Considering more than elephants

Michelle. D. Henley (Ph.D)
Save the Elephants Transboundary Project, South Africa.

Abstract
There is an urgent need for specific long-term research aimed at addressing the interaction between elephants and water points, the effect of other ungulates on the regeneration of woodlands and the overall influence of abiotic factors such as climate change and fire, all of which have a major influence on savannah-ecosystem dynamics. There is a need to look at alternative methods of monitoring and managing the population in keeping with current ecological thinking that steers away from absolute numbers. Culling as a management action intended to conserve biodiversity would be premature, excessive and too simplistic an approach to address the complexity inherent in biodiversity change. It focuses attention on a single species as the sole manipulator of what are essentially multifaceted ecological processes. In so doing it draws attention away from the urgent need to develop an understanding of the broader processes and creates the false impression that appropriate proactive management is being applied.

Introduction
Elephants are charismatic species and the dilemma of controlling elephant populations often evokes public sentiment. Repeatedly public spokespeople, government officials and management agency employees find themselves embroiled in dialogue concerned with the management of elephants which drifts away from being anchored in scientific evidence. For this reason the effect of elephants on biodiversity has recently received considerable attention by the scientific community. As South African National Parks' (SANParks) primary objective involves conserving biodiversity, which can only be assessed in terms of scientific criteria (1), scientists were called upon to partake in the elephant debate. This lead to a large body of work which reflects our current knowledge and understanding of elephants and their effects on biodiversity. Here, I review the submissions that were made to the scientific workshop held in Luiperdskloof in March 2005 and highlight the gaps between publicly recommended management actions and existing scientific evidence. The objectives of this paper are, first, to critically evaluate the justification behind the implementation of the elephant management policy; and second, to discuss the management options that are available. The eight management options, as set out in the summary document (2) are listed although some options may not be practical or desirable. For this reason the original eight options have been narrowed down to six where overlap has occurred and the options have also been arranged

according to their favourability of application in view of proposing more sensitive and workable ways of manipulating elephant densities to achieve desired outcomes. Contraception and translocation as management options are merely listed as these topics are dealt with in sufficient detail in other submissions that have been made (3, 4, 5, 6, 7, 8, 9).

Critique of justification used to implement the elephant management policy

1) The precautionary principle

The precautionary principle originated in Germany as the *Voorsorgenprinzip* in about 1965 and has been quoted as the need to 'control inputs even before a causal link has been established by absolutely clear scientific evidence'. This principle, therefore, calls for action before harm has been shown. To fully embrace such a principle would mean that no measure of how much caution or how much harm has been done, would be required (10). In many ways this approach therefore negates the need for rigorous scientific testing of particular outcomes. Precaution as a management tool remains contentious, especially when used within restrictive, "protectionist" conservation approaches (11). Furthermore, the precautionary principle has been described as a value judgement suitable for poor data situations whilst opportunities for modelling exercises would be far more effective in any adaptive management strategy (2)

2) Carrying capacity: a popular misconception

Historically the objective of elephant culling in the Kruger National Park was to maintain a stable population density of one elephant per square mile (0.4 elephants/km^2). This was the prevailing policy between 1967 and 1994 (12). While the concept of a static carrying capacity within a dynamic environment has no scientific basis (13, 14), the idea that Kruger National Park (KNP) can only support a population of 7 000 elephants has nevertheless become deeply entrenched within the minds of the general public. The current population of 11 454 (I.J. Whyte pers. comm.) is generally viewed as an overpopulation and in itself the primary reason to control elephant numbers. The majority of media reports reinforce these perceptions. There is reason for concern about the ineffective means by which the refined KNP elephant management policy has been conveyed to the broader public through the media. If the public is to participate in the debate then the management of elephants can not be based on a perceived over-population fed by a uniformed press. We need to carefully choose our words when dealing with the public and avoid utterances using conclusive or definitive statements that have not been scientifically validated. These include statements such as 'There **is** an overpopulation of elephants' or 'Elephants **have** exceeded their carrying capacity'. The majority of scientists do not agree with these perceptions, while only 19% of media releases dealing specifically with the culling debate leading up to the workshop, have avoided this pitfall (Table 1). The revised KNP elephant management policy (15) has moved beyond absolute numbers and rather focuses on attempting to maintain the processes that uphold ecosystems. It is important that this refinement to the policy be conveyed clearly to the broader public so that the current situation, and projections into the future, may be evaluated rationally.

3) Fence-line contrasts

The roan enclosure (N'waxitshumbe exclosure), in the northern basaltic region of the KNP, has been used retrospectively as an exclusion plot to measure the effect of elephant impact and other herbivores on marulas (*Sclerocarya birrea*) (16). Other than roan (*Hippotragus equines*), a few grey duiker (*Sylvicapra grimmia*) and steenbok (*Raphicus campestris*) large herbivores, including elephants have been excluded from the enclosure. The enclosure was erected in 1967; the same year the culling programme was implemented in the KNP. Results show that within this enclosure high densities of marulas, including mature trees, occur while no mature trees are found within the surrounding landscape. The results therefore verify that elephants may have an impact on the mature canopy of specific tree species within particular vegetation types. However, a number of important points have been overlooked:

- Although the fire frequency within and outside the enclosure was similar, the fire intensity within the enclosure was less as fires within the enclosure were lit under carefully selected weather conditions (as cited by 17). The high density of younger trees found within the enclosure when compared to the surrounding landscape, could be indicative of trees that are escaping a 'fire-trap' (18). Conditions within the enclosure have favoured recruitment of marula trees into older age classes.
- As none of the mammals within the enclosure were exclusively browsers, none of the marulas within the enclosure showed signs of browsing (19). The surrounding landscape is however occupied by a whole suite of potential browsers, including impala which are known to 'predate' heavily on young seedlings (20, 21, 22). The lack of recruitment of trees into older age classes could therefore possibly be ascribed to age-specific herbivory by ungulates other than elephants.
- Tall trees that were present within the roan enclosure at the time of its erection have also disappeared in the absence of elephant. Other environmental factors, such as climate may therefore be driving both tree size and abundance (23). The lack of a relationship between the density of elephants and the proportion of trees that have died over a 26yr period throughout the park (24) as well as Hofmeyr's (25) findings that few trees are directly killed by elephants, corroborate the suggestion that even though elephants are utilising mature trees no direct blame can be attributed to elephant impact (24).
- The culling programme did not prevent the disappearance of mature marula trees from this landscape even though the enclosure was erected at the very time that culling was started in KNP. Owen-Smith (26) makes the important observation that elephants will still have an impact on their favoured plant species, even at low densities. Pellew (27) found that mature umbrella thorns (*Acacia tortilis*) were being lost at a rate of 6% per annum despite an elephant density of 0.2 elephants/km^2. Trollope *et al.* (28) also concludes that culling has not prevented a change in the structural diversity of the woody vegetation in the KNP. Results indicate that culling can therefore not be seen as a way of preventing elephants selecting for favoured species but merely an attempt to slow the process down.

The roan enclosure was erected as a breeding camp for roan and was not designed to tease apart the causal mechanisms behind changing vegetation patterns. It took 20 years of specifically designed exclusion plot experiments in Amboseli National Park, to separate the effects of climate, fire, elephants, other herbivores and human impact on

Table 1 Examples of statements used in the media with regard to the management of the Kruger National Park's elephant population. Online media releases that were consulted between March 2003 and March 2004 relating to this topic are listed below.

DATE	MEDIA SOURCE	TITLE	DEFINITIVE PHRASES USED
15 Mar 04	Press release: Utrecht University, Netherlands	African elephant in danger of becoming victims of their own success	"..elephant populations have increased well beyond the carrying capacity…"
16 Mar 04	The Herald	Elephant cull "is the only way to stop catastrophe"	"..elephant populations were stripping reserves of natural vegetation and threatening other species."
14 Apr 04	United Press International	Thousands of elephants may be killed	"…keep their populations from growing beyond capacity."
18 May 04	US Newswire	Cull no answer to control Kruger elephants, says IFAW	"Last week the former head of conservation at the park suggested that recent fatal attacks by elephants on human beings might be triggered by stress brought on by overpopulation."
24 May 04	SABC News	Elephant culling could resurface at Kruger Park	"…that can only accommodate 7 000 of them."
27 May 04	News 24	Kruger won't cull elephants	"The ideal elephant population for the Park is about 7 000, to prevent damage to the park's biodiversity."
9 July 04	Mail & Guardian	Canning Kruger's elephants	"…as scientists say there are too many elephants…"
14 July 04	Reuters	Past nuke test may unlock Africa ivory sales	"…far above the optimal number of around 7,000…"
2 Aug 04	Daily News	The fate of the elephant lies in our hands	**None** (mention of the figure '7 500' but merely in a historical context)
13 Aug 04	Zimbabwe Independent	Zimbabwe to lead SADC jumbo team	"…which is twice the desired carrying capacity."
14 Aug 04	Press release: WESSA	Great Elephant Debate	**None** (mention of the word over population but in the correct context of "…perceived over-population…")
7 Sept 04	Inter Press Service	South Africa: To cull, or not to cull?	"… the problem of elephant overpopulation."
20 Sept 04	The Boston Globe	In southern Africa, too many elephants	"…elephants exceed the capacity of the land…"
20 Sept 04	Sunday Times	Radical plans to cut elephant overpopulation	"…the Kruger National Park can only accommodate 7 500 elephants…"
14 Oct 04	BauNews	Elephant debate not a ploy to reintroduce culling, says Mabunda	"…elephant population that is placing enormous stress on the biodiversity of game reserves."

Table 1 (continued) Examples of statements used in the media with regard to the management of the Kruger National Park's elephant population. Online media releases that were consulted between March 2003 and March 2004 relating to this topic are listed below.

DATE	MEDIA SOURCE	TITLE	DEFINITIVE PHRASES USED
17 Oct 04	Sunday Times	Elephants face cull as numbers rise	"Experts claim that there are too many elephants in the country's parks…"
18 Oct 04	News 24	Elephants: vets offer help	"Scientists say this is well above what the environment can withstand…"
20 Oct 04	BauNews	Elephant debate heats up	"…to manage the country's oversized elephant population."
21 Oct 04	Reuters	South Africa weighs killing off excess elephants	""We do have serious problem in terms of numbers of overpopulation…"
21 Oct 04	Independent Online News	To cull or not to cull	**None**
21 Oct 04	BauNews	SANParks mandate reaffirmed at Indaba	**None**
22 Oct 04	Mail & Guardian	SANParks reconsiders elephant culls	**None** (mention of the word 'carrying capacity' and the figure of '7 500' but merely in a historical context)
22 Oct 04	BauNews	Elephant management plan proposed	**None**
23 Oct 04	The Australian	A 'just war' no one wants	"…in an area that experts say should hold no more than 7000."
25 Oct 04	Pretoria News	Massive elephant culling on the cards	"reduce the vast over-population that is causing havoc …"
3 Nov 04	Business day	SANParks brews plan to cull elephant herds	"…reduce the "exorbitant" number of elephants…"
22 Nov 04	Ijnter Press Service News Agency	One park, three countries	"…but the park's capacity is just 7,000."
13 Mar 05	Reuters	South Africa edges towards culling elephants	"Kruger National Park is in crisis because of rising numbers of the world's largest land mammal…"
15 Mar 05	The Independent	Elephants in Africa return to the culling fields	"At Kruger Park, more than 13,000 elephants now populate the park, 6,000 more than the optimum level."
20 Mar 05	News 24	Culling tourism boycott looms	"Kruger Park has more than 12 000 elephants and is overpopulated by at least 5 000."
27 Mar 05	Independent online	Kruger elephants head for Mozambique	"Kruger has about 13 000 elephants, and its maximum carrying capacity is set at about 7 000."

woodland loss and restoration (29). Two such experiments were started in the KNP in 2002 and will run for the next 25 years. The important question remains how did elephants co-exist with favoured tree species historically, and what has changed in the process of adult tree mortality and regeneration? Factors influencing the patterns of tree regeneration and recruitment are of critical importance to understand and manage the processes involved as this information will help us know whether tree mortality is sustainable in the long run.

4) Look at Tsavo and Chobe

Regrettably, the data obtained from Tsavo NP relies on incidental information despite the huge debate that surrounds the temporary woodland loss in this ecosystem (30, 31). Although the *Commiphora* woodlands were drastically decreased, considerable regeneration has taken place (32). Furthermore, it is generally accepted that the decline in woodland species was balanced by an increase in open grassland grazers (30). Hence reductions in species diversity as a result of changes in the vegetation caused by elephants are undocumented (26).

Records indicate that Chobe's elephant population increase represents a return to pre-ivory trade abundance. In many African parks the recent vegetation structure and composition developed in the absence of elephants over a 70-100 year period (22), largely as a consequence of excessive hunting in the 1800's and early 1900's. Elephant populations within most protected areas are still recovering from low densities caused by intensive ivory hunting at the turn of the previous century. Although the vegetation is being modified by increasing elephant numbers, we are still unsure whether long term food production for elephants is being increased or decreased or whether the vegetation is merely reverting to a historic state reminiscent of times when elephants were unaffected by hunting (26). If the vegetation is reverting back to a previous state or in the process of establishing a new stable state, then we may be attempting the impossible task of sustaining high elephant densities whilst seeking to maintain the characteristics of the vegetation that would only have persisted if no or few elephants were present (33, 34).

Furthermore, in Chobe and elsewhere a correlation between high elephant densities and changes in the structural diversity of the vegetation does not necessarily imply causality. High densities of other herbivores, like impala, recovering from a rinderpest outbreak in the late 1800s, could be preventing woodland regeneration by intense seedling predation (22). In spite of Chobe's numerous elephants, vegetation impact has been localised and scientific studies have failed to establish any general concern for biodiversity (35). Therefore there are at present, no authentic reports of an irreversibly degraded natural ecosystem caused by elephant over-utilisation (35, 37).

What management options do we have?

1) Actively collect lacking information before considering any reduction programme

This option may be viewed by some as delaying the inevitable and would be justifiably so if a consensus had been reached within the scientific community that there is an overpopulation of elephants in KNP with a consequential looming threat to biodiversity. However, from the scientific community in general, there has been a call for an informed decision once more valuable information has been integrated into outcome based scenarios (18, 37). Part of managers' sense of urgency to address the problem immediately has come from the assumption that exponential growth within the population will continue indefinitely and it will become impractical to cull a large population of elephants. However, population growth is more likely to decrease as resources become limited and a situation could for example be reached where a population twice the size but growing at half the rate will produce the same surplus of animals. Arbitrarily placing a ceiling on the population through culling will prevent density dependence feedbacks from slowing the rate of population growth (35). Culling during the exponential growth phase of a population invariably results in an increased birth rate because food supply per head is raised (38). Furthermore, increased growth rates and consequential impact on the vegetation is exacerbated by the findings that regional specific culling induces inter-regional movement as elephants readily occupy areas from which individuals have been removed (37).

Information that is lacking and which still needs to be gathered has been highlighted under specific headings (refer to Table 2). According to du Toit (39) an understanding of key interactions could be reached within a decade with the establishment of study sites across density gradients in each landscape. Elephant impacts in KNP are not homogenous due to variations in the distance to water (40, 41). The heterogeneity in landscape use therefore already provides opportunities for broad-based research programmes without the necessity to artificially manipulate elephant numbers through culling operations to achieve this outcome. These research opportunities can further be encouraged by the closure of additional water points while allowing certain density dependent factors to reduce the growth rate in areas where elephants are forced to aggregate. Within the proposed management plan to manipulate densities within six zones, replication of any given impact level would be poor (42). Both du Toit (39) and Ferrar & Rossaak (1) stress the importance of establishing an internationally respected steering committee or council of independent scientifically competent experts to counteract the limitations of institutional settings. Unless research is conducted to actively address the gaps in our current understanding, we will continue treating the symptoms instead of directing our focus at the underlying causes of changes in vegetation structure and composition.

2) Expand habitat use

Under natural circumstances, local over-utilisation of woody vegetation by elephants within the KNP could be prevented by dispersal. Bulls are generally the first to colonise new areas (43, 12). Cows have the added burden of ensuring the safety of younger family members within the herd and consequently they may tend to take fewer risks than bulls (44). The colonisation of new areas by bulls could be of particular importance as bull groups have been found to have a heavier impact on the vegetation than family units (45, 46) and all possible attempts should be made to encourage dispersal of particularly bulls as a natural population regulatory process. Furthermore, dispersal could be driven by a build up of densities of animals and pre-emptive culling could further disrupt this process if source areas are prevented from reaching high densities of elephants. A current study on elephant movements within the Associated Private Nature Reserves (APNR) on the western border of the KNP has indicated that bulls do expand their ranges according to specific needs which tie in with their reproductive cycle and social benefits. The home

Table 2 Aspects of information that is still lacking and that needs to be gathered to clearly understand whether culling will achieve its goals and how best to understand the processes that are involved.

LACKING INFORMATION	RELEVANCE TO OUR UNDERSTANDING	REFERENCES
Historic perspectives	Will assist in determining whether the current elephant population and vegetation structure is within the normal range of variability	2, 22- 23, 33-34 48-52
Heterogeneity of elephant impact in relation to their distribution in:		
- Time	- Will determine whether recovery time for vegetation is sufficient as animals are encouraged to disperse or forced to contract their range away from threatened species during dry season periods	2, 24, 31, 35, 37, 40-41, 49, 51, 53-58
- space	- Will determine whether woodland refugia can be maintained over larger areas despite local declines at smaller scales	
Abiotic and biotic factors influencing population dynamics:		
- Climatic (drought, global warming), edaphic and fire effects on regeneration and mortality rates of vulnerable plant species	- Will elucidate the causal mechanisms involved in changing vegetation structures and ultimately address whether culling will achieve the desired outcomes	17-19, 25, 35, 49, 51, 54, 59
- Browsing by elephants and other herbivores on regeneration and mortality rates of vulnerable plant species	- Will determine whether the impact of elephants and other herbivores is sustainable	22, 24, 51, 39
- Effect of droughts and limited resources (dry season periods) on density dependent feedback loops in elephant populations	- Will determine whether elephants can regulate their population growth in accordance with their available resources	35, 37, 42, 51. 54, 59
Food selection		
- evaluation criteria for plant species (according to elephant and fire impact susceptibility)	- Will assist in identifying vulnerable species in response to specific attributes that make them highly sort after	17, 42, 56, 60-61, 63
- sex related dietary distinctions	- Will determine whether sex related differences in range and foraging behaviour would require separate management plans	51, 54, 62
- individual propensity to damage particular species	- Will determine whether it is feasible to remove particular individuals that selectively remove certain species	54, 60, 62
- behavioural mechanisms involved in tree felling	- Tree felling driven by social/sexual aspects as opposed to nutritional benefits will alter evaluation criteria for certain species	60, 63
Interspecific interactions		
- positive change in habitat suitability for other species (increase in grazers as woodlands open up, facilitation of refugia for invertebrates, increased nesting sites for birds through large branch breakage etc.)	- Will assist in evaluating whether elephant impact and vegetation transformation is detrimental to other species	22, 58, 64-69
- Negative change in habitat suitability for other species (decrease in browsers or woodland species, decrease in nesting trees for vultures etc.)	- Will determine whether elephant impacts need to be regulated and controlled to achieve suitable outcomes	22, 31, 50, 58-59, 64-66, 68-69

range of bulls may exceed an area of 5 000 km^2 and span both the proposed high density (where elephants will be allowed to increase) and low density (where elephant numbers will be kept low) management zones within the KNP (47). These results indicate that although the boundaries of the respective elephant management zones have been defined to roughly conform to the boundaries of elephant clans (12), the effectiveness of the proposed zonation strategy may not be applicable to the range behaviour of bulls.

Dispersal of elephants or the expansion of their range will depend on whether nutritional, social and/or safety benefits are available to them in new areas. Former recolonisation rates in the KNP have averaged 5-7km per year (as cited by 56). The establishment of the Great Limpopo Transfrontier Park with Mozambique in particular, will allow considerable opportunities for elephants to either disperse or to expand their range. Mozambique has adopted a National Strategy for the Management of Elephants according to which they aim to increase their elephant population by 20% by 2010 (70). Recent reports have indicated voluntary movements of elephants into Limpopo National Park despite the more than 20 000 people which still occupy the area. Although the potential for human-elephant conflict exists, especially in areas where people are distributed in close proximity to water sources, results from studies conducted in East Africa indicate that elephants do have a spatial awareness of danger. Elephants were found not to use their range homogenously but linked home sectors where they spent most of their time with travel corridors. Travel corridors outside protected areas were crossed under the cover of darkness and the travelling speeds along these corridors were much faster than in other areas (71). While elephants may not occupy areas where human densities exceed 15/km^2 (72), they could potentially still use areas inhabited by humans applying compatible land-use practises as travel corridors because of their spatial awareness of safe areas. Other than safety benefits driving elephant movements as in East Africa, or social benefits as with the range expansion found within the APNR, travel corridors would provide access to nutritional benefits available in other areas. The Gourma elephants of Mali migrate in a counter clockwise circle with a 450km circumference in relation to the seasonal availability of water and food resources (73) while in Namibia, elephants make use of particular segments of their home range in response to the seasonal fruiting of trees (K. Leggett pers.comm.). Elephants are therefore capable of adaptive behaviour in response to spatio-temporal variability in habitat conditions (54). Enabling elephants to vary their habitat use in both space and time by providing opportunities for large scale movements would alleviate the severity of local impacts. Irrespective of the motivating forces behind large scale movements, results indicate that it would be possible to induce a range of elephant densities by keeping open crucial corridors identified by high-resolution radio tracking and thereby spread elephant impact between different segments of their range (37, 71).

3) Restrict habitat use

Manipulating elephant densities by restricting their habitat use locally through more sensitive and indirect ways other than culling could have the desired effect of increasing biodiversity at larger scales. Furthermore compressing elephants' range could heighten densities in particular areas and eventually lead to population declines through various reproductive delays when density dependant feedback loops come into play because of limited resources (54). The following options can be used to restrict habitat use by elephants:

- *Reduction in the number of water points*
  On average elephants restrict their foraging distance and consequentially their impacts on the vegetation, from between 15km (as cited in 24) to 17.5km (74) from water. Breeding units in Samburu and Buffalo Springs in Kenya significantly avoided areas greater than 5km from water (75) while in Chobe breeding herds moved no further than 3.5km from rivers in the dry season and 5km in the wet season (76). Even though 184 water points have been closed in KNP very few areas are further than 5km from water in the dry season (24, 40, 78). A high density of water points will reduce the home range area and ultimately homogenise the intensity of patch use (37). Despite the overall short distance between water points in the KNP, water distribution still plays an important role in concentrating elephant impact in certain parts of the landscape (40).

  Elephants concentrate their feeding habits around surface water which gives rise to so-called piospheres or zones of impact around waterholes due to increased herbivory (78). In terms of elephant impact, piospheres will eventually be characterised by a dominance in impact tolerant or avoided plant species (41, 24). Monitoring the coalescence of piospheres in relation to elephant densities provides an innovative way of monitoring ecosystems for biodiversity. As the rate of expansion of poispheres will occur in direct relationship to climatic conditions and the distribution of elephants, such monitoring programmes will move away from species specific management and focus more on ecosystem processes which are in keeping with the revised management plan (40, 41). Results obtained from elephant impacts on the riparian woody vegetation in relation to surface water have shown that an overabundance of surface water leads to a moderate but homogenous impact on particularly the structural diversity of riparian vegetation. When the distance between surface water increases, impact becomes more intense but patchy, thereby creating refugia for impact intolerant plant species. These findings have important biodiversity consequences because although local structural and compositional diversity may be compromised close to surface water, biodiversity is increased at larger spatial scales (40, 41, 53).

  By manipulating artificial water availability in relation to the local distribution of threatened plant species, the probability of elephants encountering vulnerable species will be diminished and their persistence in refugia can be safeguarded. This management action would be of particular importance in the dry season when elephants are mostly browsing (23, 46) and have a greater impact on the woody vegetation. Threatened species are often found on uplands where water rarely persists beyond the wet season. Trees in bottomlands and riparian zones are often less threatened because of their deep root systems and direct access to water sources (79). Artificial water points in uplands could attract specifically bulls into these areas and consequentially cause severe impact on threatened species. The closure of waterholes that act as bridges between riparian zones would relieve the pressure on vulnerable species. On the contrary, wet season grazing pressure can be encouraged in uplands to reduce the fuel load and potentially release recruiting individuals from suppression by fire (24, 49, 79).

Elephants of both sexes aggregate around natural water sources as opposed to artificial water supplies although bulls appeared to be more evenly distributed in relation to surface water than mixed groups (80). Closure of water points on uplands would further encourage aggregations of both genders of elephants in riparian zones. An indirect consequence of closing water on uplands could therefore also include an increase in intraspecific conflict between bulls and hence possibly increased mortality rates in certain age and sex classes. Henley & Henley (47) found a peak in the number of musth bulls associating with breeding herds towards the end of the wet season. As surface water starts diminishing there could be a larger proportion of musth bulls associating with breeding herds in close proximity to riparian zones. As breeding herds readily occupy riparian zones (81), younger or non-musth bulls would have been capable of avoiding intraspecific conflict with musth bulls by occupying uplands with artificial water away from breeding herds. The closure of additional water points could therefore either promote dispersal of younger or non-musth bulls into Mozambique or increase intraspecific conflict by impacting on the social system of elephants. These indirect consequences of manipulating surface water may come into play over and above the other positive outcomes of increased heterogeneity of elephant impact across the landscape.

- *Creating tree sanctuaries*

Tree sanctuaries can be created according to the distribution of impact intolerant species. As mentioned above, tree sanctuaries can be created by the closure of waterholes in the immediate vicinity of such areas. Furthermore exclusion plots could be erected around particularly vulnerable species and if properly designed these exclusion plots would not only protect rare species but could also provide much needed data on how climate and other herbivores affect recruitment rates. In addition mature specimens within exclosures could act as valuable seed banks to populate surrounding areas (29). It would however, be important to remember that exclosures and exposes represent extremes of continuums and that historical perspectives would still be critical to determine what landscape features managers hope to achieve (50).

In East and South Africa direct application of chicken wire to mature tree stems have prevented such trees from being bark striped by elephants (82, 83). The same technique has been used to protect specific trees with nesting sites of white back vultures *(Gyps africanus*) (S. Ronaldson pers. comm.). Other ways to protect particular specimens of vulnerable trees include the placement of bee hives in strategic trees as elephants are sensitive to the sound and sting of bees (84, 85). The question then needs to be asked: if the impact upon these vulnerable species can be minimised by innovative techniques, what remains of the 'elephant problem'?

4) Contraception

5) Translocation

6) **Increase mortality**

By increasing the mortality within the population, the growth rate can be lowered and presumably a reduced population density will lead to a decrease in the probability of encountering vulnerable plant species.

An increase in mortality can be achieved by the following means, again listed in order of their preference of application:

- *Environmental manipulation*

  The closure of all artificial water points could be used to regulate Kruger's elephant population by increasing juvenile mortality rates if waterholes are spaced further than 15km apart. However because closure of all artificial water points may have unknown effects on other species and as water holes enhance tourist game viewing opportunities, only certain boreholes have been identified by KNP management for closure. Even with the closure of these boreholes, less than 10% of the KNP will have surface water spaced far enough apart to influence juvenile mortality rates (2). Nevertheless, the inability of the water stabilising programme in KNP to increase natural mortality rates should not distract from the opportunities that will arise by the continued closure of additional waterholes and the creation of tree sanctuaries. Both these methods of environmental manipulation would still increase the heterogeneity of elephant impact on the vegetation. This would have the desired effect of increasing biodiversity at larger scales, creating refugia for vulnerable species and could indirectly limit population growth as resources become limited in areas where elephants are forced to congregate. To this effect it would be important to draw up questionnaires for the general public to complete to determine whether some degree of environmental manipulation may not be more acceptable than large scale culling, especially if the same outcome for biodiversity conservation can be achieved.

- *Biological control*

  Biological control in the form of disease could become an important measure of population control. Disease would not be recommended as an active management option but could nevertheless be an outcome that might occur naturally and thereby contribute to increased mortality rates. Recently anthrax outbreaks have been recorded in Chobe NP while anthrax outbreaks in Namibia have led to 474 deaths over a 28 year period (86). However, such outbreaks are expected to only take effect when resources become severely limited and animals become more susceptible to disease because of a loss of body condition. Disease does therefore have the potential to become another important density dependent regulatory factor in controlling population growth, especially in areas where elephant densities have been forced to increase due to environmental manipulation.

- *Selective culling*

  While there is little justification for shooting elephants throughout the KNP, disturbance shooting on the periphery of the KNP could help to concentrate elephant numbers in the central region of the park (49). During the dry season and marula fruiting season, when there is a peak in fence breakouts particularly by bulls (87), this management option may need to be practised to relieve pressure on the boundaries of reserves (49). Presumably, with time other animals will learn to avoid these high risk areas and restrict their range to safe areas.

As males are known to have a higher impact on the vegetation (45, 46), the distribution of bulls will largely determine where impacts are most severe (54). Furthermore, bull elephants have demonstrated individual variability in tree species selection in particular areas. These findings may mean that we will not only need to separate sexes in the implementation of any management plan, but we may need to manage the heterogeneity of responses that elephants bring as individuals (62). The selective removal of bulls that have a propensity to damage particular trees may therefore become necessary from time to time (54).

- *Large scale culling*
  As the perceived impacts of elephants on biological diversity in the KNP have little scientific support, culling as a management tool to increase mortality would be premature (37). Current elephant impacts have not approached any thresholds of potential concern under the revised elephant management plan (15) and culling could therefore only be justified as a risk-containment measure to safeguard threatened components of biodiversity (49). While other more sensitive ways of achieving and testing the same outcomes are available to managers, it would be more appropriate to implement alternative management options. Culling would not only be excessive but also simplistically assumes that elephants are the sole modifiers of a complex system in which previous culling operations have already shown that the desired outcomes could not be achieved. According to Lötter (88) "Culling can only be ethically justified if a clear and convincing case can be made that it is *the last resort* for dealing with an urgent problem *after all other options have convincingly failed.* Analogous to justifying a war in which fellow humans will be killed, culling can be justifiable only as an ethically flawed procedure to be employed under strict conditions."
- *Hunting*
  As hunting is highly selective with respect to sex, age and outstanding physical features (89, 90), hunting can never be used as a population control method as any population controlled in this way would develop a skewed sex ratio and age structure. Other than the aesthetic, economic and genetic value of large tusked bulls, older large tusked bulls are also of social importance to breeding females as females preferentially mate with older more experienced bulls (91, 92, 93). The importance of older bulls within elephant society has also recently been highlighted by other studies (94, 95, 96), and it may well be that not only matriarchs within family units have a crucial social function (97).
- *Uncontrolled poaching*
  The rest of Africa has already shown that because of the value of ivory, poaching can not be controlled or applied in a sustainable manner. It is nevertheless important to remember that the persistence of wildlife populations that directly compete with humans for resources will depend on the political stability of the governmental institutions that are responsible for their protection and conservation.

To briefly summarise the points discussed above and conclude:

- There is no proof that elephants are overpopulated in the KNP as no TPCs have been approached by current densities (49). Hence there is no immediate concern about elephants' impact on the vegetation.
- Elephants can not be considered the sole manipulators of ecological processes. When considering changes in the vegetation due to the impact by elephants the most important step would be to determine the percentage of trees killed by elephants per annum and whether recruitment by surviving saplings and seedlings can maintain the tree population (26). If this is monitored over a sufficiently long period, KNP could potentially predict changes in species composition and structure over time by means of modelling exercises. The condition of the system can thus be assessed although this gives little or no insight into the numerous underlying processes that affect the status of the components (mature trees and elephants) in an ecosystem (26, 36, 38). If the persistence of a mature canopy is desired, then recruitment is essential (98). A broad-based monitoring programme would need to be put into place that would not merely track changes but also look at causal effects by creating control areas which separate the effects of elephants from those of climatic variability, fire and other herbivores. An effective way in which these objectives can be met is by exclusion experiments (36, 99).
- There is general agreement amongst the scientific community that spatial-temporal heterogeneity in elephant impact should be encouraged as this could lead to an increase in biodiversity over larger scales (35, 37, 39, 40, 41, 53).
- To increase the spatio-temporal heterogeneity of the landscape elephant densities can be manipulated either directly through culling or indirectly through more sensitive means.
- While culling has failed to prove that landscape selection can be artificially enforced (37) and the desired outcomes reached (landscapes with mature trees, favoured by elephants), elephant range use is naturally heterogeneous because of water point distribution (37, 39).
- Environmental manipulation could be applied and monitored as a more sensitive approach to managing the elephant population and encouraging populations to move towards densities in certain areas where natural processes would slow the rate of population growth.
- Transfrontier Conservation initiatives represent a large-scale expansion of habitat while small scale local compression in areas with impact tolerant plant species should be encouraged. By indirectly manipulating elephant distribution through waterhole closure and the creation of tree sanctuaries, habitat use can be restricted locally to safeguard threatened species at critical times of the year and could also diminish pressure on boundary fences. Both large-scaled habitat expansion and small-scaled local compression will promote spatial and temporal heterogeneity of elephant impact.
- The monitoring of piospheres offers an alternative means of decision making which steers away from focussing on elephant numbers as it incorporates processes that are dependent on the distribution of elephants in both space and time and their use of resources in direct relation to climatic variables (24, 41).

- If we are to embrace ecosystem processes as propagated by the revised elephant management plan (15), we will need to accept change. These changes may lead to a divergence from former perspectives based primarily on subjective interpretations of what the landscape should look like. Undisrupted ecosystem processes will probably incorporate local declines in plant species structure and composition in support of long-term persistence and stability of vulnerable species at larger scales.

There is a need to supply reasonable and workable alternatives to past management options and caution against leaving SANParks with the feeling of 'damned if we do and damned if we don't' (1). We are living in exciting times as the drivers that uphold ecosystem processes have already been put into motion: **fences are coming down and waterholes are still being closed**. Let us strive to appreciate the diversity of ecological processes, irrespective of their outcomes as Caughley (38) did when he stated:

"I am intrigued by ecological processes, delighted by the dynamics of both plant and animal populations, and impressed by the adaptive solutions that evolution has bestowed upon them. These days I can watch these processes at work relatively unfettered in only a few places, and most of those places are designated parks. I warm to a national park according to how much it differs from an efficient farm, a cultured botanical garden, or a well-run zoo. Where Bell* is likely to reach for his Mauser, I am likely to wait and watch a little longer, perhaps because I have more faith in ecological processes and in the robustness of their solutions…."

*Caughley here refers to one of his scientific colleagues.

Acknowledgement

SANParks is acknowledged for creating the opportunity for submissions. Rina Grant and her team are especially acknowledged for collating the information and organising the workshop. I would like to thank all the scientists that have given of their time and effort to provide us with the information and ideas for the road ahead.

References

1. FERRAR, T and A. ROSSAAK. 2005. WESSA's roadmap for negotiating the elephant cull-de-sac providing the basis of the executive summary titled the role of science in SANParks decision making (Chapter 9). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
2. RODGERS, K.H. 2005. Elephant and biodiversity- a synthesis of current understanding of the role and management of elephant in savanna ecosystems. Outcomes of the Science workshop, Luiperdskloof (Chapter 12). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
3. WHYTE, I., R. VAN AARDE and S.L. PIMM. 1998. Managing the elephants of Kruger National Park. *Animal Conservation* 1: 77-83.
4. FAYRER-HOSKEN, R.A., G.D. GROBLER, J.J. VAN ALTENA, H.J. BERTSCHINGER, and J.F. KIRKPATRICK. 2001. Immunocontraception of African elephant contraception. *Nature* 407: 149.

5. PIMM, S.L. and R.J. VAN AARDE. 2001. Population control – African elephants and contraception. *Nature* 411: 766.
6. BERTSCHINGER, H.J., A.K. DELSINK, J.F. KIRKPATRICK, D. GROBLER, J.J. VAN ALTENA and R. SLOTOW. 2005. Contraception of African elephants using porcine zona pellucida vaccine – basic principles. (Chapter 9). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
7. BUSS, P.E. 2005. Estimated costs of using contraception to manage the elephant population of Kruger National Park. (Chapter 9). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
8. MACKEY, R.L., B.R. PAGE, D. GROBLER and S.R. SLOTOW. 2005. The projected comparative effects of contraception and culling on the elephant population of Kruger National Park. (Chapter 15). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
9. WHYTE, I.J. 2005. The feasibility of current options for the management of wild elephant populations (Chapter 9). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
10. MILNE, A. 1993. The perils of green pessimism. *New Scientist* (June): 34-37.
11. COONEY, R. 2004. *The Precautionary Principle in Biodiversity Conservation and Natural Resource Management: An Issues paper for policy-makers, researchers and practitioners*. IUCN, Gland, Switzerland and Cambridge, UK xi + 51pp.
12. WHYTE, I.J. 2001. Conservation management of the Kruger National Park elephant population. P.hD thesis, University of Pretoria, Pretoria.
13. MACNAB, J. 1985. Carrying capacity and related slippery shibboleths. *Wildl Soc. Bull.* 13: 403-410.
14. MCLEOD, S.R. 1997. Is the concept of carrying capacity useful in variable environments? *Oikos* 79: 529-542.
15. WHYTE, I.J., H.C. BIGGS, A.GAYLARD and & L.E.O. BRAACK. 1999. A new policy for the management of the Kruger National Park's elephant population. *Koedoe* 42: 111-132.
16. JACOBS, O.S. and R. BIGGS. 2002. The status and population structure of the marula in the Kruger National Park. *South African Journal of Wildlife Research* 32: 1-12.
17. BROCKETT, B.H. 2005. Fire and elephant interactions in southern African savannas (Chapter 6). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
18. HOFMEYR, M. and ECKARDT, H. 2005. Changes in vegetation in the KNP related to elephant activity. (Chapter 5). In *Elephant effects on biodiversity; an*

assessment of current knowledge and understanding as basis for elephant management in SANParks. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants

19. HOFMEYR, M. 2003. The spatial demography of elephant impacts on selected tree species in the Kruger National Park. Unpublished report to the US Fish and Wildlife. Skukuza. 43pp
20. PRINS, H.H.T. and H.P. VAN DER JEUGD. 1993. Herbivore population crashes and woodland structure in East Africa. *Journal of Ecology* 81: 305-314.
21. HAIG, A.W. 1999. The impact of impala and elephant on demography and dynamics of *Sclerocarya birrea* subsp. *caffra* (marula) in the eastern lowveld of South Africa. B.Sc. (Hons.) dissertation. University of Pietermaritzburg, University of Natal, Pietermaritzburg.
22. SHARPE, C., P.A. AARRESTAD, H.P. ANDREASSEN, S.S. DHILLION, T. DIMAKATSO, J.T. DU TOIT, D.J. HALLEY, H. HYTTEBORN, S. MAKHABU, M. MARI, W. MAROKANE, G. MASUNGA, D. MODISE, S.R.MOE, R. MOJAPHOKO, D. MOSUGELO, S. MOTSUMI, G. NEO-MAHUPELENG, M. RAMOTADIMA, L. RUTINA, L. SECHELE, T.B.SEJOE, S. STOKKE, J.E. SWENSON, C. TAOLO, M. VANDEWALLE and P. WEGGE. 2004. The return of the giants: ecological effects of an increasing elephant population. *Ambio* 33: 276-282.
23. CONDRON, J., J.A. LEE-THORP, M. SPONHEIMER, C.C. GRANT and D. CONDRON. 2005. Carbon isotopic assessment of the diets of elephants in Kruger National Park – seasonal and spatial variability (Chapter 4). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
24. KRUGER, L. and R. GRANT. 2005. Chapter summary and conclusion (Chapter 8). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
25. HOFMEYR, M. 2005. Spatial demography of selected tree species in the Kruger National Park in relation to elephant impacts (Chapter 5). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
26. OWEN-SMITH, R.N. 1988. *Megaherbivores-The influence of very large body size on ecology*. Cambridge University Press, Cambridge.
27. PELLEW, R.A. 1983. The impacts of elephant, giraffe and fire upon *Acacia tortillas* woodlands in the Serengeti. *Afr. J. Ecol.* 21: 41-74.
28. TROLLOPE, W.S.W., L.A. TROLLOPE, H.C. BIGGS, D.PIENAAR and A.L.F. POTGIETER. 1998. Long-term changes in the woody vegetation of the Kruger National Park with special reference to the effects of elephants and fire. *Koedoe* 41: 103-112.
29. WESTERN, D. and D. MUITUMO. 2004. Woodland loss and restoration in a savanna park: a 20-year experiment. *African Journal of Ecology* 42: 111-121.

30. PARKER, I.S.C.. 1983. The Tsavo story: an ecological case history. In *Management of Large Mammals in African Conservation Areas*, ed. R.N. Owen-Smith, pp. 37-49. Pretoria: Haum.
31. CHAMAILLĖ, S. and H. FRITZ 2005. Rainfall drivers of dry season savanna productivity (Chapter 4). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
32. LEUTHOLD, W. 1996. Recovery of woody vegetation in Tsavo National Park, Kenya, 1970-94. *African Journal of Ecology* 34: 101-112.
33. GILLSON, L and K. LINDSAY. 2003. Ivory and ecology-changing perspectives on elephant management and the international trade in ivory. *Environmental Science and Policy* 6: 411-419.
34. GILLSON, L and K. LINDSAY. 2002. Ecological reality questions the need to cull. CITES briefing document, October 2002, 8pp.
35. OWEN-SMITH, R. N. 2005. Ecosystem resources influencing elephant populations. (Chapter 4). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
36. SINCLAIR, A.R.E. 1983. Management of conservation areas as ecological baseline controls. In *Management of Large Mammals in African Conservation Areas*, ed. R.N. Owen-Smith, pp. 13-22. Pretoria: Haum.
37. VAN AARDE, R. J., T.P. JACKSON, R.A.R. GULDEMOND, A.A.KINAHAN, Y. DE BEER, A.M. SHRADER, S.M. FERREIRA, T. OTT and E.R. LEHMAN. 2005. Elephants and their management in the Kruger National Park (Chapter 9). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
38. CAUGHLEY, G. 1983. Dynamics of large mammals and their relevance to culling. In *Management of Large Mammals in African Conservation Areas*, ed. R.N. Owen-Smith, pp. 115-126. Pretoria: Haum.
39. DU TOIT, J.T. 2005. Understanding elephants as agents of heterogeneity in Kruger. (Chapter 9). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
40. GAYLARD, A. 2005. Distribution of elephant impacts on riparian woody vegetation in relation to surface water distribution (Chapter 8). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
41. GAYLARD, A. 2005. Elephant-induced changes to the compositional and structural diversity of riparian woody vegetation in relation to surface water distribution. (Chapter 5). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
42. O' CONNOR, T. 2005. Alternative perspective on KNP management policy for serving research (Chapter 12c). In *Elephant effects on biodiversity; an*

assessment of current knowledge and understanding as basis for elephant management in SANParks. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants

43. HALL-MARTIN A.J. 1992. Distribution and status of the African elephant *Loxodonta africana* in South Africa, 1652-1992. *Koedoe* 35: 65-88.
44. SUKUMAR, R. 1991. The management of large mammals in relation to male strategies and conflict with people. *Biol. Cons.* 55: 93-102.
45. STOKKE, S. & DU TOIT, J.T. 2000. Sex and age related differences in the dry season feeding patterns of elephants in Chobe National Park, Botswana. *Ecography* 23: 70-80.
46. GREYLING, M.D. 2004. Sex and age related distinctions in the feeding ecology of the African elephants, *Loxodonta africana*. PhD thesis, University of the Witwatersrand, Johannesburg.
47. HENLEY, M.D. and S.R. HENLEY 2004. Population dynamics and elephant movements within the Associated Private Nature Reserves (APNR) adjoining the Kruger National Park. Unpublished November progress report to the Associated Private Nature Reserves. (20 pp.).
48. KAY, C. 2005. The role of elephant in creating diversity in vegetation structure, function and composition, and the consequences for biodiversity (Chapter 5). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
49. OWEN-SMITH, R. N. 2005. Vegetation-elephant interactions. (Chapter 5). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
50. COWLING, R. and G.I.H. KERLEY. 2002. Impacts of elephants on the flora and vegetation of Subtropical Thicket in the Eastern Cape. In: Kerley, G.I.H., Wilson, S., Massey, A. (Eds.), Proceedings of a workshop on Elephant Conservation and Management in the Eastern Cape. Terrestrial Ecology Research Unit Report 35, University of Port Elizabeth.
51. HENLEY, M.D. 2005. A neighbour's perspective on the new management policy of the Kruger National Park (Chapter 5). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
52. GILLSON, L. 2005. The role of elephant in creating diviersity in vegetation structure, function and composition, and the consequences for biodiversity (Chapter 5). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
53. GAYLARD, A., M.L. CADENASSO and S.T.A. PICKETT. 2005. In prep. Heterogeneity shaped by African elephants in semi-arid savannas: the significance of space and scale.
54. OWEN-SMITH, R. N. 2005. Summary and conclusions. (Chapter 4). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as*

basis for elephant management in SANParks. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants

55. BIGGS, H. 2005. Valuescapes in elephant management – learning necessitates diversity (Chapter 9). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
56. CUMMING, D., A.GAYLARD, G. CASTLEY and I. Whyte. 2005. Management chapter –draft summary/synthesis (Chapter 9). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
57. OWEN-SMITH, N. 2004. Functional heterogeneity in resources within landscapes and herbivore population dynamics. *Landscape Ecology* 19: 761-771.
58. OWEN-SMITH, N. 2003. Elephants and ecosystems. for proceedings of the Norwegian BONIC programme workshop held in Kasane, Botswana.
59. LEGGETT, K. 2005. The effects of long-term aridity and drought effects on elephant populations (Chapter 4). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
60. MIDGLEY, J.J. and D. BALFOUR. 2005. Review article - Why do elephants damage savanna trees? (Chapter 15). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
61. BAXTER, P. and GETZ, W. 2005. Modelling elephant effects on semi-arid savannas (Chapter 5). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
62. SLOTOW, R. 2005. Understanding individuals in order to manage populations (Chapter 9). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
63. MIDGLEY, J.J. 2005. Vegetation-elephant interactions from an evolutionary perspective (Chapter 5). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
64. KERLEY, G.I.M. and M. LANDMAN. 2005. Gardeners of the gods?: The role of elephants in the Eastern Cape subtropical thickets. (Chapter 7). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
65. MORRISON, K. and A. KEMP. 2005. Some notes on the impacts that elephant (*Loxodonta africana*) have on southern ground hornbills (*Bucovus leadbeateri*) (Chapter 7). In *Elephant effects on biodiversity; an assessment of current*

knowledge and understanding as basis for elephant management in SANParks. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants

66. DEACON A. 2005. Evaluation of the small vertebrate habitat requirements which can be influenced by elephant (Chapter 7). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
67. GOVENDER, N. 2005. The effect of elephant habitat alteration on ground dwelling invertebrate diversity (Chapter 7). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
68. VALEIX, M., H. FRITZ, S. CHAMAILLĖ-JAMMES, M. BOURGAREL and F. MURINDAGOMO. 2005. Assessing the elephant influence on the structure of African ungulate communities using long term and semi-experimental data (Chapter 7). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
69. BOTHA, A. 2005. Brief on the impact of elephant over-population on tree-nesting vultures and other raptors in national, provincial and private parks and reserves (Chapter 7). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
70. BLANC, J.J., C.R. THOULESS, J.A. HART, H.T. DUBLIN, I. DOUGLAS-HAMILTON, C.G. CRAIG and R.F.W. BARNES. 2003. *African Elephant Status Report 2002: An update from the African Elephant Database.* IUCN/SSC African Elephant Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. vi + 302 pp.
71. DOUGLAS-HAMILTON, I., T. KRINK and F. VOLLRATH. 2005. Movements and corridors of African elephants in relation to protected areas N*aturwissenschaften* 92 (4): 158-163.
72. HOARE, R.E. & DU TOIT, J.T. 1999. Coexistence between people and elephants in African savannas. *Conservation Biology*. 13 (3): 633-639.
73. BARNES, R.F.W., E.M. HĖMA, DOUMBIA, E. and M.B. SAMAKĖ. 2004. Initial measures for conservation of the Gourma elephants, Mali. Unpublished interim summary progress report, 44pp.BRAACK, L.E.O. 2000. Proposals for a Gaza/Kruger/Gonarezhou Trans-frontier Conservation Area. South African National Parks, Skukuza.
74. YOUNG E. 1970. Water as faktor in die ekologie van wild in die Nasionale Kruger Wildtuin. DSc thesis University of Pretoria.
75. WITTEMYER, G., W.M. GETZ and I. DOUGLAS-HAMILTON. In prep. Seasonal movement, spatial segregation and social dominance in the African elephant.
76. STOKKE, S. and J.T. DU TOIT. 2002. Sexual segregation in habitat use by elephants in Chobe National Park, Botswana. *African Journal of Ecology* 40(4): 360-371.

77. PIENAAR, D. 2005. Water-provision in the KNP (Chapter 8). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
78. ANDREW, M.H. 1988. Grazing impact in relation to live stock watering points. *Trends in Ecology and Evolution* 3: 336-339.
79. OWEN-SMITH, R. N. 2005. The role of water provision on elephant effects on vegetation. (Chapter 8). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
80. SMIT, I.P.J. 2005. Elephant distribution relative to artificial and natural water sources (Chapter 8). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
81. MAC FADYEN, S. 2005. The spatial analysis of elephant density and distribution patterns in the Kruger National Park (Chapter 2). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
82. GORDON, C.H. 2003. The impact of elephants on the riverine woody vegetation of Samburu National Reserve, Kenya. Unpublished report for Save the Elephants.
83. HENLEY, M.D. and S.R. HENLEY. 2005. Population dynamics and elephant movements within the Associated Private Nature Reserves (APNR) adjoining the Kruger National Park. Unpublished February progress report to the Associated Private Nature Reserves. (17 pp.).
84. VOLLRATH, F. and I. DOUGLAS-HAMILTON. 2005. African bees to control African elephants. *Naturwissenschaften* 92 (11): 508-511.
85. VOLLRATH, F. and I. DOUGLAS-HAMILTON. 2005. Elephants buzz off! *Swara* 25(3): 20-21.
86. LINDEQUE, P.M. and P.C.B. TURNBULL. 1994. Ecology and epidemiology of anthrax in the Etosha National Park, Namibia. *Onderstepoort Journal Veterinary Research*. 61 (1): 71-83.
87. BENGIS, R.G. 2005. The KNP elephant challenge: some animal health and social-economic considerations. (Chapter 9). In *Elephant effects on biodiversity; an assessment of current knowledge and understanding as basis for elephant management in SANParks*. FTP site, ftp://ftp.parks-sa.co.za/gislab/outgoing/elephants
88. LŐTTER, H.P.P. In prep. Should elephants be culled? [2] – Which management options are ethical? Which options of limiting elephants are ethical? Should humans interfere in the lives of elephants through culling? The ethics of limiting elephant numbers.
89. JOUBERT, S.C.J 1996. Master plan for the Management of the Associated Private Nature Reserves. 206pp.
90. STALMANS, M., B.ATTWELL and L.ESTES, 2002. Hunting in the Associated Private Nature Reserves. Environmental Impact Assessment Process. Draft

Scoping Report to the Department of Finance and economic Development (Limpopo Provincial Government). 74 pp.
91. POOLE, J.H. and C.J. MOSS. 1981. Musth in the African elephant (*Loxodonta africana*). *Nature* 292: 830-831.
92. POOLE, J.H. 1982. Musth and male-male competition in the African elephant. PhD thesis, Cambridge University Press, Cambridge.
93. POOLE, J.H. 1987. Rutting behaviour in African elephants: the phenomenon of musth. *Behaviour* 102: 283-316.
94. SLOTOW, R., G. VAN DYK, J. POOLE, B. PAGE and A. KLOCKE. 2000. Older bull elephants control young males. *Nature* 408: 425-426.
95. SLOTOW, R., D. BALFOUR and O. HOWISON. 2001. Killing of black and white rhinoceros by African elephant in Hluhluwe-Umfolozi Park, South Africa. *Pachyderm* 31:14-20.
96. SLOTOW, R & G. VAN DYK. 2001. Role of delinquent young "orphan" male elephants in high mortality of white rhinoceros in Pilansberg National Park, South Africa. *Koedoe* 44: 85-94.
97. MCCOMB, K., C. MOSS, S.M. DURANT, L.BAKER, and S. SAYIALEL. 2001. Matriachs as repositories of social knowledge in African elephants. *Science* 292: 491-494.
98. PELLEW, R.A. 1983. Modelling and the systems approach to management problems: the *Acacia*/elephant problem in the Serengeti. In *Management of Large Mammals in African Conservation Areas*, ed. R.N. Owen-Smith, pp. 93-114. Pretoria: Haum.
99. MALAN, J.W. 1992. The relationship between elephants and the riverine tree communities of the Northern Tuli Game Reserve, Botswana. M.Sc. thesis, University of Pretoria, Pretoria.