had been excluded than where livestock were present. They argued that it was likely a result of increased litter cover and vertical vegetation obstruction in the livestock exclosures. Although there are obvious problems with extrapolating these sets of data to African savannas, a general correlation between variability in vegetation structure and variability in small mammal species seems reasonable. Also, the availability of litter and low vegetative cover is probably important in maintaining small mammal habitat. Caro (2002) compared small mammal richness and abundance within the Katavi National Park in Tanzania and outside the park. He found small mammal richness significantly higher outside the park. However, he found this difference to be correlated, not with vegetation cover or plant biomass, but with seed diversity and seed biomass. From these results he concludes that food availability might be the most important factor in determining small mammal species richness. The effect of elephants on seed availability to small mammals has not been well studied, and should be considered as another potential variable resulting from elephant-induced vegetation change.

3.3.2.5 - Birds

Cumming & Fenton (1997) found a significantly lower richness of woodland bird species in woodlands where elephants had damaged the tree canopy than in intact woodlands. They explain that bird diversity in general is correlated with foliage height diversity. Reduced heterogeneity in these impacted woodlands probably accounts for their observed loss of species richness. If elephants have a homogenizing influence on vegetation height diversity, woodland bird diversity will most likely decrease with increasing elephant utilization.

Raptors are a group of birds that often cause concern in discussions of elephant impacts on vegetation. Some have suggested that elephant damage of large standing trees in the savanna represents an important loss in the required nesting sites of raptors, especially vultures and other rare, open-savanna species. Surprisingly, little is available in the scientific literature on the nesting requirements of savanna raptors. Parra & Telleria (2004) found that populations of Griffon vultures in Spain are severely limited in their range by the availability of appropriate limestone cliffs for nesting. This finding may have few implications for African vultures, but it suggests a high degree of dependence on appropriate nesting sites for raptors in general, and vultures more particularly. Poirazidis *et al.* (2004) documented a preference of black vultures in Greece for trees with larger diameters (DBH), lower heights, and lower numbers of adjacent trees. They found that higher nest-site slope and greater distance from forest roads were also favored in nest-site choice. If vultures in African savannas share similar preferences, damage to large free-standing trees by elephants would probably negatively impact vulture populations. Yet, these findings also suggest that if elephants are thinning woodlands without necessarily knocking down every tree (*ie*. they leave a few, previously closed-in individuals as free-standing trees), they could contribute to the creation of new vulture nesting sites. More research is needed to determine the outcomes of elephant/raptor interactions in the context of African savannas.

3.3.2.6 - Reptiles/Amphibians

The effect of elephant-induced vegetation changes on reptiles and amphibians is one of the largest holes in our understanding of the secondary impacts of elephants in the ecosystem. Janzen (1976) hypothesized that the presence, over geological time, of large herbivores resulted in a lower overall number of reptiles and reptile species. He proposed that the alterative feeding of reptile predators on large herbivore prey combined with the destruction of reptile habitat by large herbivores are the most important components in this correlation. He found some support in the scientific literature, but there is little in his hypothesis that proves useful for examining reptile richness in the presence or absence of elephants. It seems likely that heterogeneity in vegetative cover and food availability, as with small mammals, are the most important factors in reptile and amphibian species richness. But, we did not find any data in the literature to either support or refute this claim.

3.3.2.7 - Invertebrates

The understanding of the elephant's effects on invertebrate communities is only marginally better than that of reptiles and amphibians. Cumming & Fenton (1997) found significantly lower richness of ant species in woodlands that had been degraded by elephants than in intact woodlands. These authors also noted that they heard and saw cicadas only in the intact woodlands, not in the degraded woodlands. From these findings, it appears that the presence of an intact canopy in savanna woodlands is important for insect species richness. Clearly, more information is needed for a definite picture of elephant impact on invertebrate communities

3.4 - DISCUSSION:

Changes in biodiversity due to elephant impact may not be a unique event. There is some evidence that links the loss of mega-mammals to a series of Pleistocene extinctions of smaller mammals. During the Pleistocene, 50% of the mammalian genera disappeared, including all the mega-mammals (larger than 1,000 kg)[remove comma] in the Americas (Western 1989). While hunting might have contributed to the mega-mammal extinctions, the simultaneous loss of 41% of the meso-mammals (5-100 kg) and 2% of the micro-mammals (less than 5 kg) could not have been caused by hunting alone, as the smaller animals were not prime hunting targets (see Figure 8) (Western 1989). Owen-Smith (1988) suggests that the extermination of the mega-mammals in the Americas could have caused the extinction of the smaller mammals by eliminating the source of vegetation disturbance regimes. The extinction of large mammals and the resulting structural shifts in vegetation may have led to the elimination of habitat and forage important for smaller mammals, resulting in their decline.

The current debate on the impact of elephants on biodiversity may be seen as a modern analog. For instance, in South Africa's Hluhluwe Umfolozi Game Reserve, the elimination of elephants ,which occurred around the turn of the century, coincided with the invasion of woody vegetation and a sharp decline in populations of grazers (including the local extinction of three species (Chafota 1998). In Africa, elephants are a keystone herbivore species that shapes the landscape and provides habitat through disturbance. The foraging pattern of elephants has been shown to contribute significantly to patchiness and heterogeneity at the landscape level (Gadd 2002). Therefore, it is not unreasonable to conclude that an elimination of elephants might have a similar effect as the Pleistocene mega-herbivore extinctions.

Elephants are not in danger of extinction. However, the positive effects of elephants as a keystone species are often overlooked because of a "preoccupation with over-browsing in National Parks, where elephant populations have been compressed by human activity" (Western 1989). The prevailing idea is that there are currently too many elephants in such areas. There is evidence that in the absence of natural predators, large generalist herbivores can have a disproportionate impact on biodiversity (Cumming & Fenton 1997). There is also evidence that "holding elephant densities at artificially low and constant levels is…detrimental to the system" (Gillson & Lindsay 2003).The intermediate disturbance hypothesis incorporates the adverse effects of both too many and too few elephants on biodiversity. Intermediate disturbance theory holds that biodiversity is highest in systems that have a moderate level of disturbance. In line with this theory, habitats with intermediate densities of elephants seem to support the most plant species (see Figure 9) (Western, 1989).

Although links between elephant density and habitat heterogeneity need further investigation, it is clear that localized loss of biodiversity and heterogeneity from woodland damage can occur at densities less than 0.2 elephants per km^2 (Cumming & Fenton 1997). As stated in the chapter on vegetation above, this woodland loss (and biodiversity loss) could be part of a cyclical (non-equilibrium) pattern of alternating periods woodland and grassland that arise from periods of high and low elephant impact (Cumming & Fenton 1997). Another possibility is that the increase in elephant populations is helping to restore the environment to the state it was in before the artificial reduction of elephant numbers caused by colonial hunting and the rinderpest epidemic of the 1890's.

Elephants are keystone species that facilitate both increased patchiness and heterogeneity thereby increasing available habitat and forage types for other species. However, naturally or artificially, lower elephant densities (less that 0.5 per km^2) may "conserve higher levels of plant and animal biodiversity, safeguard habitats, and reduce the risk of local population collapses of elephants, other species, or both" (Cumming & Fenton 1997). There needs to be some balance between increasing heterogeneity and maintaining woodland integrity. One promising solution is the establishment of woodland refuges, excluded from elephant impact.

The most pressing obstacle that faces elephant management is the lack of research. The basis of our findings is founded in one-sided, vegetation articles that make assumptions about the effects on other taxonomic groups. Many articles lack scientific data and rely on anecdotal evidence. There is a lack of articles on the effects of biodiversity on groups such as reptiles, birds, insects, and even mammals (especially small rodents). The impacts on these groups must be researched before any management decision, or the welfare of the ecosystem might be jeopardized. Harping on the decline of one species is not beneficial to the overall biodiversity of the system. The CITES report from 2002 states that: "A second reason for the limited usefulness of the 'carrying capacity' concept is that its assumption of a single, correct, unvarying level for an animal population – even a level that is intended to maximize the diversity of the other species sharing the habitat – ignores the variability inherent in ecological systems," (Gillson & Lindsay 2002). This quotation refers to the application of information from one ecosystem to management policy in another. Every ecosystem has different levels of resilience to elephants and therefore requires the use of different baseline research. Elephant management studies tend to concentrate on enclosed spaces. There is little information about the impact of elephants outside of national parks. There needs to be basic baseline research done on biodiversity in more taxonomic groups, outside of enclosed areas, and on entire ecosystems before a management decision can be appropriately made.

On the whole, the impact of elephants in the environment is dynamic, and is not well understood (Chafota 1998). More research needs to be done on both the direct and indirect impacts of elephants on biodiversity (across a broad range of taxa), and needs to focus on both species richness and abundance. It is also important to address the possibility that elephants might not be the only agents of biodiversity loss in savanna ecosystems. Other factors such as fire regimes and water availability probably play a key role in the habitat changes that are often attributed solely to elephants.

3.5 – Appendix 1: Figures

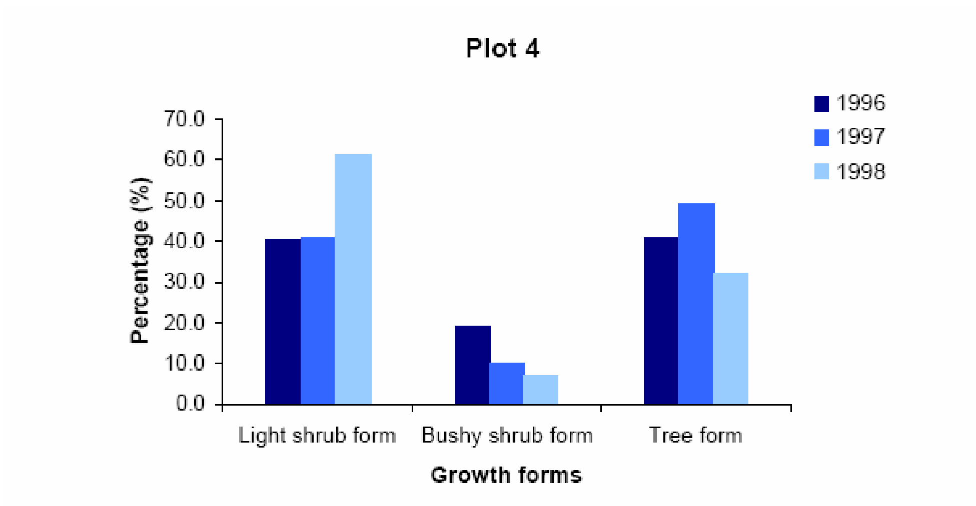


Figure 1 - Change in vegetation structure with presence of elephants in Marakele National Park (Bezuidnehout 2004)

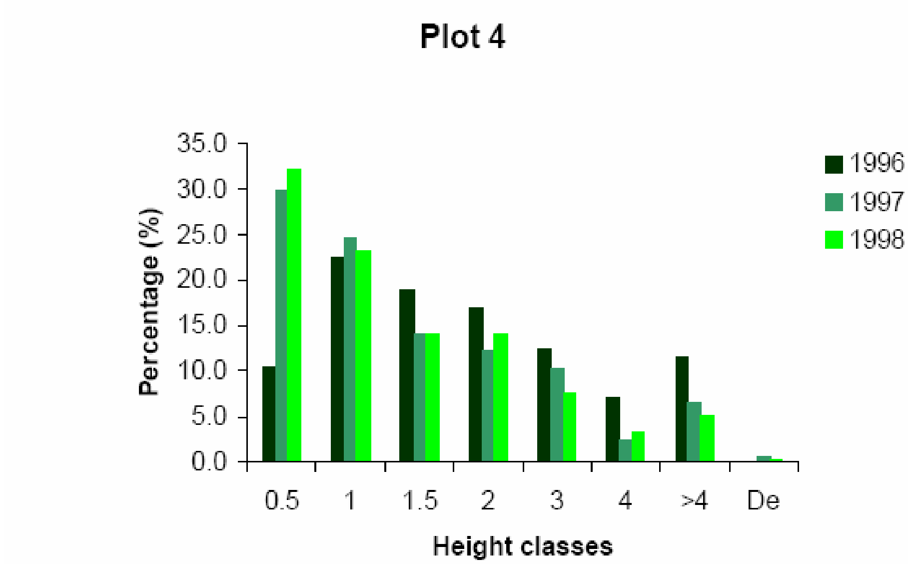


Figure 2 - Change in height classes of woody vegetation with the presence of elephants (Bezuidenhout 2004)

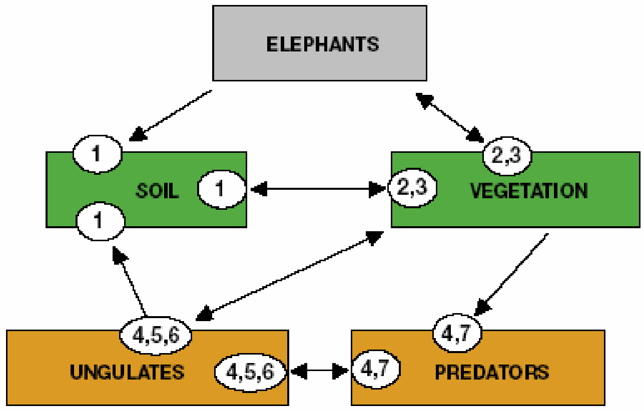


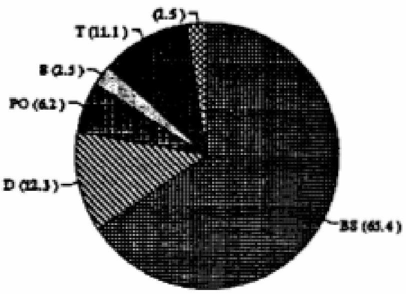
Figure 1. A schematic picture of the Chobe ecosystem and the research areas for the BONIC subprojects, referred to by the numbers from the list in the text.

of the subprojects were:

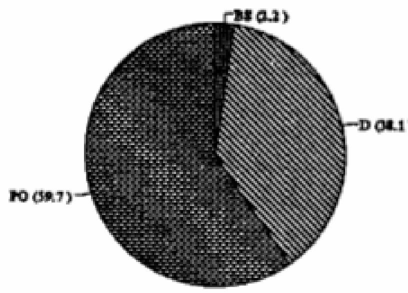
To quantify the relationships between elephants: and

1. soil properties and nutrient cycling;
2. herbaceous vegetation composition and grazing;
3. woody vegetation structure, composition, regeneration and browsing;
4. distribution and community composition of mammals and gallinaceous birds;
5. population ecology and behavior of impala (*Aepyceros melampus*);
6. behavioral ecology of buffalo (*Syncerus caffer*);
7. population ecology of lions (*Panthera leo*).

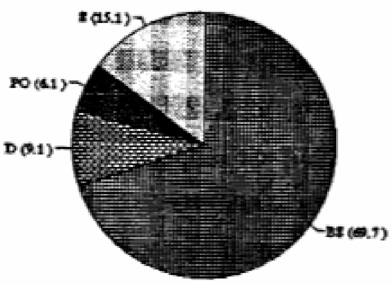
Figure 3 - Diagram of the Chobe river ecosystem in northern Botswana (Skarpe *et al.* 2004)



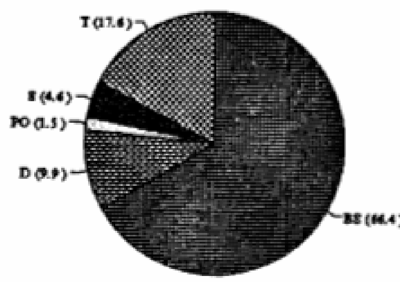
(a) Antelope Island



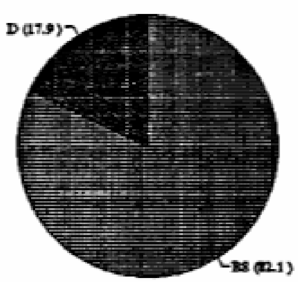
(b) Redcliff Island



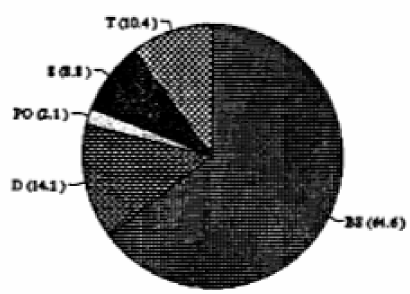
(c) Zebra Island



(d) Namagwaba Island



(e) Patridge Island



(f) Namembere Island

BS=broken stem, C=cut stem , D=dead, PO=pushed over, S=scarred, T=trampled

Figure 3. Percentage frequencies of various types of damage to mopane plants on selected islands in Lake Kariba, Zimbabwe.

Figure 4 - Elephant damage to mopane in Lake Kariba (Ben-Shahar 1996)

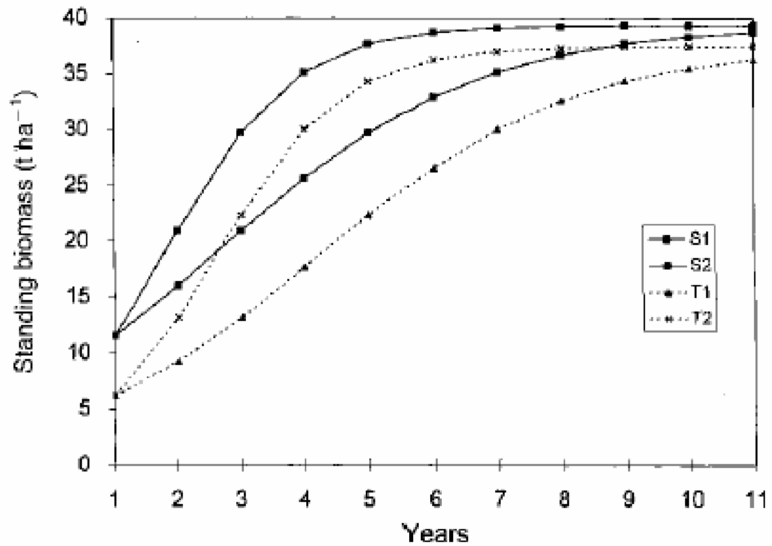


Figure 1. Biomass production of *C. mopane* woodlands comprising trees (T) or shrubs (S) under dry conditions when $r = 0.5$ (T1, S1) and optimal rainfall conditions when $r = 1$ (T2, S2) and no elephant browsing.

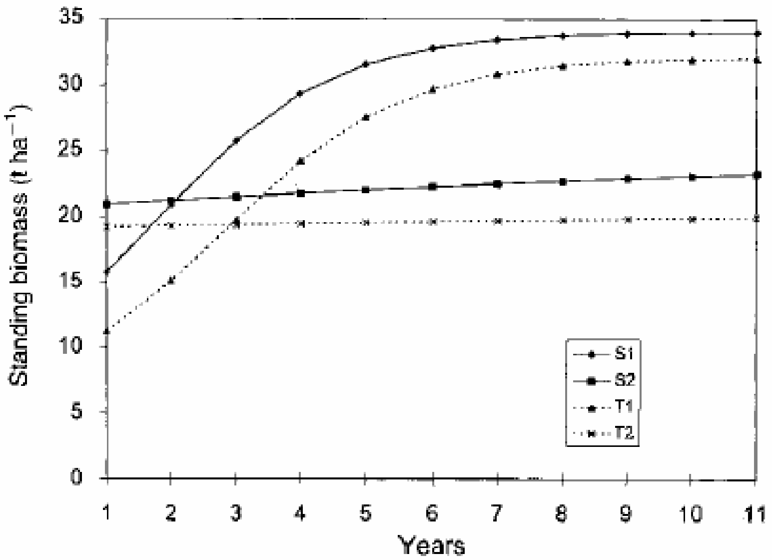


Figure 2. Biomass production of *C. mopane* woodlands comprising trees (T) or shrubs (S) under the impact of 15 elephants km^{-2} at optimal rainfall conditions when $r = 1$ (T1, S1) and dry conditions when $r = 0.7$ (T2, S2).

Figure 5 - Mopane biomass production without and with elephant browsing in northern Botswana (Ben-Shahar: 1996)

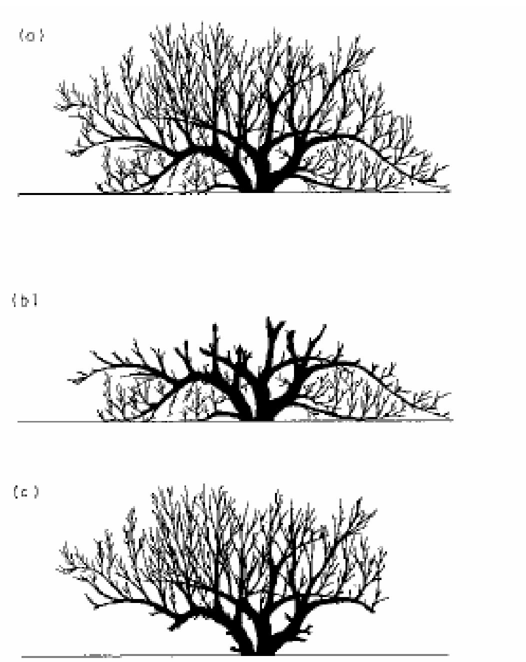


Fig. 1. Effect of (a) no browsing, (b) elephant browsing and (c) goat browsing on the growth habit and vegetative propagation of *Portulacaria afra*.

Figure 6 - Adaptation of P. afra to elephant browsing (Stewart –Hill 1992)

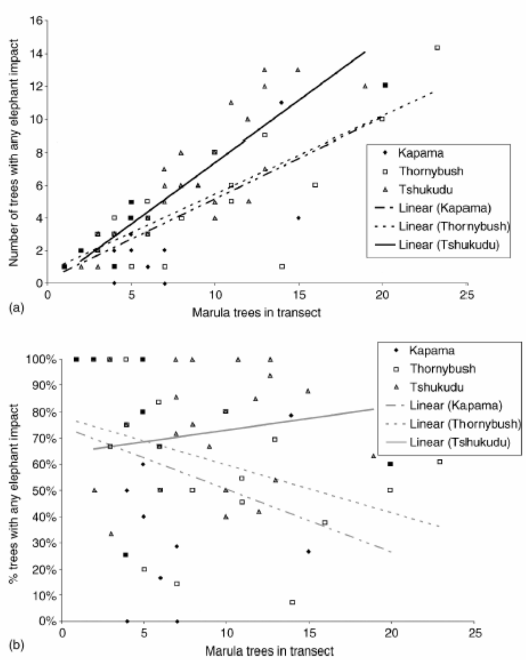


Fig 3 (a) The number of trees with any elephant impact (bark or branch, new or old) plotted against tree density in all transects ($n = 86$). Kapama: $n = 28$, $y = 0.494x + 0.231$, $r^2 = 0.62$, $P < 0.0001$. Thornybush: $n = 30$, $y = 0.476x + 0.668$, $r^2 = 0.69$, $P < 0.0001$. Tshukudu: $n = 28$, $y = 0.749x - 0.141$, $r^2 = 0.75$, $P < 0.0001$. (b) The percentage of trees in each transect with any elephant impact (bark or branch, new or old) plotted against the number of trees per transect. (Note: following regression equations reflect arcsine-square-root transformation of proportions.) Kapama: $y = -0.037x + 1.15$, $r^2 = 0.12$, $P = 0.074$. Thornybush: $y = -0.028x + 1.21$, $r^2 = 0.18$, $P = 0.020$. Tshukudu: $y = 0.010x + 0.97$, $r^2 = 0.02$, $P = 0.45$

Figure 7 – Percentage of marula trees with elephant damage in transects (Gaad 2002)

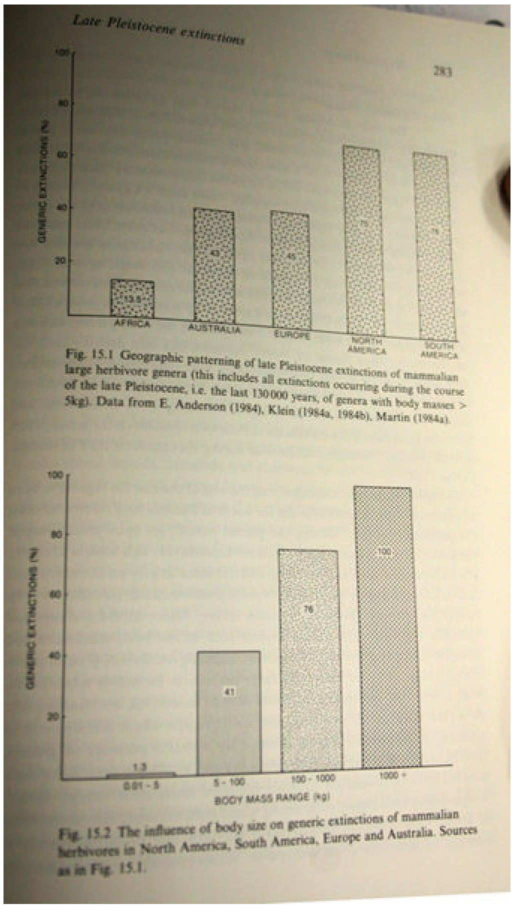

Late Pleistocene extinctions 283

Fig. 15.1 Geographic patterning of late Pleistocene extinctions of mammalian large herbivore genera (this includes all extinctions occurring during the course of the late Pleistocene, i.e. the last 130 000 years, of genera with body masses > 5kg). Data from E. Anderson (1984), Klein (1984a, 1984b), Martin (1984a).

Fig. 15.2 The influence of body size on generic extinctions of mammalian herbivores in North America, South America, Europe and Australia. Sources as in Fig. 15.1.

Figure 8 - Pleistocene Extinctions (Owen-Smith 1988)

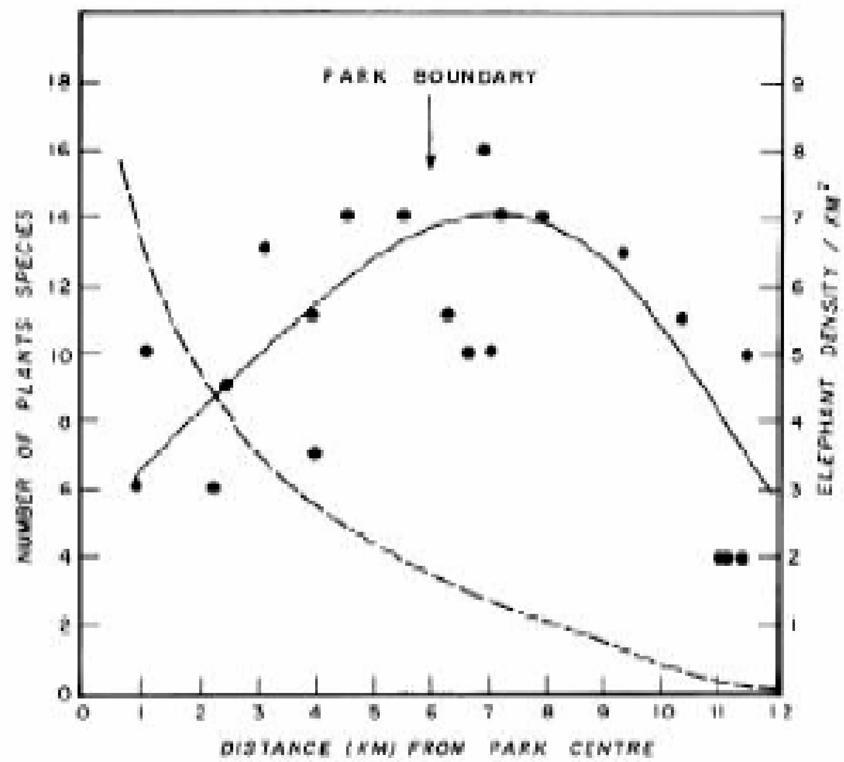


Fig. 1. Plot of the number of plant species (—) along an elephant density gradient, (—) in Amboseli. Most species are Pound in areas of intermediate elephant density, fewest in areas where elephants have been compressed or eliminated.

Figure 9 - Support for the Intermediate Disturbance Hypothesis (Western, 1989)

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3.7 – Appendix 3

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3.8 – Appendix 4

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Chapter 5. Fire

Boittin, I., Edkins, M., Watkins, B.

Summary Table

Theme	Brief description	Contributing authors
The effects of fire on savanna vegetation	• Maintenance of tree-grass co-existence • Reduction of woody cover • Prevention of Gulliver growth	Bond & van Wilgen 1996; Chesson & Warner's 1981 ; Dublin *et al.* 1990; Eckardt *et al.* 2000; Higgins *et al.* 2000; Trollope 1982; van Langevelde *et al.* 2003
Environmental determinants of fire frequency and intensity	• Weather and climate • Sources of ignition • Fuel • Soil type and nutrients	Augustine & McNaughton 2004; Bond *et al.* 1996; Bond & van Wilgen 1996; Dingman 1994; De Ridder & van Keulen 1995; Higgins 2000; Spinage *et al.* 1971; Trollope 1998; van Wilgen *et al.* 2003; van Wilgen *et al.* 2004; Walker *et al.* 1981
The relative and combined effects of elephants and fire on savanna vegetation	• Destructive foraging • Increased adult tree mortality • Three hypotheses on woodland decline: -Elephants initiate decline, fire perpetuates loss -Fire alone causes woodland decline -Fire initiates decline, elephants perpetuate loss • Woodland decline analogous to state of vegetation prior to poaching of megaherbivores and Rindepest epidemic.	Ben-Shahar 1992; Beuchner & Dawkins 1961; Dublin, Sinclair & McGlade 1990; Guy 1989; Eckhardt *et al.* 2000; Leuthold 1996; Mapaure & Campbell 2002; Skarpe *et al.* 2004; Tafangenyasha 1997; Mosguelo *et al.* 2002; van Langvelde *et al.* 2003

Introduction

Savannas are complex ecosystems, whose structure is determined by a range of interacting environmental factors, notably water, herbivory, fire, and edaphic features. These factors influence the balance between trees and grasses observed in savannas. The establishment of numerous game parks in Southern and Eastern Africa during the past century has lead to a high concentration of elephants (*Loxodonta africana*) in savanna reserves. Many of these parks have recorded large scale reductions in woody vegetation cover (Buecher & Dawkins 1961, Dublin *et al.* 1990, Ben-Shahar 1993, Guy 1989, Mapaure & Campbell 2002, Mosugelo *et al.* 2002, Tafangenyasha 1997). Elephants have been repeatedly blamed for the decline of woody cover. This has lead to concerns about habitat loss for woodland-dependent species and a general decline in biodiversity (Skarpe *et al.* 2004). The Kruger National Park is no exception to the observed trend (Eckardt *et al*. 2000) and the 'elephant problem' has become a highly controversial debate. Kruger Park Management, in collaboration with the Organization for Tropical Studies (OTS), has initiated a literature review aimed at gathering scientific information on how to deal with the management of elephants. In this section we investigate the interaction of fire and elephants and their role in the decline of woodlands in the savanna biome.

Methods

Literature regarding the impact of elephants and fire on vegetation and the persistence of woodland plant species were gathered. Sources included the OTS reference database, the OTS library, lecture notes from the OTS course and the internet. We consulted with Navashni Govender, the fire ecologist for Kruger National Park. Information was compiled into the following sub-topics:

1. The effects of fire on savanna vegetation
2. Environmental determinants of fire frequency and intensity
3. The relative and combined effects of elephants and fire on savanna vegetation

Literature Review

The effects of fire on savanna vegetation

Savannas are characterized by a grass-tree co-existence, determined by a multiple of environmental influences. Fire, in particular, seems to play a crucial role (Higgins *et al.* 2000; van Langevelde *et al.* 2000) in the establishment of this balance. Chesson and Warner's (1981) model, known as the "storage effect", has been noted as being the most accurate in explaining the grass-tree coexistence (Higgins *et al*. 2000). Recruitment fluctuations seem to be the major factor as to why trees do not out-compete grass, and cause what is known as "bush encroachment". Fire intensity in savannas is sufficient to suppress tree recruitment to such a level that trees are neither dominant (as in forests) nor excluded (as in grasslands) in the landscape. Seedlings in savannas may persist as suppressed juveniles, or Gullivers, in that level of vegetation at which fire intensity is the highest. This vegetation level is known as the "fire trap". (Bond & van Wilgen 1996). Gullivers are plants, typically multi-stemmed shrubs or trees, which struggle to emerge from the herbaceous layer as juveniles. Gullivers may persist for years, surviving repeated burning by resprouting from ageing root systems. They may eventually grow tall enough to escape the "fire trap" and mature into adult trees. Alternatively, they may die without ever reaching maturity. Trees that are taller than the fire trap are known to survive repeated burnings without being much affected (Dublin *et al.* 1990; Trollope 1982).

Higgins *et al.* (2000) developed a savanna model which showed that Gulliver escape into mature trees was dependent on the fire frequency and intensity. According to the old fire management policy of Kruger National Park, vegetation was burnt at regular 3-year intervals. This short period between burns was noted for the 64 % decrease in woody cover observed on basalt soils between 1940 and 1998 (Eckardt *et al.* 2000). Higher herbivore numbers on granite soils led to a lower fuel load, and therefore a lower fire impact, leading to a 12% increase in woody cover at these sites. Furthermore, it was found that the inter-fire period was largely determined by rainfall and not management, and did not increase with the more recent lightening-strike simulating strategy of fire management (van Wilgen *et al.* 2004). It is possible that the difference in woody cover between the two soil substrata is due to different intensities of fires between the sites, where basalt soils produce greater fuel biomass and therefore more intense fires. This would fit with Higgins *et al.*'s (2000) model, which states that fire intensity is the most likely determinant of Gulliver death. Nonetheless, the impact of frequent fires on tree establishment should be investigated (van Wilgen *et al.* 2004).

ENVIRONMENTAL DETERMINANTS OF FIRE FREQUENCY AND INTENSITY

Fire frequency and intensity in savannas is highly dependant on many different environmental determinants: weather and climatic factors, sources of ignition, available fuel load and soil conditions.

Climate refers to broad trends in the weather characteristic of a region, whereas weather refers to the more immediate conditions of that region (Bond & van Wilgen 1996). Both climate and weather affect fires and determine whether or not a region is likely to be affected by fires. The dry conditions characterizing savannas make them prone to frequent fires. However, it was shown that rainfall is also a key factor in determining fire frequency and intensity. Increased rainfall results in increased fuel load (Bond & van Wilgen 1996; van Wilgen *et al.* 2003; van Wilgen *et al.* 2004). Atmospheric conditions, including wind and temperature, also contribute to fire frequency and intensity (Higgins 2000). In Kruger National Park, the annual rainfall variations, extending between 350mm in the north to around 750mm in the south, coupled with alterations of extended wet and dry periods have led to a variable fire regime (van Wilgen *et al.* 2004).

Another factor that contributes to fire development is sources of ignition. For natural fires, lightening is one of the chief sources of ignition (Spinage *et al.* 1971; van Wilgen *et al.* 2004). Other natural sources include sparks from hardened quartzite and active volcanoes (Bond *et al.* 1996). Today however, the most important source of ignition is man-related. Human ignition has dramatic effects on fire frequency and intensity in the Kruger savanna, where there have been prescribed burnings since 1926. Management today seeks to naturalize fires, although fire regimes are still strongly influenced by humans (van Wilgen *et al.* 2004).

A third feature that affects fire is fuel. Fuel comprises plant matter. The structure, spatial arrangement and chemical composition of different plants, and the ability to produce or retain dry dead material are what determine their quality as fuel. The total biomass of available fuel, thus the total biomass of local vegetation, determines fire intensity and frequency (Higgins *et al.* 2000; Trollope 1998; van Wilgen *et al*. 2003). A fire will not carry with a fuel load of less then 2000 kg/ha^{-1} (van Wilgen *et al.* 2003). Herbivory influences fire regimes because high levels of herbivory reduce available fuel load and thus retards the occurrence of fire (van Wilgen *et al.* 2003).

Finally, soil types determine regions that are more or less susceptible to fire. In Kruger, the two main sources of variation in soils are found between nutrient-poor granite soils and nutrient-rich basalt soils. Different soil types have varying water retention thresholds. The nutrient-rich clay soils retain water better than the granite sandy soils making the former more conducive to grass growth. Clay soils are more likely to be the sites of fires than sandy soils (Dingman 1994; De Ridder & Van Keulen 1995; Walker *et al.* 1981; Bond & Van Wilgen 1996).

Fires exist in different forms: ground fires which burn underground, surface fires which burn just above ground surface and crown fires which burn in tree canopies. In savannas and grasslands surface fires predominate because grass is the dominant fuel type. Although the tree layer is affected by the intensity of the surface fire, trees are not considered as part of the fuel complex (Bond and van Wilgen 1996) Herbivores, edaphic features and fire are formative factors of the balance between woody and herbaceous vegetation in savannas (Augustine & McNaughton 2004).

The relative and combined effects of elephants and fire on savanna vegetation

Elephants are primary players in the savanna – their massively destructive foraging strategy coupled with the large biomass of food they require leads to dramatic effects on vegetation structure. Elephants often ring-bark trees, tear off branches or push over trees when foraging (Beuchner & Dawkins 1961). By causing wounds on trees, revealing unprotected tissues, elephants make plants susceptible to attack by pathogens, insect wood borers, desiccation and most importantly, fire (Beucher & Dawkins 1961; Guy 1989). Fire rarely kills trees unless the trunk is exposed (Guy, 1989). By damaging adult trees and revealing tissue, elephant browsing increases the adult tree mortality induced by fire (Beuchner & Dawkins 1961, Eckhardt *et al.* 2000, van Langvelde *et al.* 2003). Furthermore, by pushing trees over and keeping them low through regular browsing, trees are maintained within the "fire trap".

Causes of the widely observed decline in woody vegetation in reserves and parks in savanna Africa over the last thirty years have been the subject of considerable debate. Three widely supported explanations have been offered for the decline:

1) Woodland decline is caused by a concentration of elephants into small reserves due to the rapid expansion of human settlements (Ben-Shahar 1992). The increased destructive elephant herbivory, resulting in increased tree mortality, leads to a decrease in woody vegetation. Once the effect of elephants has reduced the woody vegetation, the grassland state is maintained and perpetuated by fire (Beucher & Dawkins 1961; Dublin, Sinclair & McGlade 1990; Leuthold 1996; Mapaure & Campbell 2002; Tafangenyasha 1997).

2) Woodland decline is a result of increased frequency of human-induced fires. The frequent fires eliminate more seedling trees than can compensate for long term adult tree mortality. Although fire has little effect on adult tree mortality, the lack of recruitment leads to an eventual decline in tree populations. If this scenario were true, a decrease in fire frequency should result in and increase of woody plant species in savannas (Dublin *et al.*1990).

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3) Woodland decline was initiated by an increase in fire frequency, but maintained by the increase in elephant population density. Browsing by elephants maintains the woody vegetation populations at low numbers (Dublin *et al.* 1990). Dublin *et al.* (1990) found that even in the most extreme cases, elephants did not affect sufficient damage to cause the mortality rate of tree populations to drop below recruitment rates. Fire, in comparison, was shown to hold tree recruitment rate well below mortality rate, even at relatively low fire frequencies. In exclosure experiments, elimination of fire and not herbivores was shown to result in a greater increase in woody species than exclusion of herbivores and not

fire (Guy 1989). Dublin *et al.* (1990) concluded that herbivory may have aggravated the woodland decline, but that fire is most likely to have initiated it.

Dublin *et al.* (1990) suggested that given the current burning rate of around 5% *per annum* in the Serengeti-Mara savanna, as in Tsavo National park in Kenya, elephant populations would have to be halved to halt woodland decline. To stimulate woodland regeneration, further reduction in elephant populations and lowering of the burning frequency would be required. Even with reduced herbivore populations, it would be difficult to maintain sufficiently low burning frequency, given the importance of fire in the savanna ecosystem and the biomass of grass that is available to burn. In the Mara, if elephant populations were to return to their 1960s level (40 % of the current elephant density), a burning rate of 10% of the parks area *per annum* would be required to allow woodland regeneration (Dublin *et al.* 1990).

East Tsavo National park exemplified the effect of decreasing elephant populations on the density of woodland species in savannas (Leuthold 1996). Prior to the 1960s, there was a high density of elephants in East Tsavo, and a low tree density was observed at study sites. Subsequently, drought and intense poaching eliminated vast numbers of elephants. The fire frequency over this time was stochastic – no specified fire regime was implemented in the park. Photos of given sites were taken in 1970 and 1994 respectively. A marked increase in woody vegetation was observed following the 24 year interval of low elephant numbers. On a finer scale, however, photographs comparing 1990 to 1994 showed how fire limited the growth of small saplings, which disappeared from the photos following burning of the sites (Leuthold 1996). This does not necessarily indicate that these saplings have died – they may persist as Gullivers – but the limiting effect of fire on small size classes of trees is apparent.

The decline in woody vegetation associated with the increase in elephant numbers has been widely considered to be a negative process, reducing the biodiversity of both plants and animals and the overall heterogeneity of the landscape. In contrast, Skarpe *et al.* (2002) propose that woodland decline is actually a shift back to a more historically typical state. They suggest that the increased density of woody species observed at the turn of the century, around the time that many parks and reserves were established, were reflections of the drastic reduction in megaherbivore population numbers due to the large-scale poaching of the 19th century and the Rinderpest epidemic. The decline of woody species in savannas could therefore be a shift back to the typical state of vegetation one would have seen prior to the megaherbivore decline (Skarpe *et al.* 2004; Dublin *et al*. 1990).

It is not elephants single-handedly that maintain the recruitment rate of trees below the mortality rate. Other herbivores, such as impala, predate the seedbank in the soil, reducing the seeds available to regenerate woodlands following fires (Skarpe *et al.* 2004). Additionally, herbivory by other large herbivores such as buffalo and rhino may limit growth of seedlings following fire (Mosguelo *et al.* 2002). To halt the decline of woodlands, management of fire, elephants and other herbivores would have to be integrated.

Future studies should investigate direct impacts of elephants on adult tree mortality. Specifically, quantitative measures of how vegetation changes in response to elephants and fire should be analysed on a fine scale. Models need to be developed that incorporate both fire and browsing effects, with respect to dynamic landscape heterogeneity. Such models can be utilized to predict realistic outcomes for use in management of both elephants and fire.

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4. Elephants and Surface Water

Christopher Barichievy, Erik Fyfe, Nicholas Tye

Summary table:

Theme	Description
5.1 Elephant water needs	Elephant are water dependent.
5.2 Surface water in KNP	
5.2.1 Natural water sources	5 perennial rivers, ephemeral rivers, pans, springs and vleis
5.2.2 Artificial water sources	A policy of artificial water provision was historically followed. 365 boreholes and 50 earth dams were constructed.
5.3 Effect of surface water on elephant distribution	Elephant distribution is closely tied to water availability.
5.3.1 Surface water seasonality	Elephants remain around permanent water sources during the dry season and spread out over the landscape during the wet season.
5.3.2 Relationships between elephants and artificial water points	Artificial water points eliminate the need for elephants to migrate during the dry season.
5.3.3 Surface water effects on different sexes	Males move further from permanent water points than females. Calves restrict the movement of breeding herds.
5.3.4 Surface water and elephant reproduction	Calf mortality increases in response to decreased water availability.
5.4 Relationships of elephants with the piosphere	Herbivores cause areas of increased trampling, decreased herbaceous cover, decreased water infiltration, decreased basal cover and decreased standing crop around water points. Elephant impacts are heaviest in the first 200m around a water point but can extend as far as 1600m.
5.5 Relationships of elephants with riparian zones	The homogenising of spatial and temporal water supply has led to increased elephant impacts in the riparian zone. Riparian trees are resilient to elephant utilisation.
5.6 Implications for elephant management	In theory the alteration of surface water availability is a possible tool for the management of elephant populations, assuming that the distances between natural water and the variability of these natural sources is sufficient to lower the fecundity and recruitment rate in elephant populations. The economic implications of closing artificial water points needs to be considered.
5.7 Suggestions for further research	-The effects of water point closure on elephant populations. -The economic value of water points versus the cost of maintaining them.

	-Specific elephant impacts in the piosphere versus overall herbivore impacts

Introduction:

The mission statement for the Kruger National Park reads, “To maintain biodiversity in all its natural facets and fluxes and to provide human benefits in keeping with the mission of SANParks in a manner which detracts as little as possible from wilderness qualities of the Kruger National Park”(www.sanparks.org). Subsequently, Kruger has adopted an adaptive approach to park management that emphasizes the importance of heterogeneity in management. The primary active-management tools available to park managers are fire policy, culling, and water provisioning (Owen-Smith 1996b).

At present, the population of African elephants (*Loxodonta africana*) in Kruger is the highest that it has been in the park’s history (Whyte *et al*. 1999). In response to concerns regarding impacts of the growing elephant population on other species within the park, Kruger National Park Scientific Services and other concerned scientists are working to assess the severity of elephant impacts on vegetation and biodiversity and to explore potential management strategies. The Organization for Tropical Studies(OTS) has assisted Scientific Services by formulating this review of research literature relating to elephant ecology, the relationships between elephants and vegetation, the influence of elephants on biodiversity, the relationships between elephants and fire, the relationships between elephants and surface water, elephant behavior, and potential management strategies and their implications.

In this section we discuss the relationships between elephants and surface water in Kruger National Park. Strong seasonality of water availability in a semi-arid savanna system is important in influencing large mammal community structure and function (Western 1975). We explore physiological water needs of elephants and elephant drinking behavior, the history of natural and artificial water points within Kruger, the impacts of surface water availability on elephant distribution and population growth, the impacts of elephants in areas of available surface water, and implications of water provisioning for elephant population management. Issues requiring further investigation include: the specific contribution of elephants to the formation of piospheres, the influence of surface water provisioning in neighboring private game reserves on Kruger elephant ecology and distribution, the influence of elephants on the availability of water to other species, the economic costs of maintaining artificial water points, and the potential economic costs of closing water points.

Methods:

We utilized several sources for scientific literature relating to elephants and surface water. We searched the OTS database, the Skukuza library, and various online databases. Databases most used include the Emory University online library, the Wits University online library, and Google Scholar. We also referenced articles cited in relevant papers. Professional consultations include Dr. Angela Gaylard, Dr. Rina Grant, and Dr. Ian Whyte. Finally, we utilized Angela Gaylard’s personal library of elephant-related resources.

Literature Review:

5.1 ELEPHANT WATER NEEDS

African elephants are considered a water dependent species (Owen-Smith 1996a). Elephant body liquid balance is important for thermoregulation (Owen-Smith 1988). Although elephants do not have sweat glands, they can excrete moisture through their skin. Furthermore, as temperature increases and relative humidity decreases, elephants visit waterholes more frequently to spray themselves as well as to drink (Young 1970). Elephants drink 1-3 times daily when water is prevalent and once every 2-3 days during the dry season (Owen-Smith 1988).

The distribution of elephants is influenced by water distribution (Owen-Smith 1988). During the dry season, elephants concentrate around permanent water sources, while during the wet season, elephants range over a broader area in conjunction with increased surface water availability (Young 1970).

Elephants are capable of travelling great distances between forage and water. In an extreme example, desert dwelling elephants in the Namib Desert, Namibia, travel an average of 18km/day during the wet season and up to 34km/day during dry periods (Lovegrove 1993). The desert dwelling elephants act as an example of the ability of elephants to thrive in areas where surface water availability is unevenly distributed. (See appendix 5.1 for additional information regarding water consumption and drinking intervals of elephants)

SURFACE WATER IN KRUGER NATIONAL PARK

5.2.1 Natural water sources

In Kruger, there are 5 main water sources available to animals: perennial and ephemeral rivers, vleis, springs, and pans, which vary in location, density and temporal variability. "At the broadest scale, heterogeneity in the availability and distribution of natural surface water in Kruger is created by geology" (Gaylard *et al*. 2003). The variability of water sources creates a heterogeneous landscape with regard to the surface water availability for mammals.

Artificial water sources in Kruger National Park

Kruger National Park's water provisioning program was designed to stabilize surface water availability, to provide additional water supplies where they previously existed, and to relieve pressure on riverine habitats in time of drought. The program emphasizes the necessity to construct dams only where storage capacity would be sufficient, even during drought periods (Pienaar 1970).

The introduction of artificial watering points created spatially and temporally constant sources of water. By 1995, 365 boreholes and 50 earth dams had been constructed. Less than 20% of Kruger is thought to be further than 5km from surface water during extreme drought conditions (Gaylard *et al*. 2003). (see appendix 5.2.2a for maps of borehole distribution in Kruger) (For a full account on surface water availability in the Kruger National Park, consult appendix 5.2.2b)

EFFECT OF SURFACE WATER ON ELEPHANT DISTRIBUTION

Elephant walking habits as well as the size and shape of their home ranges are largely determined by the distribution of water points. As a result of the proliferation of artificial water points and fencing, large indigenous migratory herbivores become more sedentary, thus homogenizing grazing pressure (Young 1970). Water dependence of elephants restricts their foraging range during the dry season to areas depleted of resources as a result of high utilization pressure (Redfern *et al*. 2003). In the Haonib river catchment of northwest Namibia, elephants are closely associated with the river and move in association to rainfall (Leggett *et al*. 2003).

Differences in elephant distribution around water may also relate to soil nutrient content. Elephants occur further from water in nutrient-poor areas than in nutrient-rich areas. However, elephant densities are higher in nutrient-poor areas leading to uncertainty with these results (Redfern *et al*. 2003).

5.3.1 Surface water seasonality

In characteristically heterogeneous systems, elephants respond to seasonality of surface water availability. Overall, small differences between the elephant distance-to-water distributions in wet and dry years were observed (Redfern *et al*. 2003). During the dry season, elephants have smaller home ranges than in wet periods (Young 1970; Stokke & du Toit 2002).

Western (1975) observed that in the Amboseli system, Kenya, the range of most species contracts around perennial surface water during dry months. He also noted that, "wet season ranges are vacated by the water dependent wildlife species immediately when it rains, even before grasslands have had the opportunity to respond," suggesting that surface water availability is principal to the seasonal shifts of water dependent species (Western 1975).

5.3.2 Relationships between elephants and artificial water points

In Kruger, the home ranges of elephants do not increase in the wet season as might be expected. Seasonal variation in elephant distributions has been affected by the homogenous distribution of permanent water points across the landscape. The distance between water sources is no longer affecting the movement of breeding herds. An increase in the density of water points reduces home range area and increases the intensity of patch use. An increase in patch use intensity may be detrimental for local vegetation and may be incorrectly ascribed to high population density (Grainger *et al*. unpublished).

Large populations of herbivores take advantage of the proliferation of artificial perennial water points throughout the dry season, temporally homogenizing pressures on vegetation in the vicinity of rivers and permanent watering points"(Weir 1971). Thrash and Derry point out that the influence of permanent water point distribution is greater then productivity of vegetation in determining the carrying capacity of a vegetation type (Thrash & Derry 1999).

Owen-Smith (1996a) explains that water points spaced too closely together increases vulnerability of species to starvation-induced mortality during droughts. He advises that establishing permanent water sources between rivers should not occur unless the rivers are greater than 30km apart.

5.3.3 Surface water effects on different sexes

Stokke & du Toit (2002) observed differences in elephant distribution in relation to sex. During the dry season in Chobe National Park, bulls were observed to travel greater distances from permanent water sources than cows. However during the wet season, both males and females were found close to permanent water sources even though surface water was more widely available. Stokke & du Toit hypothesize that forage quality is greater in the vicinity of the floodplain than quality further inland. The behavioral dimorphism in relation to surface water is likely a result of the larger size of bull elephants and the influence of juveniles on the movement of breeding herds (Stokke & du Toit 2002). The provision of artificial water points negates the need of breeding herds to restrict their movements along permanent natural water sources. Cow home range size decreases dramatically in response to water patch richness density (Grainger *et al*. unpublished).

5.3.4 Surface water and elephant reproduction

Due to lack of high poaching levels and no culling in Amboseli national park Kenya, The elephant populations respond primarily to environmental variability and so it has been used in a case study on the effects of water on elephant populations.

In Amboseli, Moss (2001) observed that reproductive activity declines in periods of drought. Furthermore, demographic studies in Amboseli and elsewhere have shown that juveniles have higher mortality in periods of drought. Severe drought from 1973–1976 was characterised by high calf mortality, as was another drought in 1991. In Amboseli, the direct effects of water unavailability is shown through the high mortality in younger age classes, adults have higher human contacts and thus also experience heightened mortality, be it indirectly. Drought results in inadequate nutrition, limited water and increased energy expenditure (Moss 2001). Similarly, desert elephant populations, which are arid adapted and have had a stable population for 20 years also show an increase in calf mortality in response to drought periods. (Leggett *et al*. 2003)

During the water provisioning program elephant populations were aggressively managed by culling, keeping the population at approximately 8000. This means that no elephant-rainfall relationships can be drawn from that period (Owen-Smith & Ogutu 2003).

Relationship of elephants with the piosphere

The radial movement of herbivores to and from point source watering points creates a gradient of increased trampling, grazing and browsing impacts around the water point. This area of higher degradation is termed a "piosphere" (Owen-Smith 1996).

Herbivores as a group impact the piosphere in several ways. Thrash and Derry (1999) found that the mortality of woody plants vulnerable to trampling and browsing is inversely proportional to distance from waterholes. Plants adapted to withstand heavy browsing replace vulnerable species. This translates into an increase in increaser grass species and a decrease in decreaser grass species. Thrash (1997) found that large herbivores have a negative impact on the herbaceous forage, fire fuel potential, basal cover and standing crop. Habitat and herbivore species are thus negatively impacted by a close proximity of watering points.

It is more difficult to determine the specific contribution of elephants to the formation of piospheres. Fruhauf (1997) who looked at the effect of elephants in particular, found an increase in elephant impact on several species, such as *C. mopane*, *P.violaceae* and others in relation to proximity to the watering point. Most notably impacted was the *C. mopane* woodland, showing significant impact up to 1600m from the water source. The variation in impact shows a selective browsing behaviour, which has important implications for managing biodiversity around watering points. A separate study in the Central Kalahari Game Reserve found no significant effects of distance from water points on plant species composition. Elephants were not considered as one of the common large herbivores in this study, and it is hypothesized that in the presence of elephants, changes in vegetation would be more evident (Makhabu *et al* 2002). Generally elephant impacts seem to be most pronounced in first 100-200m surrounding water points, but can extend as far as 1600m (Gaylard pers.comm.).

5.5 Relationship of elephants with riparian zones

Traditionally elephants make use of riparian vegetation in the dry season, and move into interior regions during the wet season when surface water is more plentiful (Young 1970). The heavy utilisation of riparian woodlands is thus limited to the dry season and plants may recover during the wet season. Riparian vegetation is considered to be resilient to disturbance due to higher levels of water, clay, and nutrients in the soil (Owen-Smith 1996a, 1996b).

The introduction of artificial perennial water points in the interior has made it possible for the colonisation of these regions by resident elephant clans, and this then suppresses seasonal movements of other elephants out of the riparian zone. The resultant year-round use of the riparian zone exacerbates elephant impacts on riparian woodland regeneration (Owen-Smith 1996b).

5.6 Implications for elephant management

In Hwange National Park, Zimbabwe, the widespread use of artificial water points led to a significant buildup in animal numbers (specifically elephant, buffalo, zebra). In conjunction with widespread borehole malfunction in 1994, almost 1000 fresh elephant carcasses (mostly calves) were found in surveys. Further analysis of the potential to support the water needs of animals within the Hwange estimated that water pumped by 22 diesel pumps could only provide 20-40% of daily needs of the elephant population of approximately 20,000-30,000. With too little water, elephants would be forced to move out of the park during dry periods and other species would likely be affected from elephant dominance of water points (Owen-Smith 1996a).

After reviewing the literature, we suggest that management of elephant populations in the Kruger National Park through the manipulation of water sources is theoretically possible. Our suggestion assumes that the distances between natural water and the variability of these natural sources is sufficient to lower the fecundity and recruitment of elephant populations. However the conflict between tourism and ecology proposes a difficult resolution. Private land owners on the western boundary of the Kruger National Park have a different mandate to Kruger, being much more dependent on the presence of water holes for tourism. This should be taken into consideration, as Kruger is no longer a closed system. "The encouragement of uniform animal distribution does not correspond with the National Park goal of maintaining natural processes and biodiversity"(Thrash 1998).

Having completed this literature survey, we aimed to summarize our findings, however Norman Owen-Smith summed up elephant management through water manipulation more succinctly than we ever could:

"If surface water was restricted to just a few localities by the late dry season, elephants would deplete available food in these places, and experience starvation plus the additional cost of traveling back and forth between feeding areas and drinking places. Juveniles would suffer most, and become vulnerable to heightened mortality. An additional

mortality factor, now being observed both in northern Botswana and Hwange, is increased predation by lions on calves and young elephants separated from herds under the crowded conditions. Such compounded mortality could be sufficient to halt population growth. Stress to the elephants would be severe, but for just a brief period of the year. Once the rainy season commences, the elephants would spread widely, and hence exert relatively little pressure on woodlands. These conditions are developing along the Chobe and Linyanti Rivers in northern Botswana, as well as around the waterpoints maintained in Hwange, but managers are misguidedly trying to alleviate them by providing additional water."

"What about woody plant populations, especially species growing near the perennial waterpoints? Following depletion of favoured species, regions near perennial water would be largely abandoned by elephants for most of the year, contrary to the current situation along the Chobe alluvial terrace. This would allow the surviving plants a longer period to recover, albeit at depressed abundance levels. Temporal variability between years in the persistence of ephemeral waterpoints (pans) could also affect the period during which elephants concentrated near perennial water sources, and hence the windows of opportunity for plant populations near water to recover. Climatic variability could furthermore enable the episodic recruitment of dense cohorts of seedlings, saturating browsers and providing "herd" security against predation by elephants on the saplings."

"This speculative scenario suggests how elephant populations might attain zero growth with only localised severe impacts on vegetation, provided perennial water was sufficiently restricted in its availability. Stabilizing ephemeral sources, or providing additional perennial waterpoints, as wildlife managers are prone to do, only spreads the elephant impacts more widely, and allows the elephant population to grow larger before animals experiences sufficient stress and crowding during the dry season to halt population increase. While waterpoints also bring important benefits for wildlife viewing and hence for attracting tourists, these benefits have to be weighed against the adverse consequences for the ecosystems processes that may formerly have regulated elephant and tree populations at levels permitting mutual coexistence across heterogeneous landscapes"(Owen-Smith 2003).

5.6 Suggestions for further research

We recommend an integrated research project, combining ecology, tourism, and economic impacts regarding water point closure, if this has not been commenced already. In the process of this review we noticed a few gaps in the knowledge base, either through lack of research or unavailability of the results. They are as follows:

-Effects of water point closure on elephant populations.

-The economic value of water points versus the cost of maintaining them.

-Specific elephant impacts in the piosphere versus overall herbivore impacts (only one published study found)

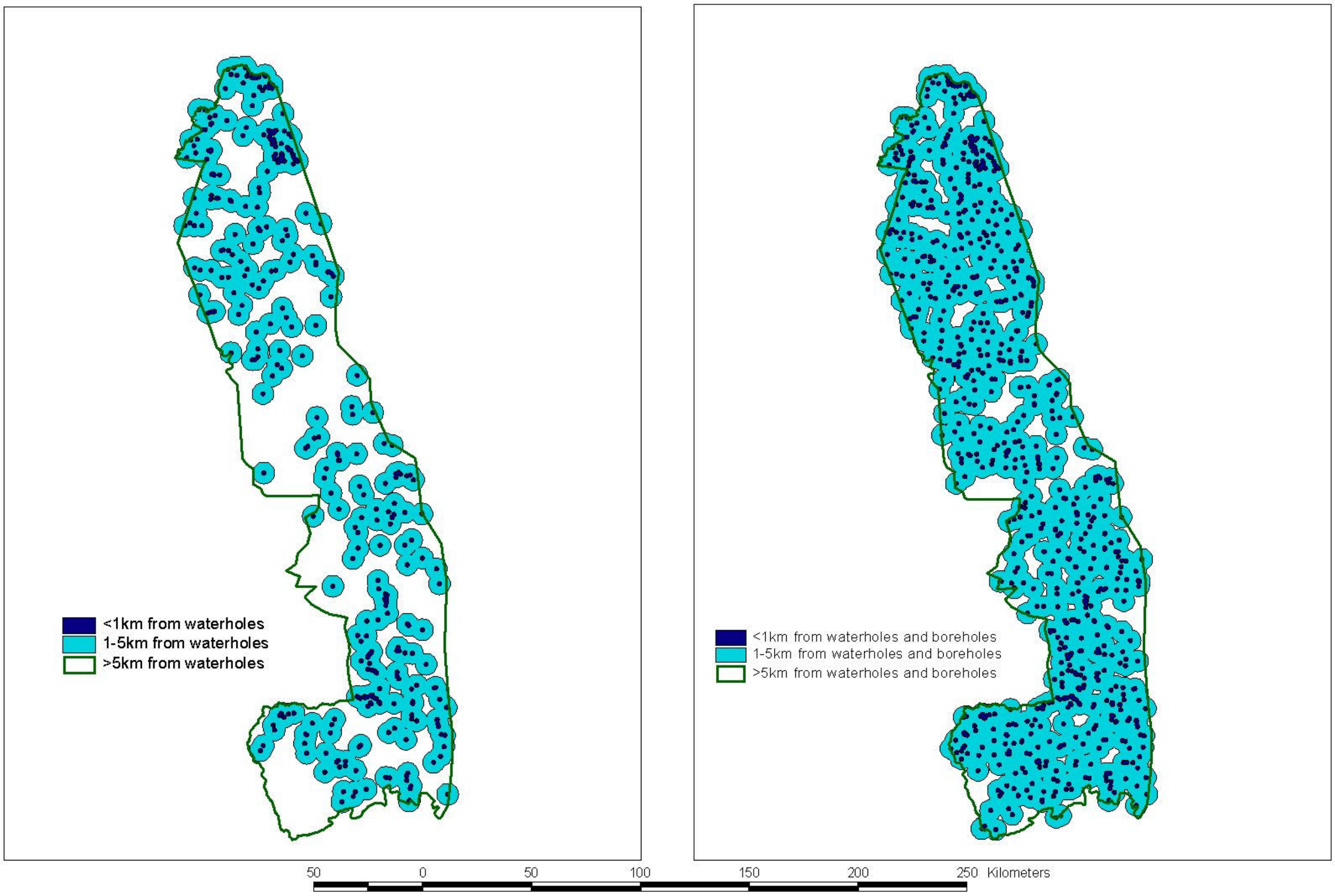
APPENDIX:

5.1 Use of surface water by elephants

	Mean water consumption (l/animal/day)	n (herds)	Mean drinking interval (hours)	Maximum drinking interval (hours)	Mean daily water consumption per animal (l)
Elephant herds	35 (6.9)	9	43	>72	88.61
Elephant bulls	77 (26.9)	23	43	>72	88.61

(Annotated from Young 1970)

5.2.2a Effect of boreholes on landscape distances from water in Kruger National Park.



(DRAWN BY SANDRA MACFADYEN)

5.2.2b Gaylard, A; N. Owen-Smith and J. Redfern.(2003) *Surface water availability: Implications for heterogeneity and ecosystem processes*. The Kruger experience, ecology and management of heterogeneity. Chapter 8. pg 171-188. publishers: Island press, Washington D.C.

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CHAPTER 6. MANAGEMENT

***POLICY*: MATTHEW KLASEN AND JESSICA WINANS *TRANSLOCATION*: EMILY MORRISON*CONTRACEPTION*: A. RACHEL ROEMER**

***CULLING*: WILLIAM BELL *ETHICS AND VALUES*: JANIE HAUSER AND HILARY LANGER**

Abstract

Title	Themes	Points	Description
7. Management			
7.1 Policy	7.11 Obligatory Policy Influences	7.11a CITES	-International treaty limiting international trade in African elephants
			-Limits on revenue potential from culled elephants
		7.11b IUCN and AfESG	-International conservation organization with focused African Elephant Specialist Group
			-Provides tools for management, research, and information sharing
		7.11c KNP	-Promotion of biodiversity through natural facets and fluxes
		7.11d SAN Parks	-Represent the biodiversity of South African landscapes for sustainable use
		7.11e Biodiversity Bill	-Mandates the preservation and maintenance of South African biodiversity
			-Ensure species survival through formal listing of threatened species
	7.12 External Policy Influences	7.12a Policies of Other African Nations	Zimbabwe:
			-Rapidly increasing elephant population
			-Consideration of non-culling management options, but move toward a culling-focused proposal
			Namibia:
			-Largely free-range elephant population
			-CITES request to sell additional ivory on the international market following culling operations
			Kenya:
			-Management practices based on an aversion to culling
			-Widespread biodiversity declines partly due to hands-off management scheme
		7.12b Other South African Policies	Addo:
			-Two-pronged focus on elephant management and biodiversity promotion
			-Variety of management techniques utilized, with culling as last resort

Title	Themes	Points	Description
			EMOA:
			-Group of South African elephant owners to promote the survival and welfare of the elephant population
			-Facilitate cooperation between different stakeholders in elephant management debates
	7.13 Specific Management Issues	7.13a Human-elephant conflict and fencing	-Larger elephant populations create increasing conflict between escaped elephants and local human populations
			-Imperfect containment mechanisms
		7.13b Risk analysis, uncertainty, and monitoring	-Necessity of developing policy despite uncertain information, particularly causal mechanisms
			-Need to adapt management program to monitoring data
	7.14 Indirect Management Techniques	7.14a Do-nothing, laissez-faire	-Allow the natural system to take its own course without any substantial management intrusion
		7.14b Land Acquisition	-Reducing elephant impacts by increasing park area
		7.14c Exclosures	-Preventing elephant movement into sensitive areas through fencing
7.2 Translocation	7.21 History of Translocation		-Background information on origins of overpopulation and how translocation technology has developed
	7.22 Ideal Translocation Procedure	7.22a Pre-Translocation Measures	- Outline of procedure to follow before translocation (monitor populations, decide on appropriate individuals to be translocated)
		7.22b Translocation - the Process	-Move cow-calf families together but bulls alone.
			-Release into boma first
		7.22c Post-Translocation Measures	-Monitor for misbehavior after release
	7.23 Benefits and Successes of Translocation		-Non-lethal alternative to culling
			-Increases tourism
			-Restock reserves
	7.24 Obstacles of Translocation	7.24a Expense	-R10,000 per elephant translocated
			-Transportation costs
			-Projected costs for Kruger Park Population
		7.24b Failure Potential	- Possibility of elephants returning to home range
		7.24c Elephant Stress and Mortality	- Deaths in Kenya translocation
			- Possible misidentification of targeted individual
	7.25 Overcoming Translocation Obstacles		- Many parks already have elephants or are too small to accommodate large numbers to be translocated
	7.26 Conclusion	7.26a Suggestions for further studies	- Translocation is a short term solution
			-May be viable after further research
7.3 Contraception	7.31 Characteristics		- >90% efficacy

Title	Themes	Points	Description
	of an effective contraceptive		- Deliverability by remote darting
			- Reversibility enabling individuals to re-enter the breeding population
			- Safety to pregnant animals and their fetuses
			- Inability of the agent to harm other animals or humans if ingested
			- Limited effect on behavior/social organization
			- No long-term general health effects
			- Low cost
	7.32 Female Contraceptives	7.32a Oestradiol-17β	- A steroid hormone that is an effective contraceptive but causes behavioral changes and long-term physical side effects
		7.32b pZP	- An effective immunocontraceptive that seems to be safe and reversible
		7.32c Trials of immunocontraceptives in KNP	- Two trials of using pZP were conducted in KNP and showed promising effectiveness, safety and relatively easy administration to a small number of elephants.
		7.32d Continued trials in private reserves	- Two private reserves are currently conducting trials of pZP and, thus far, the vaccine has been a very effective and safe contraceptive.
	7.33 Obstacles and solutions for the use of contraceptives in KNP	7.33a Logistics and cost	- 2,250+ elephants will need to be incorporated into a vaccination program for it to be effective. The costs of locating and darting that number of elephants currently prohibits the implementation of such a program in KNP.
		7.33b Possible solutions and current research	- Synthetic form of pZP
			- Darts that semi-permanently mark the animal
			- Slow-release mechanisms to reduce frequency of boosters
	7.34 Other biological alternatives to culling	7.34a Sterilization	- Produces similar reductions to the population as culling
			- Requires only a few hundred young females to be sterilized
			- Sterilizing agents for use in both males and females (GnRH) are being developed
		7.34b Induced abortion	- Research into compounds that are effective and easily administered are underway
			- Associated with many ethical issues
		7.34c Epididymal Contraception	- Contraceptive that targets males
			- A slow release mechanism for long-term effectiveness may be possible
		7.34d Progestins	- Contraceptive that targets males
			- Focus on use in large bulls because it does not alter behavior and will maintain the effect these bulls have on suppressing mating behavior of younger males
	7.35 Conclusion and suggestions for further studies		- Further research into more effective and longer lasting forms of pZP
			- Further research of novel contraceptive and sterilization methods

Title	Themes	Points	Description
			- Development of models to predict effects of contraceptives - Public education about the use of contraceptives - Investigation into combinations of contraception and sterilization methods
7.4 Culling	7.41. Culling methods	7.41a Selection	Quotas based on annual production
		7.41b Drugs vs. brain shooting	Using scoline or brain shooting to kill elephants- Kruger method
		7.41c Helicopter vs. ground	Killing animals from air or from ground- Zimbabwe method
		7.41d Trophy hunting	Trophy hunters should not be used to control elephant numbers
	7.42 Population effects		Effects of culling on elephant populations
	7.43 Animal Utilization	7.43a Processing	Value of elephant parts and field processing
		7.43b Green hunting	Non-lethal animal utilization
		7.43c Ivory trade	Considerations of elephant culling on ivory trade
	7.44 Thoughts		Derived opinion and areas of concern
7.5 Ethics and Values	7.51 Introduction to Wildlife Management Ethics/Values		-Individual biases are based on human values -Humans alone are capable of developing and exercising management policies. -Humans are the only species capable of moral judgment and decision making. This does not necessarily imply human superiority. -Intrinsic value is not a non-anthropocentric concept. Intrinsic value exists because it exists within human reason and values
	7.52 Ethical Issues surrounding possible control methods	7.52a No Action 7.52b Contraception 7.52c Translocation 7.52d Culling	
	7.53 Conclusion		

Introduction

South African National Parks (SAN Parks) held the Great Elephant Indaba in October 2004 to share its proposed elephant management plan with the general public. This meeting did not fully resolve the underlying biological, political, and ethical debates surrounding the proposed policy. Because of the uncertainty that resulted, SAN Parks wished to better articulate the scientific basis for its proposal in preparation for further discussions of the policy.

In early February 2005, Dr. Rina Grant of Kruger National Park asked leaders of the Organization for Tropical Studies' Spring 2005 South Africa program to conduct a review of the available literature on elephants and their ecological impacts. This review was conducted during February 2005. Seven students conducted the management portion of this review, focusing on policy, translocation, contraception, culling, and ethics. We hope this document will provide KNP and the South African public with a foundation for analyzing the diverse challenges of elephant management and facilitating a constructive debate on the proposed management plan.

Methods

The preliminary search for information was through internet search engines such as "scholar.google.com". We attempted to limit our findings to published scientific papers from journals, reports and books but a vast amount of information was available in the form of newspaper and magazine articles. Subsequent searches for relevant material were done within specific scientific journals through university online databases. Experts were personally contacted and interviewed to elaborate on particular topics. We would like to thank Ian Whyte for thoughtfully providing useful literature on elephant contraception, translocation and culling.

Literature review

7.1 POLICY

The management of elephants is task laden by social, political, and biological issues. Here we summarize an array of African elephant management policies. While some policies have been more successful than others, each policy perspective adds to the overall understanding of the management of African elephants and is therefore valuable in developing future management policies.

7.11 Obligatory Policy Influences

While formulating a final Kruger elephant management policy, KNP/SAN Parks is required to make policy decisions that comply with various domestic and international statutory obligations. These obligations occur at different levels of government and are often interrelated, but nevertheless they must be reflected in a final policy. At the international level these obligations are contained in the Convention on International Trade in Endangered Species of Fauna and Flora (CITES) and of the World Conservation Union (IUCN). Domestically, the elephant management policy must reflect the mission statement of SAN Parks, the recently updated overall management plan for KNP, and South Africa's new 2004 biodiversity law.

7.11a CITES

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) was agreed to by representatives of 80 countries in March 1973 (*What is CITES*). In 1989, following a widespread reduction in numbers of African elephants (Loxodonta africana), the international community within the CITES framework implemented a comprehensive ban on the international trade of elephant products. The African elephant was listed as an Appendix I species, the most strict CITES category that limits all international trade.

Faced with increasing elephant populations and increased human-elephant conflicts, the nations of Botswana, Namibia, and Zimbabwe in 1997 proposed a limited down-listing of the species to less-restrictive Appendix II (*Zimbabwe*). This proposal, which was accepted at the 10th CITES conference of parties, allowed these nations an extremely limited permit-based international trading system. In 1999, South Africa proposed a similar down-listing for the elephant population of Kruger National Park, which was also accepted. All funds raised through elephant sales were to be applied to an improved elephant monitoring effort and for land acquisition. At the 12th conference in 2002, South Africa requested and was permitted to conditionally sell up to 30,000 kg of ivory from Kruger National Park (RSA 13.08).

Assuming that some amount of culling may be necessary to preserve the biodiversity of KNP provisions will need to be made for best utilizing the elephant carcasses that remain following culling operations. While other nations have successfully used elephant-product sales to raise funds for conservation purposes, KNP's limited ability to sell elephant products under CITES Appendix II will largely preclude this potential fundraising method. As an alternative, KNP would benefit from a management policy that allows efficient domestic use of elephant products (ivory, hide, and meat), perhaps most effectively by nearby communities.

7.11B IUCN AND AFESG

The World Conservation Union (IUCN) is an international organization made up of government and non-government organizations from 140 countries. According to the director of the IUCN, *"IUCN builds bridges between governments and NGOs, science and society, local action and global policy. It is truly a world force for environmental governance."* Within the IUCN is the African Elephant Specialist Group (AfESG), which focuses on the conservation and management of African elephants (*AESG*). The group provides expertise and advice regarding elephant management at the regional and national levels, and is also involved in international policies such as CITES. The group formed in the 1970s and has since grown to include three base locations within Africa: Kenya, Burkina Faso, and Cameroon.

The AfESG provides tools for elephant management and research, which include strategies for elephant management in different regions of Africa. The organization also produces the journal, *Pachyderm- Journal of the African Elephant, African Rhino and Asian Rhino Specialist Groups*, which addresses key issues in research and management. The IUCN has recently released new management tools regarding the translocation of elephants as well as strategies for maintaining genetic diversity.

7.11C KNP

All KNP management policies have the obligation to conform to KNP's overriding vision and associated goals. A new park management plan accepted in March 1999 states the purpose of KNP as follows: "*To maintain biodiversity in all its natural facets and fluxes and to provide human benefits in keeping with the mission of the South African National Parks in a manner which detracts as little as possible from the wilderness qualities of the Kruger National Park"* (*KNP Vision*).

As written, the proposed zonated elephant management plan reflects the key elements of this mission statement. By containing elements of adaptive management, the policy allows for fluxes in elephant populations and a learn-by-doing approach to the preservation of biodiversity. But because an overall mission statement is quite broad, certainly a broad range of elephant policies could successfully fit this vision. Whether the proposed elephant management policy is the 'best' policy to adopt on a normative level is still uncertain.

7.11D SAN PARKS

In addition to fulfilling the mission of KNP specifically, any elephant management plan should reflect the mission of SAN Parks as a national conservation organization. Specifically, SAN Parks commits itself to "*develop and manage a system of national parks that represents the biodiversity, landscapes, and associated heritage assets of South Africa for the sustainable use and benefit of all*" (*SAN Parks*). An adopted elephant management plan should work toward maintaining the unique biodiversity qualities of KNP in relation to the 19 other national parks of South Africa. In addition, the policy should in some way reflect the historical and cultural history of the park, especially the archaeological sites located within KNP.

7.11E BIODIVERSITY BILL

One of the newest pieces of South African conservation legislation is the national biodiversity law signed by President Mbeki on May 31, 2004. The legislation aims to correct the deficiencies in the previous legal framework for biodiversity that included a great deal of inconsistency and overlap between local, provincial, and national authorities. This prior biodiversity legislation had been cited as being in some respects inadequate for properly enforcing South Africa's commitment to CITES.

The new law eliminates these prior deficiencies by setting a coherent national policy for biodiversity promotion and protection. It works with South Africa's National Environmental Management Act to "*manage, conserve, and sustain South Africa's biodiversity and its components and genetic resources,"* allowing the biodiversity law to supersede all other national legislation when a biodiversity conflict is at issue (*RSA Biodiversity §*3(a) and §8(1)(a)).

In terms of elephant management, the biodiversity law binds KNP and SAN Parks to maximize KNP's indigenous biodiversity in its policy. This biodiversity imperative is quite similar to the mission statement of both KNP and SAN Parks, but this legislation makes biodiversity maintenance a legally binding commitment. Though the regulations needed to clarify and enforce this legislation are still being crafted, KNP will need to keep abreast of these developments. Specifically, the requirements for listing endangered, vulnerable, and protected species will be of interest to elephant policymakers in the near future. If particular KNP species are listed, for example, KNP may need to adapt its management proposals to give further protection to these species. While KNP's current TPC-based adaptive management system can help manage the populations of endangered species, the requirements of the biodiversity bill and implementing regulations may require KNP to take more comprehensive efforts to protect species. The national government, for example, may desire a dedicated effort to saving single species rather than having a high reliance on natural facets and fluxes to maintain biodiversity.

7.12 External Policy Influences

In addition to the mandatory requirements described above, KNP/SAN Parks should adopt a final elephant management plan that reflects knowledge gathered within different contexts in South Africa and abroad. These include park policies in South Africa, the practices of private elephant conservation entities in South Africa, and the management experience of other nations that must deal with similar elephant management scenarios.

7.12a Policies of Other African Nations

While the context of other African nations is certainly not identical to that of South Africa, their elephant management experiences should be an important input into KNP's policymaking process. Despite a general lack of available information about African elephant conservation efforts managed by African governments, a few helpful case studies can be constructed. The experiences of Zimbabwe, Namibia, and Kenya help place KNP's elephant concerns in context and should inform its ultimate policy decisions.

Zimbabwe

Like the South African case, Zimbabwe has recently experienced a dramatic increase in elephant numbers. Zimbabwe's elephant population in 2001 was estimated to be 88,100, and in 2003 was estimated by experts to have grown to approximately 97,000 individuals (Foggin 2003). Like South Africa, Zimbabwe historically had a large-scale culling policy from 1960 until the late 1980s, in total reducing the population by 40,000 individuals. In the recent past the population has been allowed to increase without human intervention, but negative biodiversity and human-elephant effects are increasingly being realized. Some have suggested that Zimbabwe's elephant population is heading for an "inherent and unavoidable" die-off, but at this time no population crash has occurred (Foggin 2003).

Zimbabwe has considered many of the same management options as KNP is contemplating at the moment, although a coherent heterogeneity-based zonation system has not to our knowledge been suggested. High elephant densities, approaching 6 elephants/km^2, have been attributed to the widespread use of artificial water points; park authorities are considering closing these points as has been proposed in KNP (Foggin 2003). Mass translocations have been proposed like in Kruger, but Zimbabwe has few suitable elephant habitats that are currently devoid of elephants, and also lacks South Africa's expertise with tranquilizing, transporting, and acclimatizing translocated elephants. And although contraception has been discussed as a possibly feasible control option, it has been de-emphasized due to elephant behavior side effects and logistical hurdles. Zimbabwe is moving toward a large-scale culling program but has expressed frustration that such an economically intensive process would be limited by CITES in its ability to realize economic benefits from resulting elephant products. Authorities worry that a large-scale culling program would anger the international community and make further CITES concessions more difficult to obtain.

Zimbabwe's situation is very similar to that of South Africa in its similar elephant population increases and resulting biodiversity losses. It is different, however, because 15% of its elephants live outside formally protected conservation areas and because it has fewer economic and personnel resources to devote to intensive management processes.

Namibia

Namibia is much more dissimilar to South Africa in its elephant management policies for a few reasons. First of all, a substantial proportion of its elephant population is located outside of formal protected reserves. No completely fenced reserve akin to Kruger exists in the Namibian conservation system. Because of this, there is a greater potential for conflict with local communities. A great deal of animosity has developed toward elephants and their conservation champions by local populations negatively affected by elephants (Sutton 1998).

To deal with a free-ranging elephant population increasingly in conflict with humans, Namibia requested a CITES ivory quota during the 13th Conference of Parties in October 2004 (Bulte *et al*. 2004). It has turned to elephant culling as the dominant technique in its management regime. To our knowledge, contraception or translocation have not been seriously considered as viable methods for controlling the Namibian elephant population. This is most likely due to logistical and financial constraints in the less developed Namibian conservation system.

Kenya

Of all African countries, Kenya has been the most resistant to elephant population reduction through culling. Kenyan park managers have taken a hands-off approach to elephant management but have experienced large decreases in biodiversity arguably due to this policy. Amboseli National Park, for example, has remained strongly anti-culling and anti-population regulation despite experiencing a 50% decrease in plant species diversity (D. Western, pers. comm, as cited in White et al. 2003). Gerenuk and giraffe species have been entirely extirpated from the reserve.

Unlike Zimbabwe and Namibia, Kenya has largely determined that its elephant population will be allowed to grow without any human-induced regulation. This policy is similar to KNP's post-1994 moratorium on culling. While the Kenyan context cannot be directly applied to Kruger, it is possible that similar biodiversity 'crashes' may result in KNP if a more intensive management policy is not adopted.

7.12b Other South African Policies

Addo Elephant National Park (AENP):

Within South Africa, Addo Elephant National Park is home to the largest elephant population outside of Kruger National Park. The park, which was originally established in 1931 with a singular mandate to conserve the elephant population of the Eastern Cape, has undergone significant expansion and has had great success in rebuilding the Cape elephant population. Today the park continues to expand and conservation efforts have extended beyond the building of elephant populations to a broader focus on biodiversity. The park's management practices are highlighted in AENP's Integrated Environmental Management System (IEMS), which contains a strong elephant management policy; and in fact, Knight *et al*. suggest AENP be used as an example when developing other elephant management policies.

AENP's management plan has many unique aspects, such as the use of Armstrong fencing, which is not used for elephant management anywhere else in South Africa. Armstrong fencing, while having a steeper initial cost, is more economical than electric fencing in the long run and provides a more impermeable boundary. The management policy is very explicit in management objectives and methods, as shown in some of the key points summarized below.

The park seeks to maintain an effective elephant population with a minimum of 200 breeding adults, while maintaining ecological diversity among vegetation and wildlife species. Genetic diversity is maintained through population supplementation, and the populations are sustained at the meta-population level. Population levels are managed through "the most humane and cost effective means" (*Addo*). Land acquisition, translocation, contraceptives, select ethical hunting operations, and control of problem animals are all management techniques used before culling which is only looked to as a last resort. The park has a break-out policy that involves land owners and provincial authorities and only resorts to shooting as a final option. Constant research and monitoring occurs within AENP to measure elephant impacts of vegetation and other herbivores. Other key aspects of the policy include emphasis on elephant access to resources; the presence of corridors and barriers to elephant movement; fencing; water sources; and political influences on elephant management.

Ultimately, AENP's approach to elephant management is unique because elephants were the foremost priority at the onset of the parks conservation policy planning. The policy has since been adapted to emphasize biodiversity; however, elephants continue to be one of the main components of the IEMS. The elephant situation in KNP is slightly more complex than that in the AENP and therefore not all AENP management strategies would be appropriate. Yet AENP does possess an effective elephant management strategy that follows international and SAN Parks guidance, and it is important to consider its management techniques when creating KNP's new policy.

EMOA

The Elephant Managers and Owners Association (EMOA) is a networked organization of elephant owners, scientists, elephant specialists, and conservation bodies in South Africa and other southern African nations. EMOA was formed in 1995 and sprung from an organization called the Translocated Elephant Information Center that formed when researchers became concerned with the state of translocated elephants. The EMOA rapidly gained membership and today boasts more than 70% of all South African elephant owners as members. EMOA's mission is "to promote and monitor the conservation, protection and welfare of the African elephant."

Much of EMOA's role in elephant management is in encouraging cooperation between various parties involved, as well as monitoring and advising in policy and research actions. EMOA produced an elephant management manual, *Managing African Elephants: Guidelines for the introduction and management of African elephants*, that was influential in the formation of the elephant management policy in Mozambique's Limpopo National Park. EMOA's management strategies largely focus on translocation and land acquisition, but also address other important management issues such as hunting and the utilization of elephants as an economic resource.

7.13 Specific Management Issues

An elephant management policy for Kruger National Park, in addition to incorporating the above influences, must address a few key issues. There are certainly hundreds of small issues that must be addressed, but we will focus on two of the most significant within the KNP context. First, the elephant policy must address issues of human-elephant conflict and its mitigation. Second, it must be designed to minimize the risk to biodiversity and elephant populations, embrace the uncertainty and adaptive nature of current elephant ecological research, and develop an effective program for monitoring and responding to ecological change.

7.13a Human-elephant conflict/Fencing

Human-elephant conflicts have increased as elephant habitat has been fragmented and elephants have been forced to live in smaller areas. Elephants enter villages and destroy crops and in some cases kill local people. Electric fencing has been the major management technique used to reduce human-elephant conflict; however, elephants often break through the fences, particularly when the fences are not well maintained (Boone; Hobbes). As mentioned above, Addo Elephant National Park has begun to use Armstrong fences which are more likely to keep elephants in their fenced area. The Armstrong fences can be used within proximity to villages and traditional electric fence can be used to create the border of lower risk areas (Knight *et al.* SANParks). It is important that a break-out policy, as well as a problem elephant policy be included in elephant management policy, because often local people will immediately resort to shooting elephants. When developing these policies, it is therefore essential to include local landowners and local governments in policy decisions.

7.13b Risk Analysis, Uncertainty, and Monitoring

One of the primary concerns of any ecological management plan is how to deal with the inherent uncertainty of the natural world. A proper management policy should ensure that no unneeded risks are taken and that a system is never irreversibly forced into an undesirable state. It is imperative that these concerns apply to any accepted elephant management plan.

A final policy will also have to deal with the scientific uncertainty that still remains surrounding the true degree of elephant impacts and biodiversity declines. As presented in Sections 2 and 3 of this report, it has been proposed that many factors are to blame for the recent decline in woody tree species abundance and richness, including fire policies, water provisioning, and elephant-induced destruction. Yet despite these varied causal proposals, it is generally understood that elephants play at least a contributory role in structural vegetation changes. The true causal mechanism has not been determined, and may never be determined, but a policy nevertheless must be developed despite this unsettled understanding.

Deciding on a proper policy is a difficult process, but determining how to monitor the success or failure of the policy may be just as challenging. First, a monitoring program must utilize its limited resources to effectively monitor the biodiversity of an approximately 2,000,000-Ha park. Second, it must select reasonable and accurate proxies for the general category of 'biodiversity;' which plant species should be monitored has been addressed in section 2 of this report.

Finally, once a monitoring program is in place, it now is up to park managers to determine how this information will affect subsequent management responses. KNP's general management framework is to use Thresholds of Potential Concern (TPCs) for management, which include a desired level for a particular monitoring parameter and an allowable deviation from this limit before action is taken. It allows park managers to set a desired value for a range of different variables and permits a reasonable amount of natural variation before management steps are taken.

7.14 Indirect Management Techniques

A few primary management techniques have traditionally dominated the debate over elephant population management. A discussion of these topics, including translocation, contraception, and culling, will follow the policy section of this report. But various other options, although perhaps not as influential, still have the potential to affect elephant populations and enhance biodiversity. These include a laissez-faire, hands-off approach to management, allowing natural elephant population increases; a dedicated policy of land acquisition and park expansion; and the construction of elephant exclosures to protect disturbance-sensitive species.

7.14a Do-nothing (laissez-faire)

As well as activist approaches to the elephant problem, there always exists the possibility of continuing the current course and taking a 'do-nothing' or 'laissez-faire' approach. Since elephant culling was halted in 1994, KNP managers have taken such an approach to elephant management. Although contraception trials and small-scale translocations have continued throughout this period, active population management has largely ceased. Leaving nature alone to its own purposes, as in this method, has historically been seen as the proper way to manage a self-regulating natural environment.

Despite the romantic nature of this argument, however, it is clear that there have been negative biodiversity impacts in Kruger since the hands-off policy began in 1994. There is still debate over whether elephants are the primary cause of these impacts, but the general consensus is that a more directed approach is required. Perhaps in a completely non-anthropogenic environment this method could be used, but KNP's limited area and ecologically arbitrary fenced boundaries make this paradigm difficult to realize (see *Review* 1996). The experiences in Kenya's Amboseli National Park (see section 7.12a above) also suggest the unsuitability of a hands-off approach to elephant and biodiversity management.

7.14b Land acquisition

A frequently discussed alternative to elephant population control is the acquisition of additional property to expand existing reserves. This has been utilized in South Africa's Addo Elephant National Park (discussed in section 7.12b). This method is more complicated for KNP, however, because of its location along the borders of Mozambique and Zimbabwe. In addition, Kruger's importance as a tourist destination and employment opportunity has concentrated infrastructure at park entrances, making most land acquisition unfeasible for logistical and cost reasons. Funding for land acquisition has been proposed through the CITES framework but at this point has not been widely utilized as a funding source (RSA 11.20).

The Greater Limpopo Transfrontier Park (GLTP) and its development is akin to an acquisition of additional KNP land in some respects, especially if additional fencing is removed between KNP and Mozambique's Limpopo Park. Yet the apparent stability of elephant home ranges suggests that elephants may not readily migrate to these new areas without a stimulus. Increasing the size of KNP would most likely result in a short-term reduction in elephant impacts but would not prevent further elephant population increases and subsequent biodiversity effects.

7.14c Exclosures

Since many studies have suggested that elephant damage and herbivory are disrupting biodiversity and vegetation structure, a logical response would be to eliminate herbivore impact through exclosures. The easiest and most widely used method for realizing this goal would be through electric fencing. KNP has already used this technique for creating three fenced exclosures to maintain populations of roan antelope (Grant 2005). Evidence from these exclosures indicates that in the absence of large herbivores, larger classes of trees and shrubs predominate, perhaps greatly due to the absence of elephants. Research on elephant exclosures in Kenya's Amboseli National Park indicates that simple elephant exclosures consisting of single 2m-high electrified wires can substantially increase tree seedling recruitment when compared to elephant-dominated control areas (Western & Maitumo 2004).

The first step in using a system of enclosures to preserve KNP biodiversity from potential elephant impacts would be to analyze existing biodiversity survey data or conduct additional surveys to identify floral 'hotspots.' Concerns about the viability of enclosures include the need to conduct a proper biodiversity survey, the construction and maintenance costs of electrified fencing, and the challenges of how to best exclude elephants while 'including' other herbivores. The idea of creating botanical reserves as part of the proposed elephant management plan is conceptually similar to a physical exclosure—by keeping elephant numbers low, park managers intend to obtain results similar to complete elephant exclusion.

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7.2 Translocation

7.21 History of Translocation

Elephant populations in sub-Saharan Africa increased dramatically after the ban on poaching in 1989 and subsequently the ban on culling in 1994 (Wray 2004). Elephants are adaptable animals, with no natural enemies aside from humans, and the fact that humans have supplied them with unlimited resources and banned procedures that would limit their population has allowed for their tremendous growth (Bengis 1996). Africa's entire elephant population is currently estimated to be between 400,000 and 660,000, 80% of which is spread between Botswana and Zimbabwe (Du Toit 2004). The concentrated numbers of this species has subsequently led to habitat destruction by elephants and loss of biodiversity (IUCN 2003). In response to overpopulation, elephant translocations (movement of an individual or family from one place to another) began in the 1970s in South Africa (Hofmeyer 2004). At this point, technology restraints allowed only juvenile elephants (who's parents had been culled) to be moved (Hofmeyer 2004). Unfortunately, separating juveniles from their mothers created stress, and sometimes caused the juvenile's death (Hofmeyer 2004) (Table 1). Translocation became more acceptable in 1993, when Clem Coetzee developed a way to move family units of elephants in Zimbabwe, a method soon adopted by SAN Parks (Hofmeyer 2004). Moving complete family units increased the survival rates of translocated elephants, and in the last nine years over 750 elephants in family units have been translocated by Kruger National Park teams alone (Hofmeyer 2004).

7.22 Ideal Translocation Procedure

In order for translocation to be successful, (i.e. to promote viable, free living populations), it is important to follow strict measures before, during, and after the process has occurred. (See Fig. 1 for further detail). The process of translocation is expensive, so it is important to execute the process quickly and effectively. The three general stages of translocation are pre-translocation, the actual translocation process, and post-translocation.

7.22a Pre-Translocation Measures

During the pre-translocation process, the main objective is to monitor populations, considering the group's sex, age and structure, and to determine the most suitable individuals or family groups to be translocated (Dublin 2003). Monitoring is important to identify those individuals who must be translocated together to avoid breaking up the cow-calf family units (Dublin 2003). Budgeting, communicating with stakeholders such as people living in the vicinity of the release site, and ensuring that proper resources will be available in the release site occur in the pre-translocation stage as well (Dublin 2003).

7.22b Translocation- the Process

In the next stage, the actual translocation, experienced personnel (i.e. veterinarians) must be present to monitor the elephant's heart levels, body conditions, temperature, etc and to administer sedatives and immobilizers (Dublin 2003). As important as it is to move cows and calves together, bulls should be moved in isolation, to minimize aggressive behavior (Dublin 2003). Finally, the elephants should be released into a boma (a small holding camp, 1 to 2 hectares long) before being released into the reserve (Hofmeyer 2004).

Releasing the elephants into a boma first has been shown to reduce elephant stress levels and allows them to get accustomed to electric fencing (Dublin 2003).

7.22c Post-Translocation Measures

The final phase of translocation consists mainly of monitoring elephants for abnormal behavior such as crop raiding for up to a year (Dublin 2003).

7.23 Benefits and Success of Translocation

Translocation, if implemented with careful planning and sufficient funding may prove to be a viable, non-lethal alternative to culling. In the1970s, when translocation was in its infancy, only Kruger, Addo and Thembe National Parks had elephants (Garai 2004). Currently, fifty-eight reserves in sub-Saharan Africa have elephants, which are historically a big tourist attraction (Garai *et al.* 2004). For example, Angola, who had previously lost its elephant population because of years of civil war, now has the beginnings of a “Big 5” population (Dunn 2000). Translocation also offers the chance to resettle elephants in areas where they have not existed for decades (Butler 1995).

7.24 Obstacles of Translocation

Although the theory of translocation as a method that would reduce populations without culling is attractive, issues such as expense, difficult logistics of the procedure, human-elephant conflict, and the lack of demand and space available for the elephants all inhibit the possibility of translocation from being a viable option.

7.24a Expense

One of the biggest issues associated with translocation is the expense. For example, moving just four elephants in Uganda cost U.S. $100,000 (Nelson *et al.* 2003). The process of translocation is estimated at approximately R10,000 per elephant, not including transportation (Hoffmeyr 2003). Elephants are translocated in “Hannibal”, a truck which cost U.S. $140,000 to build (Njumbi 1996). If one considers that the elephant population of Kruger is growing at approximately 7% per year and that there are currently 11,500 elephants in the park, simply keeping the population stable would involve moving 800 elephants each year, at a total cost of R8,000,000 every year, without the guarantee of a successful process (Du Toit 2004). Moreover, Chobe National Park in Botswana, where the elephant population is estimated to be between 80,000 and 120,000, would need to move even more elephants to maintain a healthy population (Whyte 2005). Funding is available from non-profit animal rights groups, but this seems to be a large sum of money to spend to simply maintain a population at already unacceptable levels.

7.24b Failure Potential

Even if funds are raised and the elephants are translocated, there is no guarantee that the operation will be successful. Elephants tend to keep to their relatively large home ranges (which is approximately 880 km^2 for a Kruger Park elephant), and often attempt to return to the area from which they were moved (Du Toit 2004).

The fact that elephants can communicate over extremely long distances of 5-10 km, assists them in this process (Poole 1996). If the procedure fails, the expenses and planning of the translocation will have been in vain.

7.24c Elephant Stress and Mortality

Other problems associated with translocation are the stress animals experience upon capture and the possibility of death during the move (Butler 1995). For example, in the 1995 translocation of elephants from Mwea-Tsavo National Reserve in Kenya, 5 out of the 26 elephants died from stress related to the drugs they were administered (Njumbi 1996). There have also been cases in which the matriarch has broken through the electrified fence and has had to be shot and killed (Garai *et al.* 2004). Although studies have shown that moving entire family units as opposed to juveniles alone greatly increases the success of the procedure, it is often difficult to track and identify all of the individuals in a family (Whyte 2004). Elephants have extremely strong social bonds, and leaving a member of the family behind would likely cause great distress to that individual and the family being translocated (Whyte 2004).

7.24d Lack of Space and Demand for Elephants

The amount of space available to move elephants is quickly being depleted (Whyte 2004). Many of the parks who, at the early stages of translocation were interested in receiving elephants now have their own viable populations, and others, such as Limpopo National Park in Mozambique do not have room to take the massive amounts of elephants that Kruger would need to translocate to adequately reduce the population (Whyte 2004). After considering the issues facing translocation, it seems that this method would be most effective when used in combination with other options such as contraceptives and, as a last resort, culling (IUCN 2003).

7.25 Overcoming Translocation Obstacles

To make the translocation procedure as effective as possible, and overcome the obstacles associated with it, precautions to minimize stress and harm for the elephant must be taken. It is important to monitor the population to avoid translocating animals with a history of behavioral issues such as crop raiding, to never translocate female or juvenile elephants alone, and to carefully monitor the elephant populations before, during, and after the translocation process (Dublin 2003). It is also necessary to consider all funding options, particularly from animal rights organizations before eliminating translocation as a possibility. Organizations such as The International Fund for Animal Welfare paid $142,857 to fund the transportation costs for the translocation endeavor in Mwea-Tsavo National Reserve in Kenya, in 1995 (Butler 1995). With the help of organizations like the IFAW and Born Free, the population was effectively reduced by 44% in 1995 (Njumbi 1996). It is also worthwhile to gain the support of people living near release areas, as they are the potential victims of elephant misbehavior like crop raiding (Dublin 2003). Educating these people about the dangers associated with living in the vicinity of elephants, but also arming them with tools to combat these issues is extremely important. Options such as olfactory and auditory repellants (specifically oleo-resin capsicum which reduced the instance of bear attacks in the United States) may help people to confront elephants in an effective, non-violent manner, and perhaps gain their support for the translocation process (IUCN 2003).

7.26 CONCLUSION

The process of translocation has made vast improvements in transportation technology, planning measures, and in carrying out the actual translocation. However, after an extensive literary review, the consensus seems to be that translocation is a diversion of the problem of elephant overpopulation in sub-Saharan Africa, not a solution. Though several successful translocation procedures have occurred, translocation seems to be a short term solution, with a fairly high potential of failure. Additionally, when one considers the vast expenses that would need to be dedicated to simply maintain unacceptably high populations of elephants, it seems that the only way translocation may be effective is in combination with other techniques (IUCN 2003).

7.26a Suggestions for Further Studies

In reviewing the literature discussing translocation, there seemed to be several key areas that deserve further research. For example, post-monitoring procedures occur for approximately one year, and no long term monitoring of released elephants has occurred (Dublin, 2003). It seems that if translocation can be proven as an effective way to distribute elephant populations, then perhaps more funding would be allocated for the process. Additionally, Joyce Pool (1996) discussed in brief the issue of an elephant's ability to communicate over long distances and how this ability may help the elephant find its way home. A study determining whether there is a relationship between the distance of the release site from the elephant's home range and the tendency to return to that home range would help translocation teams to decide upon a proper distance between release site and original home range. Perhaps improvements in translocation that develop due to this further research may help it to become a more viable option.

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Appendix A: *Definitions*

(From Guidelines for the *in situ* Translocation of the African Elephant for Conservation Purposes)

Boma: A fenced-in enclosure where African elephants will be kept for the acclimatization period before release into the wild.

Cow-calf Group: A cohesive group of females and their calves led by the matriarch or another older female, which associate regularly and closely with one another over time. Individuals in these groups are believed to have a high degree of relatedness but this has not been established through known genetic identification techniques

In situ: Within the historical range of the African elephant

Release site: The geographical point at which elephants are released after translocation within appropriate habitat and range selected to support a viable population of the species over the long term.

Translocation: The deliberate movement of wild African elephants from one natural habitat to another for the purpose of their conservation and/or management at the source site, release site, or both.

Appendix B

Table 1: Mortalities of juvenile elephants in the early days of translocation for the years 1992-1994 (during this period only animals < 10 years old were moved). (Garai et al. 2004).

Size class	Elephants introduced (no.)	Deaths (no.)	Cause of death
2, 3	43	2	mothers stressed, calves died
2, 3, 4	31	5	4 unknown, 1 killed by other elephants
1, 2, 3	30	2	1 male unknown, 1 male resold, died after long trip
2, 3	26	4	1 pneumonia, 2 accident, 1 stress, cold and constipation
2, 3	17	1	stress, was alone
1	12	8	stress, malnutrition
3	12	1	overdose of M99
3, 1	10	1	smallest died of stress
3	8	2	1 bullied, 1 killed by rhino
1	8	1	killed by lightning
2	6	1	snakebite?
1	6	3	sand colic, stress, sold, malnutrition?
2	4	1	killed by lion
1	4	1	would not eat branches
1	3	3	stress, malnutrition?
1	3	3	salmonella
3	3	1	pneumonia and stress
Overall	226	40	17.7%

Size classes: 1= 1.20-1.34 m shoulder height; 2= 1.35-1.48 m; 3= 1.49-1.80 m; 4= 1.8-2.1 m

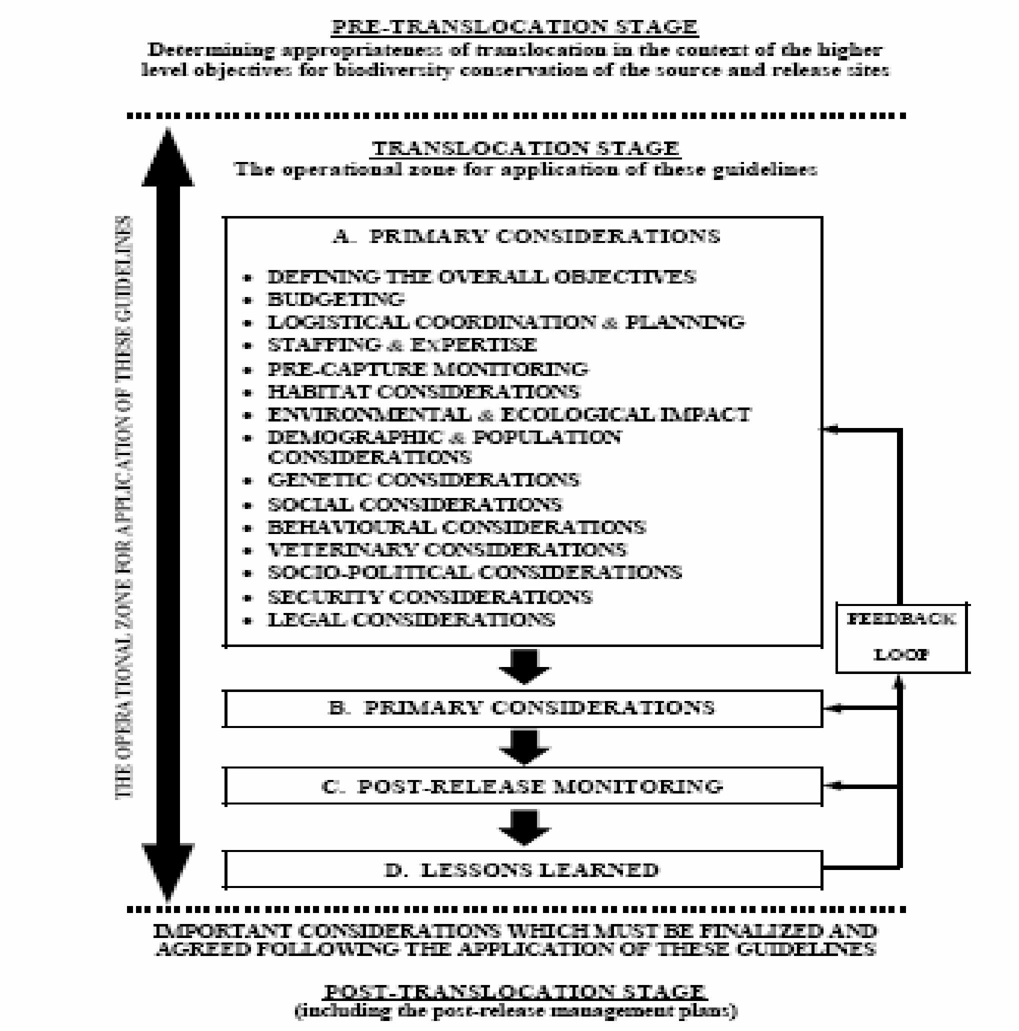

Figure 1: Condensed version of the Ideal Translocation Process (Dublin 2003).

This figure breaks down the specific procedure involved in an ideal translocation process into further detail than was discussed within the text.

7.3 Contraception

The use of contraceptives to reduce the birth rate of elephant populations and control their numbers is an attractive alternative to culling. Contraceptive methods not only avoid ending elephants' lives but also offer the possibility of reversibility (Whyte *et al.* 1998). Increasing the inter-calving period of elephant cows through contraception could control the population while still allowing for an increase in birth rates in the face of a drought or other threat to the species (Whyte *et al.* 1998). There are, however, obstacles that must be overcome in order for contraception to be a feasible method for controlling the large elephant population in Kruger.

7.31 Characteristics of an Effective Contraceptive

The use of contraceptives to control wildlife populations is a relatively recent phenomenon, considering the widespread use of contraceptives in humans. There are several types of contraceptives that target the reproductive system in slightly different ways. These include non-hormonal chemicals, steroid hormones, non-steroidal hormones and immunocontraceptives (Kirkpatrick & Rutberg 2001). There is a vast amount of literature on the use of contraceptives to control wildlife populations including, but not limited to, foxes, birds, rodents, kangaroos, deer and feral horses as well as elephants (please see the reference list for more information).

An ideal contraceptive has several characteristics, some specific to large herbivores like elephants, which must be met in order for it to be effective in the long run (Kirkpatrick 2004; Kirkpatrick & Rutberg 2001):

- Prevention of pregnancy in >90% of the individuals treated
- Deliverability by remote darting (oral, surgical or hand-injection administering are not feasible in the case of elephants because of the stress to the animals, the cost and the danger involved)
- Reversibility of the effects in the reproductive system enabling individuals to re-enter the breeding population
- Safe for pregnant animals and their fetuses in case a pregnant animal is accidentally vaccinated
- Inability of the agent to harm other animals or humans if ingested
- Limited effect on behavior and social organization
- No long-term general health effects
- Low cost

7.32 Female Contraceptives

7.32a Oestradiol-17β

Within the scope of this literature review, it appears that only two specific contraceptives have been tested on wild elephants. One of these was a steroid hormone, Oestradiol-17β, which acts by reducing or eliminating ovulation (Kirkpatrick & Rutberg 2001). Steroid hormones have been shown to have significant contraceptive value but also cause detrimental physical and behavioral side effects (Kirkpatrick & Rutberg 2001). In the case of wild elephants, the use of Oestradiol-17β was observed to cause behavioral changes that upset the social structure of the herd and made it dangerous for both cows and their calves (Whyte *et al.* 1998). A search for literature on the biological causes of these behavioral changes was inconclusive. Unless the side effects of steroid hormones can be overcome they are an unacceptable option for controlling wild elephant populations in Kruger National Park.

7.32b Porcine zona pellucida (pZP)

At this point it appears that porcine zona pellucida (pZP) is the most viable female contraception option for use in wild elephant populations. pZP is an immunocontraceptive, which induces an immune response that inhibits fertilization of the egg (Kirkpatrick & Rutberg 2001). The technique has been tested successfully on many species and has proven effective and safe. The criteria for an effective contraceptive, as outlined above, have been met for populations of wild horses and deer using pZP (Kirkpatrick *et al.* 1997). The vaccination has been tested to ensure that it does not travel through the food chain and does not appear to affect somatic tissue (Kirkpatrick & Rutberg 2001). Please see Appendix A and the Reference List for more information on the biological mechanisms of these contraceptive methods.

17.32c Trials in Kruger National Park

Trials to evaluate the effectiveness and viability of pZP as a contraceptive method to control elephant populations were conducted in Kruger National Park starting in 1996. Prior to these trials the contraceptives had been tested in the lab and on elephants in captivity and were shown to be effective and safe (Fayrer-Hosken *et al.* 1997, 1999). The pregnancy rate of the pZP treatment group was found to be significantly lower than the control group in both trials. The vaccination was also found to be safe for pregnant elephants and the effects were reversible after a full year of treatment. Please refer to Appendix B for a more detailed description of these trials.

7.32d Continued Trials in Private Reserves

A contraception program using pZP was started in 2000 in Makalali Game Reserve and is still being continued. The results thus far are encouraging. Of the cows originally vaccinated none have born any calves. The safety of the vaccination has been supported by the births of healthy calves by fourteen vaccinated cows. In addition, behavioral changes causing increased matings and presence of bulls have not been observed. Another program using pZP started in the Mabula Game Reserve within the last two years. To date there is not enough information to draw conclusions from the second program but the monitoring of both programs will continue to provide valuable information about the feasibility of pZP as a contraceptive in elephants (Delsink *et al.* 2002, 2004). Please see Appendix C for a more detailed description of these programs to date.

7.33 Obstacles and Solutions for the Use of Contraceptives in Kruger National Park

In order to increase the inter-calving period sufficiently (from between 3-9 years to an average of 12 years) to control the elephant population in Kruger National Park approximately 75% of all reproductively active females will need to be incorporated into a contraceptive program. At this point pZP requires a booster injection annually to sustain its effectiveness. In 1998 3,000 elephants were estimated to be sexually active, which means that contraceptives need to be administered to approximately 2,250 individuals in the first year of the program. Additional females that are reaching sexual maturity need to be added to that number each year. Consequently, it will take about eleven years to reach a zero populations growth rate and, by that time, about 4,000 female elephants will need to be included in the contraception program. These estimates are based on a population growth rate that does not take culling into consideration and assumes a consistent growth rate of 1.5% per year. A higher mortality rate would reduce the percentage of females to which contraceptives need to be administered (about 61% if the mortality rate was increased to 2.5%) (Whyte *et al.* 1998).

7.33a Logistics and Cost

The high number of elephants that will need to be vaccinated in an effective contraceptive program brings logistical and economic issues to the forefront of this discussion. In addition to the cost of helicopters and darts to deliver the vaccination, elephants currently need to be fitted with radio collars in order to locate them for booster vaccinations. The frequency of booster vaccinations is also a concern. At this point the contraceptive must be administered multiple times in the first year and then annually thereafter (Kirkpatrick 2004). The trials in Kruger along with other research have shown that the vaccination is effective but a contraceptive rate of >90% has not been confirmed through more extensive field tests. In addition, elephants require a dose of pZP ten times greater than that of deer or horses in order for it to be an effective contraceptive (Kirkpatrick & Rutberg 2001). Current production techniques of pZP from pig ovaries may not be able to provide enough vaccine annually for a park the size of Kruger (Kirkpatrick & Rutberg 2001). Both the frequency and sheer volume of the vaccination add to the cost of a contraceptive program. Neither the specific costs of contraceptives nor the specific logistical costs of a contraceptive program (such as the use of helicopters, delivery system, radio collars, etc.) could be found in published records to include in this literature review. However, experts on the subject expressed their concerns about the high costs and logistical complexity making a contraceptive program entirely impractical (Pimm & van Aarde 2001, Whyte *et al.* 1998).

7.33b Possible Solutions and Current Research

The cost of actually administering contraceptives will be reduced substantially once the methods have been successfully tested in wild elephants (Butler 1998). Research on the effectiveness of contraceptive methods is very expensive and logistically challenging, mainly because the elephants must be sedated in order to determine their pregnancy and health status. This requires not only expensive equipment but also the valuable time of veterinarians and other experts. Humane societies have had a role in providing funding for some of this research (Butler 1998) and may provide funding in the future. Continued research of pZP in elephant populations is underway and is important to first of all determine its long-term efficacy and reversibility as well as improve the vaccination and make it more cost effective.

Research to improve on the deliverability and practicality of animal contraceptives in general is currently underway. The development of a synthetic form of pZP, rather than extracting it from pig ovaries, would enable enough vaccine to be produced for a large elephant contraceptive program (Kirkpatrick & Rutberg 2001). According to Kirkpatrick (2004) there are two ways to improve upon the high frequency of the vaccination that is currently required. The first is to develop a vaccination that only needs to be given once in the first year, rather than multiple times, and then annually thereafter. A slow-release mechanism that can be administered once that is relatively effective for several years is another option (this has been tested with some success in horses). Research targeting both of these aspects is underway (Kirkpatrick & Rutberg 2001).

Eliminating the need for radio collars would significantly reduce the overall cost of a contraceptive program. Dart that both deliver the vaccination reliably and mark the vaccinated animal with a semi-permanent dye are manufactures. However, at this point the dyes only last for several weeks and darts are not yet available to identify vaccinated animals after a year or more (Kirkpatrick & Rutberg 2001).

7.34 Other Biological Alternatives to Culling

7.34a Sterilization

The sterilization of a few hundred female elephants just before their first pregnancy would produce the same reduction in the population as administering contraceptives to thousands of elephant cows. It is estimated that a zero percent growth rate could be reached by sterilizing 250 young female elephants each year. Sterilization removes elephants from the breeding population to produce a similar effect as culling, but without putting an end to elephant lives. However, there are ethical issues associated with sterilization as well as logistical, economic and medical dilemmas. (Whyte *et al.* 1998) The irreversibility of sterilization also makes elephant populations vulnerable to poaching, drought or disease (Whyte 2004).

The guidelines for a safe and useful sterilizing agent generally follow the guidelines for an ideal contraceptive in that it is easy to administer and that it not travel through the food chain. In addition it should have a consistently permanent effect and be applicable to both males and females. Gonadotropin-secreting cells have been noted for their potential as good targets for a sterilizing agent. Gonadotropin-releasing hormones (GnRH) have been used to reversibly suppress reproduction through this target (Nett *et al.* 2004) by causing a failure of follicle growth and ovulation in females and reduced testis function in males (Turkstra *et al.* 2004). Recent research has been done using a GnRH-PAP (pokeweed antiviral protein) conjugate that has the potential to permanently damage cells as to cause sterilization (Nett *et al.* 2004). The conjugate has been tested in several different mammal species and the development of immunosterilization techniques should be followed in the future.

7.34b Induced Abortion

Research has been done on compounds that will effectively cause abortion in injected animals. Like contraceptives such as pZP, these compounds would be delivered remotely by dart, which has been tested in deer already. Such a method would have to be administered annually and ethical issues associated with induced abortion will be similar to those of human abortion (Kirkpatrick & Rutberg 2001). At this point induced abortion does not look like a feasible population control method for elephants in Kruger. Please see the Reference List for further literature on induced abortion (Allen & Stout 2004).

7.34c Epididymal Contraception

Contraceptive methods that target the epididymis have the potential to cause infertility in male elephants. Research on such methods is quite limited compared to other contraceptives and the presence and structure of an epididymis in elephants is not known. In general, the epididymis is important to the production and transport of sperm. By targeting this aspect of the male reproductive system with immunocontraceptives the production of sperm could be altered or depressed. The development of such contraceptives is in its early stages but it is possible that in the future a slow-release vaccination could be available for use in elephants (Cooper & Yeung 2004).

7.34d Progestins

Medroxy-progesterone acetate (MPA) is a progestin that has the potential to act as an effective male contraceptive. MPA is cheap and its short-term effects on bull elephant behavior and reproduction have been studied. Scientists predict that a single dose of MPA would cause infertility in bull elephants for months. A further prediction is that a combination of hormones (androgen and oestrogen) and MPA would act as a contraceptive without causing any behavioral changes so that bulls can remain socially dominant in a herd. This is particularly useful to elephant population management because it has been shown that the presence of a dominant bull in a herd suppresses the sexual activity of younger males. If the older, larger bulls, which mate the most frequently, were targeted their reproduction would be reduced without allowing younger bulls to increase their reproduction. There is still much to be learned about the effects of progestins on elephants and studies both in captive settings and on wild African elephants have been suggested (Lincoln *et al.* 2004). Please see the Reference List for additional literature on the effects of older bulls on younger males (Rasmussen *et al.* 2002, Slotow *et al.* 2000).

7.35 Conclusion

Contraceptive methods can be effective in controlling elephant populations in the long-term but they do not provide a short-term solution (Colenbrander *et al.* 2004). Further research is vital to the development of more efficient and more cost effective contraceptive techniques. A combination of different contraceptive methods targeting both male and female elephants might be the most effective technique.

Suggestions for further research: (Colenbrander *et al.* 2004)

- Development of models to predict the effectiveness of contraceptives and other factors affecting elephant populations
- Continued research into the use of pZP as a contraceptive
- Research, testing and development of using GnRH as a sterilizer
- More research into contraceptives that target male elephants
- Public education about the benefits of contraception and how it works (Kirkpatrick 2004)

The most effective management program might include a combination of contraceptive and sterilization methods. Sterilization could be used primarily to decrease elephant populations while contraceptives could be used to maintain the reduced population. It appears, from the research done for this literature review, that South Africa is one of the world leaders in considering progressive contraceptive methods for elephant population control. It is probable that other countries will look to South Africa and the Kruger National Park for guidance and advice for managing their own elephant populations.

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Appendix A: Biological mechanisms of contraceptives in female elephants

- oestradiol-17β
  - Scientific background
  - Oestradiol is a female sex steroid (McMorran 2004)
- Steroid hormones act as contraceptives through a feedback mechanism that depresses gonadotropic hormones and thereby reduces or eliminates ovulation or effects the speed of ovulation (Kirkpatrick 2001)
- Positive attributes

        - Steroid hormones have shown significant contraceptive effects in many species including deer and wild horses (Kirkpatrick 2001)
    - Negative attributes
    - Free-roaming wildlife species require large amount of the compound, which makes easy delivery with a dart difficult (Kirkpatrick 2001)
    - Was found to cause long-term pathologies as well as behavioral changes in other species, including horses (Kirkpatrick 2001)
    - In elephants the steroid causes decreased lactation and therefore lower calf survival if the cow is still nursing young (Whyte *et al.* 1998)
    - Causes cows to be in sexual heat continuously and may suffer from being excluded from their family group and/or harassed by bulls (Whyte *et al.* 1998)
    - May cause cancerous growths as has been found in other species (Whyte *et al.* 1998)
    - Porcine zona pellucida (pZP)
        - Scientific background
        - The zona pellucida is a layer of proteins that surrounds mammalian egg cells (Barber 2000)
        - Porcine zona pellucida is obtained from pig ovaries and has been shown to be an effective contraceptive in many mammal species (Barber 2000)
        - When injected into the target animal pZP induces an immune response, which causes the production of antibodies that attack the zona pellucida layer. When the antibody level is high enough fertilization of the egg by sperm is inhibited (Barber & Fayrer-Hosken 2000a, Barlow 2000, Kirkpatrick 2001).
    - Positive attributes
        - Has proven effective in over a hundred mammals, including elephants and other herd animals (Kirkpatrick 2004)
        - Use has been monitored extensively in wild equids and white-tailed deer (Kirkpatrick et al 1997)
        - Can be administered to wild animals in the field without sedation by remote darting (Kirkpatrick 2004)

        - Immune response does not appear to affect other somatic tissue (Barber & Fayrer-Hosken 2000b)
        - Does not have side effects on other animals should they consume the contraceptive (Barber & Fayrer-Hosken 2000b)
    - Negative attributes
        - Dosage requirement is tens times that of deer or horses (Kirkpatrick 2001)
        - >90% effectiveness has yet to be proven in elephants
        - Reversibility is arguable (Whyte *et al.* 1998) and may cause permanent damage to ovarian function and infertility (Barber & Fayrer-Hosken 2000b, Whyte *et al.* 1998)
        - At this point pZP must be administered multiple times in the first year and then annually thereafter (Kirkpatrick 2004)

Appendix B: Trials of pZP in Kruger National Park

Trials of the effectiveness of pZP were conducted in Kruger National Park started in 1996 after the vaccination had been tested on captive elephants elsewhere. In the first trial, 41 adult female elephants were anesthetized and an ultrasound examination was performed to ensure that they were not pregnant. Twenty-one of the elephants were injected with the vaccine and fitted with a radio collar. Twenty other elephants, which were paired with treated elephants from the same family group, were given a placebo and tagged. Treated elephants were located and treated with two booster injections from a helicopter; the first after a six week interval followed by the second six months later. Twelve months after the initial treatment the elephants were located and tested again for pregnancy. Nineteen of the treated elephants were located, nine of which were pregnant (<50%). Eighteen of the placebo group were found, sixteen of which were pregnant (~89%). These results suggest that pZP is significantly effective as a contraceptive (χ^2, P=0.005). In addition, one of the treated elephants gave birth to a healthy calf with no side effects, confirming that the technique is effective (Fayrer-Hosken 2000).

In a second round of trials ten additional elephants were treated with pZP and given boosters two and four weeks after the initial vaccination. Two of these individuals were pregnant after ten months (20%), which was a significantly lower pregnancy rate than the control group (χ^2, P=0.001). No behavioral changes, as had been seen with the use of oestradiol-17β, were noted. PZP was also tested for reversibility by administering another vaccination to four of the original treatment group. All of the untreated cows that were monitored were able to conceive while none of the four treated elephants were pregnant after a year, although they were still cycling (Fayrer-Hosken 2000).

These trials were limited and included only a small fraction of the number of elephants that would need to be treated if contraception program was initiated in Kruger National Park. The results were also questioned by other experts because the pregnancy rate of the control group was unusually high and this may have exaggerated the effectiveness of the pZP treatment (Pimm & van Aarde 2001).

Appendix C: Current pZP Vaccination Programs

The program in Makalali Game Reserve started in May 2000. The total elephant population was 66, which included sixteen adult females and seven 9-12 year old females. The pZP vaccination was initially administered to eighteen cows by remote dart in a series of three shots, each three weeks apart. The following year, 2001, all of the cows in the original treatment group were given a booster vaccination and another two cows were introduced into the program and given the preliminary series of three shots. In 2002 all cows in the program were given another booster and three more cows were introduced into the program. In 2003 all of the cows were given a booster. Thus far no calves have been born to cows since they were incorporated into the vaccination program. Contraception has been confirmed in five cows because they have all exceeded the average inter-calving period of four years. Ultrasound examinations were performed on four other cows and they were confirmed to not be pregnant. Fourteen cows that were vaccinated while they were pregnant have given birth to normal, healthy calves.

The Mabula Game Reserve vaccination program is in its infancy but includes three adult cows and one younger female. No new pregnancies have been observed since the commencement of the program (Delsink *et al.* 2004).

7.4 Culling

Introduction

Elephant culling is a delicate subject, and must be viewed from as many angles as possible in the decision making process. The size and constitution of elephants, combined with their unique physiology, pose great challenges to their culling and utilization. In order to examine the feasibility and necessity of any management option, culling must be addressed gingerly but thoroughly, as it is not a subject that can tolerate a narrow scope of understanding. For this reason, I will here address some of the basic, principle issues that have come to the surface in the literature, so that a context might be established regarding this option. With regard to the scope of this review, primary divisions in the material are the actual methods used to cull elephants, the effects of those methods on populations, and the utilization of the animals. Within these divisions, primary subjects include selection, drugs vs. brain shooting, helicopter vs. ground, trophy hunting, population effects, animal utilization, green hunting and ivory trade.

7.41 Culling methods

7.41a Selection

Culling quotas are calculated from annual population growth rate, requiring that accurate information on elephant reproduction be available. In 1979 the Kruger park used a simple formula for deciding culling numbers. The maximum elephant production was estimated to be around 5.5%, then rounded to 6%, then multiplied by the current population (7715 in 1998), then added to 200, to arrive at 663 animals to be culled in 1979 (Information Section, 1979). Up until 1984, these quotas were determined for the whole of the park, but between 1984 and 1994 they were determined and enforced for only 1 of four sub districts within the park each year, in the interest of creating more patch heterogeneity.

7.41b Drugs vs. brain shooting

Several issues and conflicts of opinion arise around the issue of the actual operation. The central debate is that concerning the use of dart delivered drugs or brain shooting. Up until 1994 the Kruger park used scoline (succinylcholine) (see appendix A) as its primary immobilizing agent, even though it was shown to have inhumane effects if used as the primary killing mechanism (Hattingh *et Al.* 1984a; 1984b; 1990a; 1990b; Whyte *et al.* 1999). Scoline was the only drug used because it breaks down quickly in the body tissues (Pitts 2000, Thompson 2003) allowing for the meat to be later consumed. An immense benefit to using darts is that the animal can be hit anywhere on the body surface, instead of only in the relatively small braincase. This makes the use of the helicopter much more feasible, as the shooter's target is now several orders of magnitude larger, making the operation faster, more efficient, and much less stressful for the animals while still maintaining the safety of personnel. Some work has been done on different drug combinations in culling, though the scope is limited. The addition of Hexamethonium to the cocktail reduces the chemical stress factors in culled animals (Hattingh *et al.* 1990b), but more work must be done on alternative drugs in light of pharmaceutical advancements since the cessation of culling operations.

7.41c Helicopter vs. ground

Helicopter use was not unanimously used in culling operations. Thompson (2003), leader of the culling unit that eliminated 2500 animals from the Gona-rezhou in the 1970's, speaks highly of the efficiency of the simpler, cheaper ground method. In his book, A Game Warden's Report, he describes 3 highly experienced and skilled ground shooters moving in on a group of elephants from downwind until detected. He estimates that the shooters could come within 10 meters of the targets, and within one to one and a half minutes could kill up to 40 individuals utilizing brain shot (see appendix B). This method has obvious advantages for cost efficiency as well as reducing animal stress. He also mentions that he had the opportunity of using a helicopter for these operations and found that the elephants natural of fear of helicopters resulted in the scattering of the animals over a large area, making the processing of the animals much more difficult. The obvious disadvantage of this method is that the ground crew comes in very close proximity to the stressed animals, putting them in harm's way.

7.41d Trophy hunting

One issue that occasionally appears in the issue of culling is the possibility of letting trophy hunters pay to kill rather than the government spending money to do the same job. Though at first an attractive concept, the aims of trophy hunters and the discriminatory nature of their kills preclude them from the ecological aims of government culls. Resource Africa asserts that trophy hunters selectively hunt older individuals that contribute little to the productivity of the general population and that the specific criterion of sport hunters (weight of tusks, length of horns, body size etc.) results in very low trophy off-take quotas in order to keep the trophy quality high, meaning that off-takes are well below the maximum sustainable yield for the species (see appendix C) (Resource Africa no 10). Tom Pilgram *et al.* (1984) through analysis of tusks in warehouses in Hong Kong, found that the trends indicate selective hunting of male elephants of middle age. Because this conflicts with the Kruger paradigm of targeting entire groups representing all sex and age classes, trophy hunters seem to be in invalid option for management. Williams *et al.*(2001), however, assert that trophy hunters can serve as an effective population control, especially when contrasted to poachers.

7.42 Population effects

One subject of interest that has not been studied in great detail is the actual effect of culling on elephant populations. One paper modeled survivorship of elephant populations with regard to habitat size and culling dynamics in Tsavo park in Kenya, finding that for each size class of park the probability of extinction decreased over a thousand years for increasing culling percentage of carrying capacity (Armbruster *et al* 1993). Interestingly the model also found that the maximum yield was achieved at 20% of carrying capacity at an area of 4000 mi^2 (see appendix D). Data from the period of culling in Kruger between 1984 and 1994 has also proven insightful, as demonstrated by Aarde *et al.* (1999). Data from this period in which elephants were culled in four distinct zones within the park shows that not all culls were necessary, as high densities tended to decrease on their own without culling in many instances, and goes further to establish an equilibrium density value in the park at .374 ele/km2. The effects of culling on elephant population requires more research, especially in light of the major shifts in ecological paradigms, and the proposed Kruger park management plan should provide ample opportunity for such research.

7.43 Animal utilization

7.43a Processing

An unavoidable question with regard to culling is the question of the animal use. The intense poaching of elephant populations in the 1980's stands testament to the value of the elephant's parts. Resource Africa estimates that from 40 culled individuals the total revenue from ivory, hide and meat rises to $88,400 dollars US (see appendix E) (Resource Africa no. 12). The process of utilization is tied to the matter of the culling itself. The Kruger park was highly efficient at processing due to the construction of the processing facility at Skukuza (Information Section 1979). In Zimbabwe they were forced to process the animals in the field, after taking scientific measurements and records, before returning to a small bush camp for final processing (Thompson 2003). This restricted the culling to the dry season to avoid spoiling and to facilitate the drying of the meat and hides. One possibility for the utilization for the animals is that of local use and ownership. Zimbabwe has had a great deal of success with its CAMPFIRE programs (Devender 2000) and a similar resource-sharing program could be explored in South Africa as well. Economists attribute a great deal of the conservation success that the elephant has enjoyed in recent years to the distributing of private ownership (Alessi 2004), alluding to the possibility of privatizing certain populations of Kruger elephants and allowing local communities to benefit from their utilization, as well as potentially decreasing poaching.

7.43b Green hunting

A periphery subject along the lines of utilization is that of green hunting. Though not specifically a culling method, Green hunting allows for profitable utilization of animals with a nearly infinite sustainable yield because animals can be "hunted" up to twice a year and are theoretically never removed from the population (goafrica.about.com). Proponents claim the hunt is just as rewarding as a true hunt while costing only a quarter as much at $10,000 per elephant (www.save-the-elephants.org), comparing the experience to catch and release deep-sea fishing.

7.43c Ivory trade

The aspect of utilization brings up the delicate issue of ivory trade and ties into the morals and government responsibilities. Gillison *et al.* (2003) argue that proposals of southern African governments to down list to CITES II is an indication that their culling operations are and were economically driven rather than ecologically driven. They go further to say that culling regimes go against modern ecological paradigms in their effort to maintain elephant populations at a given carrying capacity instead of a natural flux, and that attempts to maintain carrying capacity are thinly veiled attempts to maintain a maximum sustainable yield of elephants, and therefore ivory, for economic purposes. Rolfes (1997), on the other hand, claims that the best way to ensure protection of a species is through intensive field protection, revenues for which can best be generated through trade in that species' parts. Rolfes uses the example of the successful management of the white rhino to demonstrate that by utilizing the market for live animals and animal parts, enough revenue can be generated to maintain the intensive field protection necessary to preserve the species. Another interesting facet of the debate involves South Africa's history in the illegal ivory trade and the connection to the military. Ellis (1994) describes the disreputable history of South Africa as a smuggling center for ivory. Though these issues are of purely historical relevance they do bring into account the unfortunate position of South Africa's reputation and the potential of any attempts to trade in ivory from culled elephants to be misconstrued as a return to old habits.

7.44 Thoughts

(of the contriutor)

If any Kruger park culling regime is to be re-instated, the techniques that are formalized and approved must be efficient and humane, preserving biodiversity and the future of elephants as well as the safety of personnel. The old methods reflect old technology and ideas, and must be updated to incorporate new technology. Neither brain shooting nor scoline seem satisfactory, as both require either great stress to the animal or danger to personnel. The best option on these grounds would be to use another, more humane drug, such as M99 (etorphine), even if its use precludes the consumption of the meat. Since the decision to cull is made independent of economic prospects anyway, such a sacrifice should not be too great. Any gesture putting the well being of the elephant over the potential for use would also help assay the fears of anti-culling groups.

Another issue that must be addressed is the feasibility of the culling scheme in the proposed management plan. One potential problem is that in the new plan, the culling is concentrated at the far north and far south, maximizing the distance the animals must be taken to any central location for processing. If such operations are going to be carried out in the hot, wet summer, and the meat is processed and used, a second processing facility might be required.

Regardless of the actions taken, great care must be taken to learn from all activities. Effects of culling, direct or indirect, must be closely monitored and studied, to ensure that all objectives of the program are met and maintained.

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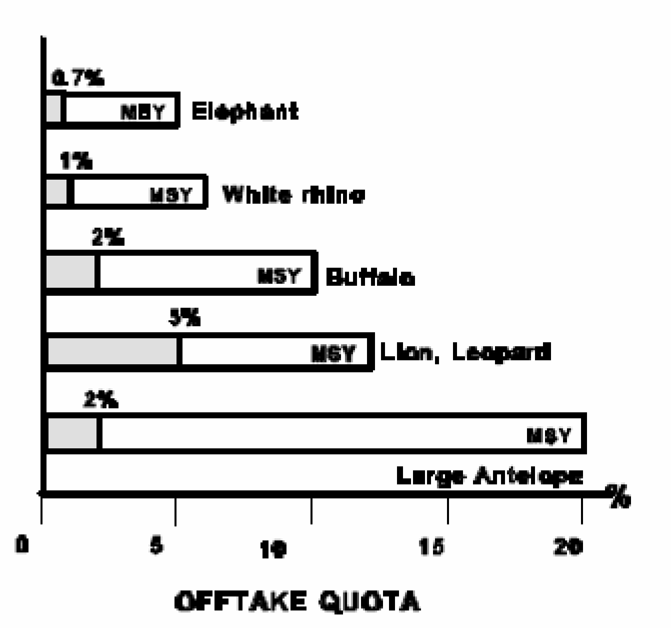
Appendix A: ***Scoline***

Succinylcholine is a short-acting, depolarizing neuromuscular blocking agent that is used extensively in anaesthesia (Pitts *et al.* 2000). The inhumane aspect of scoline is in that it paralyses the diaphragm well before the cardiac muscles, and has little or no effect on the consciousness of the animal, resulting in a slow death through suffocation in elephants (Whyte *et al*. 1999; Pitts *et al.* 2002).

Appendix B: ***Zimbabwe method***

1. A small spotter plane, flying high enough not to disturb the elephants, locates a group of elephants and radios the location back to the ground hunters.
2. The ground hunters, 3 in number, approach from downwind to as close as they can to the group without being spotted. Once they start shooting, the author claims that they can kill as many as 30-40 individuals in 2 minutes, especially if it's a group of cows and calves- bull herds scatter at the first shot while cow herds stick together protectively.
3. Once the animals are dead they are labeled by group and number, scientific data are recorded, the animals are butchered in the field and then the meat, hides, and ivory are taken back to the bush camp for processing.
4. The author estimates that an efficient team can average up to 50 elephants a day using this method, and says that helicopters are not nearly as efficient because they cause the animals to scatter. He also does not mention any extermination method other than brain shooting as being employed by Zimbabwe.

Appendix C: ***Trophy take as percentage of Maximum Sustainable Yield (MSY)*** (Resource Africa no. 10)



Appendix D: ***Affect of culling on extinction probability and average yield in modeled populations.*** (Aarde *et al.* 1999)

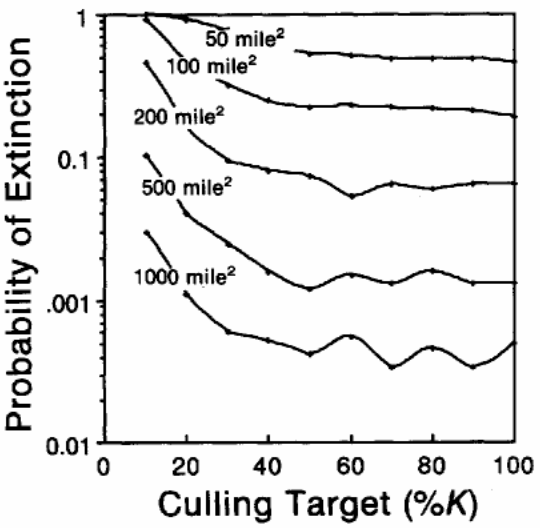


Figure 4. Log of probability of population extinction over 1000 years for six habitat areas as a function of the percentage of carrying capacity (%K) to which age-independent culling reduces the population.

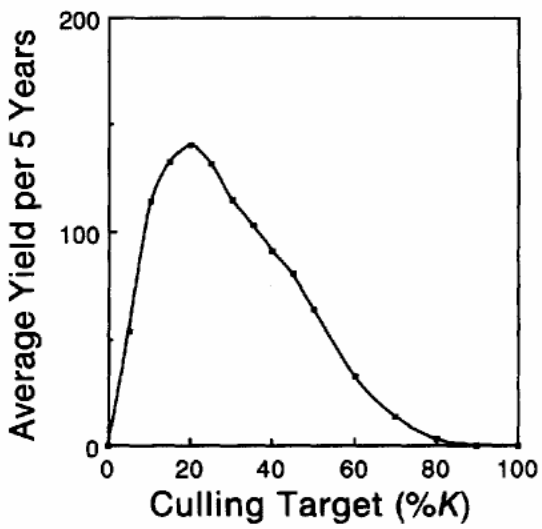


Figure 5. Average equilibrium yield per five-year interval over a 10,000 year period as a function of the percentage of carrying capacity (%K) to which age-independent culling reduces the population.

Appendix E: ***Elephant value fact table*** (Resource Africa no. 12)

Table 1: Potential Sustainable Returns from 1,000 Elephant						
Management Activity	**% of Pop**	**No.**	**Item**	**Weight kg.**	**Unit Value US$**	**TOTAL US$**
Sport hunting	0.7	7	Fees		25,000	175,000
			Meat	1,000	1	7,000
Culling	4.0	40	Ivory	6	250	60,000
			Skin	70	3	8,400
			Meat	500	1	20,000
Problem Animal Control	0.3	3	Ivory	30	400	36,000
			Skin	120	3	1,080
			Meat	800	1	2,400
Natural (m)	0.2	2	Ivory	50	500	50,000
Mortality (f)	0.4	4	Ivory	15	300	18,000

7.5 Ethics and Values

7.51 Introduction

The issue of elephant management in Kruger National Park encompasses not only scientific debate, but also numerous ethical and moral dilemmas. Many individuals and organizations have voiced opinions about what should be done with the elephant populations in KNP. Here we outline the main arguments that have been made for and against the possible elephant management options: no action, contraception, translocation and culling. We do not suggest that one line of reasoning is better than any other, but present as many views as possible so that each option's ethical implications can be understood.

When discussing the morality of any wildlife management there are a few basic ethics that guide decisions:

- Individual biases are based on human values
- Humans alone are capable of developing and exercising management policies.
- Humans are the only species capable of moral judgment and decision making. This does not necessarily imply human superiority.
- Intrinsic value is not a non-anthropocentric concept. Intrinsic value exists because it exists within human reason and values (Fakir 2004)

7.52 Ethical Issues surrounding possible control methods

7.52a No Action

Since 1994, Kruger has abided by a moratorium on culling due, in large part, to ethical concerns raised by animal rights groups. This moratorium, established to allow for a review of elephant policy, has effectively resulted in the adoption of a policy of no action. In the years since KNP's last cull, the elephant population has expanded to its highest historical level (Whyte, Aarde, and Pimm 2003). The decision to take no action still has ethical implications. High elephant densities may further stress rare species that depend on the park's ecological health. Thus, policy makers must consider the broader ethical repercussions of elephant management strategies that affect other animals. All decisions, including one of no action involve the balancing of difficult tradeoffs. (For more information, please see the chapters on vegetation and biodiversity).

7.52b Contraception

Contraception has been proposed by animal rights activists as a more ethically sound alternative to culling. Ideally, contraception would stabilize the elephant population and avoid the need to cull elephants. In a paper associated with the Fifth International Symposium on Fertility Control in Wildlife in 2001, Priscilla Cohn argues that if elephant numbers must be reduced or controlled, ethics demand contraception be used over culling (see arguments against culling below). However, the potential for contraception to alter elephant social structures has raised concerns about its implementation (Grandy and Rutberg 2001) (see behavior chapter for more information regarding social structures). Others criticize the high costs and logistics as unreasonable obstacles.

In addition, there are moral issues surrounding the proposed techniques of sterilization and induced abortions (see contraception section on sterilization and induced abortions). Is sterilizing a group of adult female elephants and letting them die during a drought years later different than culling them now? More importantly, is it more or less morally justifiable? Induced abortions are an ethically debatable issue in humans, let alone elephants. Is aborting a fetus morally different than culling it after it has been born? Furthermore, is it morally justifiable to induce an abortion in an elephant that is not capable of willing it otherwise? (For more information about fertility control in elephants as a management option, see the contraception section of this chapter).

7.52c Translocation

Technological advances have made the translocation of elephants a more humane and ethically attractive alternative to culling. However, major ethical considerations still encumber the implementation of translocation. Because elephants populations located within protected areas are likely to double every ten years (Whyte 2001, Woodd 1999 as cited in Whyte, Aarde, and Pimm 2003), translocation, at best, can only provide a temporary solution. Additionally, the high cost and lack of demand for elephants from Kruger Park make translocation unrealistic as a complete solution. Translocation can increase pressure on communities living near national parks and can result in higher incidence of human-elephant conflicts. Any decisions made about translocation must consider the ethical ramifications of weighing human and elephant needs (see translocation section of this chapter for more information on translocation and human-elephant conflicts that result).

7.52d Culling

Culling, cropping, or killing elephants as a means of population control is the most emotionally charged management option. Even the wording of the practice can be morally confusing. Biologists avoid using the word ‘killing’ to describe elephant population control because it is blunt and seems too inhumane. They are also reluctant to use the word ‘cropping’ because it carries connotations of profiting from killing elephants. Even ‘culling’, the term accepted throughout management literature, can imply the removal of undesirable features of populations through selective killing, a notion that does not reflect actual culling practices (Bengis 84). Ultimately, managers must weigh the realities of elephant policies within an ethical framework.

The rule of necessity states that the culling of elephants may be morally justifiable if no viable alternative exists. In KNP, is the culling of elephants acceptable based on necessity? Some groups contend that the rule of necessity cannot be employed ethically without further research into more morally sound options (e.g. translocation). However, others counter that the length of time needed to develop morally sound alternatives to culling could engender more serious ethical setbacks. Because no universal definition of necessity exists, eventually someone needs to define exactly what is necessary and take action (Fakir 2004).

Historically, the issue of culling was dominated by the controversy of sustainable use (see appendix A Part 1 for a more detailed description of the sustainable use paradigm). If culling is viewed strictly as a method to resolve a potential ecological crisis, then culling is principally a conservation issue and the sustainable use paradigm is not relevant. However, when ecological concerns converge with socio-economic benefits and commercial interests, sustainable use as a principle becomes a topic of moral concern. Hunting and the creation of elephant byproducts promote markets that depend on killing elephants. If these markets could benefit communities, does one allow culled elephants to be used in this way? Can we ethically endorse a plan that is created to solve an ecological issue but incorporates exploitable methods? Such human interest issues that the sustainable use paradigm was not originally designed to accommodate have complicated ethical assessments (Fakir 2004).

In more recent years, the sustainable use dilemma has been joined by the predicament imposed by animal rightists. In general, animal rightists are against culling because they find it ethically wrong to kill elephants. However, individuals and groups hold views that span the gamut from welfare-nuanced outlooks to beliefs in irrefutable rights based on the intrinsic value of elephants (Justice for Animals), (Fakir 2004). (For more specific arguments presented by the animal rights community see appendix B).

7.53 Conclusion

After researching the ethical issues surrounding elephant management, we have a better appreciation for the sensitivity and dedication that various groups have brought to this complex issue. However, it is not the place of managers to determine whether or not killing elephants is morally justifiable. No individual can argue with certainty that one set of ethics is more important than any other. Who is to say that the values of a manager who supports culling are superior to those of an animal rights activist who will not ultimately decide the fate of Kruger's elephants? We applaud KNP for reviewing multiple viewpoints and for striving to build better understanding among conflicting interests. However, the time has come for a comprehensive management plan.

Thus, KNP must develop a policy based on practicality and available scientific knowledge. We believe that there is sufficient scientific research indicating that the risks of doing nothing outweigh the ethical implications of culling. KNP, with a mandate to conserve the biodiversity within its borders, must take action to ensure that the elephant populations do not cause irreparable damage to the park's ecosystems. The review of options available for elephant population management presented in this chapter suggests that culling is ethically and practically the only viable option. KNP is in the difficult situation of weighing the worth of intelligent and charismatic animals with the value of overall biodiversity within its borders. Although we respect the magnificence of elephants, we do not think that managers can ethically prioritize the lives of elephants above the lives of other animals, especially animals that are already at risk of extinction. Culling is not a pleasant option, but it is the best option available. Culling should be introduced and should be accompanied by continued research into the potential for contraception.

We support the use of the strategic adaptive management plan that involves impact zonation and has room for the incorporation and development of alternatives such as contraception, translocation, and new options as they become available.

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Appendix A: Sustainable Use Paradigm

The sustainable use paradigm was originally devised to solve a practical problem in a pragmatic manner. When the sustainable use paradigm was first conceived, taking a puritanical conservationist stance on the issue of elephant culling would not have been morally accepted. To suggest to people who had no alternative sources of income that they could not derive benefits from culling would be unjustifiable. That's to say, SANParks could not justify killing elephants and not using the byproducts while it was illegal for people around the park were considered criminals for killing elephants in attempt to survive. Thus, if SANParks were to cull elephants and if the consequences of people not having access to the possible socio-economic benefits would lead to further hardship, poverty and destitution, SANParks could not justify culling. Ultimately, the sustainable use paradigm dictates that is immoral to create possible products from the manipulation of nature (in this case culling elephants) and not reap some kind of socio-economic benefit while people who need those socio-economic benefits exist.

Appendix B: Animal Rights

1. Elephant Voices, based in Kenya, has proposed that an Elephant's Bill of Rights be developed and implemented, based on the documented rights for Great Apes that have been accepted by some

countries. This would afford elephants greater protection against culling. As behaviorist Joyce Poole notes, "If a continuum exists between us and other creatures in terms of anatomy, physiology, social behavior and intelligence, it follows that there should be a continuum of moral standards."

2. Animal welfarists are not necessarily concerned with granting animals equality with humans. On the other hand, they are inclined to make sure any situation in which animals are to be exploited is as humane as is practical or does not cause unnecessary cruelty or death. They accept the possibility that some level of inhumane actions must be taken to ensure an overall more human world. Most animal welfarists are in favor of some kind of culling practices because they support the school of thought that killing a few in order to save the majority (including elephants and other species) is morally justifiable (Fakir 2004).

3. Some people hold a non-speciesist viewpoint. This view is about recognising the inherent value of each animal (JA website). They argue that humans can only treat animals differently than other humans if they can find relevant differences between animals and humans. It is obvious there are differences between humans and other animals, but there are also differences among humans (gender, race, age, etc.). Where should the line of relevancy be drawn when deciding whether it is ethically acceptable to kill? Darwin showed that humans are only different from other animals as much as other animals are different from each other, thus cannot claim intrinsic superiority that would justify a separate set of moral values for people and for animals. Thus, there is no justification for not including non-human animals in the moral community (Cohn 2001).

4. Animal rights groups such as Justice for Animals and Xwe African Wild Life are strongly opposed to the re-opening of culling practices. In a press advisory released in October 2004, the two groups announced that, "[they] have joined forces to oppose the reintroduction of 'culling' on ethical and ecological grounds and they have the support of a number of prominent animal welfare and animal rights organizations across the globe." They are not satisfied with the scientific research SANParks has presented that supports that the high numbers of elephants in the park are having an unnaturally destructive effect on the environment. Not only do they feel that there is not enough science to back up culling, but also that consumer lobbies are effectively pressuring SANParks into reopening culling so that elephant product markets (including ivory and trophy hunting) can be revived. Furthermore, they believe that culling is wrong because, "Extensive research has shown that elephants are highly evolved, intelligent animals with complex social and emotional lives. Killing them as part of a management plan is both cruel and unethical." (See chapter on elephant behaviour for more information on social and emotional characteristics of elephants.)

5. Taken from the Justice for Animals Website (http://www.justiceforanimals.co.za/frame.html):

6. "JA, formerly known as Front for Animal Liberation and Conservation of Nature (FALCON), was established in1985 as the first animal rights organization in South Africa, and has since also adopted the cause of ethical conservation. It is a registered nonprofit organization with active branches in the Johannesburg-Pretoria area, Durban, Pietermaritzburg, Grahamstown and Cape Town and operates under the guidance of a management committee, democratically elected by its members.

“Animal rights” is about recognizing the inherent value of each animal and campaigning for its right to be treated with respect – in other words not to be considered as property and as a means to an end. When, amongst other things, we cage animals for our pleasure or convenience, breed, raise kill them so we can eat or wear them, hunt them for trophy, fun or profit, use them in biomedical research (vivisection) or destroy their habitat, we ignore their inherent value and fail to treat them with the respect that is their due - we deny them their basic rights.

Animals do not exist for us - they are not our property - and must not be considered as a means to our ends. It is the goal of the animal rights movement to effect meaningful change in human attitude towards animals so that this change in attitude translates into real benefits for animals, both wild and domestic.

JA seeks to show that animals have rights which should be respected and which cannot logically be denied. These rights are founded on the same moral principle as that upon which basic human rights are founded - namely, that individual animals, like individual humans, have inherent value which is deserving of a respect which cannot be ignored or dismissed by humans who seek to exploit animals for fun, food, profit, glory, political expedience or cultural or religious purposes…

Our ethical conservation philosophy stands in direct opposition to the ‘sustainable-use’ movement (also known as the “wise-use” movement). This movement, which is fanatically anti-animal rights, consists of individuals, organizations, institutions and government bodies who believe that wild animals, in particular, are a resource which exists for people and should be exploited for profit, food, recreation, research and so-called cultural purposes. This ‘movement’ supports and actively promotes sport and trophy hunting, trade in live and dead wild animals, imprisonment and exploitation of wild animals in zoos and circuses, as well as the commercial farming of wild animals as a source of food, leather, etc. This “movement’ erroneously believes that if wild animals do not have a commercial value, their lives are worthless, they will be hunted and poached into extinction and the land they currently occupy will be taken over for agriculture and other environmentally unfriendly uses.”