Report on elephant movements in relation to water and the effects of the 2012 floods within the Associated Private Nature Reserves

2014

by
Michelle Henley
(PhD)
**INDEX**

Acknowledgements..............................................................................................................3  
Executive summary..................................................................................................................4  
Introduction...............................................................................................................................5  
Material and methods..............................................................................................................6  
  Field methods.........................................................................................................................6  
  Collaring elephants..............................................................................................................6  
Data...........................................................................................................................................8  
  Climate-, water point- and census data...............................................................................8  
  Tracking data.........................................................................................................................9  
Data analysis.............................................................................................................................9  
  Seasons and rainfall before (2011), during (2012) and after (2013) the floods....................9  
  Water availability in the APNR .........................................................................................9  
  Home range size in a water saturated environment.........................................................10  
  Elephant movements in relation to water points, control sites and rivers..........................10  
Results and discussion...........................................................................................................13  
  Seasons and rainfall before (2011), during (2012) and after (2013) the floods....................13  
  Water availability in the APNR .........................................................................................14  
  Home range size in a water saturated environment-......................................................15  
  Elephant movements in relation to water points, control sites and rivers..........................25  
Recommendations...................................................................................................................29  
References.................................................................................................................................31
ACKNOWLEDGEMENTS

I would like Jake Wall for creating the Save the Elephants downloader and for the development of your ingenious Movement Ecology Tools for ArcGIS (ArcMET). Barry Paul is thanked for meticulously sorting through years of tracking data to ensure that we get four hourly downloads of all the collared elephants where needed for particular analyses in this report. Dr. Alan Barret is thanked for the LoCoH analyses of the collared elephants. Adam Edge and Hannah Malin are thanked for digitizing missing water points to fill in the gaps where the spatial data was missing.

The Wardens of the Associated Private Nature Reserves are thanked for supplying the spatial data on water points as well as census, rainfall and breached dam data. In addition, Glen Thomson and Günter Reinstrof are thanked for additional rainfall data for BPNR. Richard Sowry supplied data for the Kingfisherspruit area and Ndlophu and Ingwelala provided rainfall data for the UPNR. I would also like to thank all the people that assisted with record climate data on occasion at the Elephant Research Station while based at Tanda Tula Safari Lodge over a 10 year period. Cassie and Kate Carstens are thanked for patiently typing up rainfall datasets where needed.

We would like to thank all the Wardens of the APNR who have kindly got up early in the mornings to assist with the collaring operations. We are very grateful for the wonderful veterinary services that we have received over the years from SANParks (Dr. Markus Hofmeyr and Dr. Peter Buss), WildVetsSA (Dr. Cobus Raath) and ProVet (Dr. Peter Rodgers). Ben Osmers and Grant Knight are thanked for representing wildlife pilots par excellence. Numerous private donors have contributed towards the collaring operations. These include: Stefan Breuer, Jerry & Madeleine Cohen, Joubert De Lange, Phyllis Gower, Martin & Sophie Haupt, Charlie Irish, Bruce Jenkins, Andreas Liebenburg, Song Lin, Brian and Claire Makare, Robert Mann, Marlene McCay, Tony McClellan, Barry and Mandy Mence, Chris Pearson, Peter Smelting, Lonnie Strickland, Irving and Yvonne Tucker and Nelda Villines. Numerous smaller donations from the general public have contributed towards the monthly service fees to maintain the collars. The following organisations are thanked for financially contributing towards either collars or collaring operations in one way or another: Aalborg Zoo, African Wildlife Tracking, Pennies for Eles, Tanda Tula Safari Camp, Transfrontier Africa, Wildcon Safari and Events and the Wild Spirit Group.

To all our financial sponsors that have kept us afloat, a very special word of appreciation. Overall, we would like to thank the U.S. Fish and Wildlife Services and the Wildlife and Environmental Society of South Africa for their long-term support.
EXECUTIVE SUMMARY

The Associated Private Nature Reserves (APNR) represents a water-saturated environment. The removal of 27 dams by the floods in 2012 had no significant influence on elephant movements or usage of these areas in general.

Home range sizes of both bulls and cows were larger than anticipated within the APNR and were in keeping with other findings where the wet reasons range was significantly larger than the dry season range. Bulls appear to expand their range beyond the borders of the APNR during the wet season when surface water will be freely available in the neighbouring Kruger National Park (KNP) while females shifted their ranges primarily within the confines of the APNR. However, these range expansions are more than likely driven by the availability of food resources or socialising opportunities rather than water availability. As the KNP has increased the patchiness of available forage to elephants and other species with the closure of numerous water sources since the mid 1990s, these areas may become particularly attractive to elephants with core ranges within the APNR over time. Without the closure of water points within the APNR, a shift in core ranges of elephants found within the APNR into more favourable areas, is anticipated in future. Increased competition over limited forage resources within the APNR is also anticipated, especially during the dry season when elephants are mostly browsers and as the water points are anchoring the population to the APNR during such times. Increased competition over limited food resources could decrease the reproductive output of females in future. The high density of water points within the APNR will eventually lead to the coalescence of the sacrificial zones (areas of high impact) surrounding closely spaced water holes, this will not only decrease the biodiversity of the vegetation component in the long run within the Reserves but will also increase the susceptibility of herbivores populations to periodic drought events. It is suggested that management monitor the coalescence of the sacrificial zones around water points in relation to the distribution of elephants and climatic events as an important management tool to understand how elephant densities and their distribution are influencing changes in vegetation structure and composition over time.

In this study, elephants of different age/sex groups were found to use resources distinctly. In general, rivers were favoured above feeding sites (controls) away from rivers and other water sources. Control sites were used least of all which indicate that other than water requirements, water sources and rivers have important functions in terms of socialising events and additional feeding opportunities at rivers in particular. Only females were found to use rivers significantly more so than other water sources which tie in with their requirements to maintain diets of high quality by seeking out areas with a high greenness index and plant species diversity. When estimates of usage or encounter rates were adjusted to take into account the larger surface area that rivers cover, visits to water sources by prime and young bulls became significantly more frequent than visits to rivers. No difference in usage between the site type (water point, control site or river) was found for any of the other elephant components of the population. These results indicate the importance of considering the extent of any resource potentially used by elephants, it orientation on the landscape (spatial distribution) as well as it importance to various demographic classes within the population because of their inherent differences in movement patterns.
INTRODUCTION

Water provision, fire and culling policies represent the main interventions available to managers of African savanna ecosystems (Owen-Smith 1996). Vegetation communities are influenced at local scales by the concentration of large herbivores and their impacts near permanent water sources. With decreasing distances to water sources, increased effects of grazing, browsing or trampling are often observed and have come to be known as sacrificial zones or so-called ‘piospheres’ (Andrew 1988). Local piosphere effects can include changes in herbaceous vegetation composition, woody vegetation structure and decreased standing crop, tree density and basal cover of herbaceous vegetation. At landscape level herbivore impacts are related to the spatial distribution of water sources and numerous permanent water sources could decrease the effects of piospheres at smaller scales while concurrently homogenise the impact across the landscape at larger scales. Piospheres, if spaced far enough apart across the landscape, could increase the overall biodiversity of the landscape because of various impact tolerant and intolerant plant species growing in different zones (Gaylard et al. 2003). Hence the degree of coalescence of piospheres in relation to various rainfall cycles and distribution patterns of large herbivores could represent important monitoring tools available to managers.

Objective one of the newly proposed Elephant Management Plan of the KNP (2011-2020) essentially deals with restoring the ecological processes required to limit elephants’ spatial distribution at landscape level thereby increasing their patchy use over larger scales. Two proposed methods of achieving this outcome involve minimizing the number of additional water points and dams and mimicking the effect of natural water distribution. Implementation of this objective since the mid 1990s has resulted in reductions in elephant population growth rate and an increase in the spatial variability of elephant land use, thereby increasing the heterogeneity of landscape use and promoting biodiversity. Although the KNP initially had over 300 artificial water points, ongoing reduction of artificial water holes have resulted in many areas being spaced further than 5km away from water sources. However, no such water reduction programme has occurred within the APNR except for the floods in 2012 which naturally breached 27 dams throughout the Reserves where 807 water sources have been counted.

The availability of water sources influences the home range size (Viljoen 1989). Elephants are thought to limit their range to relatively smaller areas during the dry season and disperse more widely during the wet season when free standing water should be readily available and they may need to move away from heavily utilised local patches (Grainger et al. 2005). In general, elephant home ranges tend to decrease as the density of water sources increase and artificial water supplies may mask more natural seasonal landscape uses found in areas lacking artificial water supplies or fences (Van Aarde et al. 2008). The distribution of elephants will also be influenced by both artificial and natural water sources (seasonal pans and river systems). Elephants have thought to be more attracted to river systems than to artificial water points (Smit et al. 2007; Grant et al. 2008), although De Knegt et al. (2010) indicated that for the KNP system the distance to the nearest water source, irrespective of its source, was probably more important than water occurrence at a larger scale which he ascribed to the overriding effect of artificial water supplies.

Given the above, this report aims to (1) determine the proportion of the APNR spaced 1km or 2km from any artificial water source (2) whether the wet season ranges of elephants are significantly different from the dry season ranges given the availability of water within the APNR (3) whether the decrease in a number of dams due to the floods have influenced the movements of elephants or the overall distance from water sources in general and (4) which water sources (artificial versus rivers) are used more frequently than others and the possible reasons for these findings.
MATERIAL AND METHODS

Field methods

Collaring elephants

Collaring operations were conducted according to standard procedures as practiced within the Kruger National Park (SANParks 2011). During collaring operations all study animals were darted by a veterinarian qualified to administer the chemical agents and perform the necessary veterinary procedures. The majority of collaring operations took place from a helicopter flown by a pilot experienced in wildlife capture or related procedures as darting elephants on foot or from a vehicle was potentially more dangerous. The study animal, whether a bull or cow, was darted in the large muscle groups at right angles to the body surface to ensure deep intramuscular injection of the hindquarters, back or shoulders. A30-80 was administered as a mixture with M99 with the dose dependent on the age, sex and body condition of the animal. Azaperone was frequently added to reduce hypertension while the addition of hyaluronidase to the drug cocktail assisted with drug absorption. The drugs were administered from a dart gun kept at a shooting range of 30-40 meters from the study animal. The darted animal was separated by the helicopter from the associating family group or bull group during collaring operations and after delivery of the drug. The induction times averaged 10 minutes. Induced animals would slow their pace under the effects of the drug, eventually toppling over. The immobilized animal was fitted with a collar, ensuring that the collar was not fitted too tightly especially in younger study animals. Steel cable passing through an iron rod was used to pull the collar between the ear and the neck without damaging the cartilage in the ear. Morphometric measurements were taken of the back length, shoulder height, feet circumference and diameter. Blood and tail hair samples were collected from the immobilized animals for DNA and carbon isotope analyses of short-term dietary changes, respectively. Dental impressions were taken from 11 immobilised bulls based on the methods of Rasmussen et.al. (2005). We used Speedex Putty as silicone-based impression material together with Universal Activator from Coltène/Whaledent AG (Coltène, Altstätten, Switzerland). Age estimates (accurate within ± 3 years) were made from all molar progressions as described by (Laws 1966, Sikes 1971, Jachmann 1988, Manspeizer & Delellegn 1992, Lee et. al 2011). In cases where the immobilized animal did not spontaneously roll onto its side (lateral recumbency) or could not be assisted by the ground crew to do so, thereby remaining in an upright ‘sitting’ position (sternal recumbency), collars were fitted as quickly as possible and the full antidote administered to ensure the well-being of the elephant as the bulk of the digestive tract and the shape of the thoracic cavity can lead to respiratory distress. As elephants are obligate nasal breathers the trunk was kept in a straight position and a twig inserted into the external opening of the trunk to ensure unobstructed breathing. During collaring operations the elephant’s ears were folded over the eyes to protect them from harsh sunlight, dust and trauma. The pulse rate (40-50 beats per minute) and respiratory function (6-8 breaths per minute in adults) was monitored. Body temperature was kept below 41°C by throwing jerry cans of water over the ears and body at regular intervals. The antidote was administered in one of the blood vessels in the ear and consisted of a naltrexone in combination with diprenorphine. The antidote took effect 3-5 minutes after being administered whereupon the animal got to its feet and slowly reoriented itself, usually in the direction of the other animals from which it had been separated during the collaring operation. Elephants have been collared throughout Great Limpopo National Park (Figure 1). Either GPS-satellite or GPS/GMS collars were used in order to understand the possible drivers of elephant
Figure 1: Collaring and recollaring locations for male (M) and female (F) elephants within the three study regions of STE-SA which include northern Kruger National Park, central Kruger National Park and the western Kruger National Park (Associated Private Nature Reserves).
movements which could include nutritional-, social- or safety benefits. In total, we have collared 58 elephants during 91 collaring operations in the western, eastern and northern regions of the Kruger National Park (KNP). The distribution data are backed up with observations in the field, recording changes in associations between individuals, musth status and the elephant’s reactions to observers (perception of risk). Within the APNR we have fitted 36 elephants with collars since 1998 with a number of animals being recollared over time (Figure 2). Currently have distribution data from 8 breeding herds and 28 bulls (ranging in age from 12 to over 50 years). In this report we use the data from 34 study animals which have used the APNR as part of their range for long enough periods of time to be included in the analysis. Although some of the study animals have moved from one age group to the next over the 10 year study period, elephants used in the analysis were fixed as either being prime-, adult- or young bulls while cows were only categorised according to their sex as described in previous reports (Henley 2013).

![Figure 2: The number of elephants with active GPS collars within a year and over time since 1998 for each of the three study sites (Kruger west, Kruger east and Kruger north).](image)

**Data**

**Climate-, water point- and census data**

Mean monthly rainfall was collated over an average period of more than 20 years from data supplied by Hoedspruit-, Ndlophu-, Ingwelala and the Kingfisherspruit weather stations. Rainfall data, used as representative of APNR before- (2011), during- (2012) and after- (2013) the floods, were obtained from seven recording stations throughout the Klaserie Private Nature Reserve (KPNR), two from the Timbavati Private Nature Reserve (TPNR), one from the Umbabat Private Nature Reserve (UPNR) and two from Balule Private Nature Reserve (BPNR). Water point data (catchment dams, seasonal pans and artificial water points) and census data were provided by the respective Wardens of the four Reserves. Where water point data was lacking in the APNR, these were digitized using satellite imagery. Water points were also digitized in certain areas that were not officially part of the APNR but which have recently been incorporated or still form part of the APNR complex although not officially so, as these areas are open to elephants and their consequential use. In total 853 water sources were available before the floods within the APNR. These include 290 water points in KPNR, 172 in TPNR, 75 in UPNR and 277 in BPNR. An additional 39 were digitised from areas ‘outside’ or newly
incorporated within the APNR. By removing all seasonal pans that were recorded within a 50m buffer of any river, any water points not accessible to elephants because of fenced properties within the Reserves or water points that were thought to be duplicates after overlaying spatial layers supplied by various sources, 807 water points throughout the APNR were used in the final analyses. These 807 water points were paired with 807 control points, in the same areas but randomly spaced away from any water source (water point or river). All rivers and significant drainage lines which may contain seasonal pools or areas where wells can be dug by elephants were also digitised and included in the analyses. A total of 27 dams were breached during the floods and these data were supplied by the Wardens and kept as part of a specific analysis as this event occurred recently and is not relevant to tracking data collected and used prior to 2013.

Tracking data
The telemetry data consisted of a series spatial locations, ordered in time, with unique time periods, or intervals, between each pair of consecutive locations. The precision of the GSM-GPS collars (Hawk 105 collars, African Wildlife Tracking, South Africa, Pretoria) were tested both within the APNR and the KNP (De Knegt et al. 2011) and found to be <27.8m for 95% of the records. Field testing of the satellite tracking devices (model AWT SM2000E, African Wildlife Tracking, South Africa, Pretoria) had a root mean square error of <30 m with expected location success between 88-96% when tested in the field (Harris et al. 2008, Young 2010). The final elephant tracking data set was obtained via a “data downloader” supplying near real-time entry of data into a geodatabase while a data filter removed obviously erroneous GPS fixes, based on a maximum rate of travel (as used by Austin et al. 2003). Data gaps due to field conditions such as thick vegetation, topography, satellite positioning or improper collar angles were also filtered until a cleaned dataset was imported into a number of formats. The lifespan of the collar was dependent on the frequency at which locations were acquired.

Data analysis
Seasons and rainfall before (2011), during (2012) and after (2013) the floods
Long-term rainfall data from the KNP suggest that this region is subject to an 18 year quasi-rainfall cycle. Nine years with rainfall typically above the long-term annual average and nine years of typically below average rainfall (Gertenbach 1980). Consequently, two seasons were defined and used in the home range analysis based on data from weather stations in and around the APNR that span a period of 20 years or more. A simplified composite climate diagram based on mean monthly rainfall and median daily temperature data from the Hoedspruit weather station was complied and a wet/hot season defined as spanning November-April while a dry/cold season stretched from May-October. Both October and April can be considered transitional months, depending on the rainfall cycle within a particular year and hence each of these month were ascribed to either one of the broadly defined seasons.

The average monthly rainfall within a reserve, irrespective of the number of stations at which it was recorded, was pooled and averaged across the four Reserves within a particular year (2011-2013) for each of the months. This was plotted against the mean monthly rainfall collated over the 20 or longer year period throughout the region to illustrate the sharp increase in rainfall early in 2013. To contrast the total annual rainfall within the APNR against elephant movements within and around the year of the floods, rainfall figures were added across months within a particular year.

Water availability in the APNR
Universal Trans-Mercator 36 S projections were used for all GIS (ArcGIS version 10.1, © 1995-2012, ESRI, USA) analyses in combination with various data management and spatial analysis tools available in ArcToolbox and elsewhere (Hawth’s Analysis Tools version 3.27 © 2002-2006
and ArcMET version 10.1.9 © Jake Wall 2013). Buffers of 1km and 2 km respectively were created around the 807 geo-referenced water points within the APNR. These buffers were then clipped to fit the extent of the APNR boundaries and the total surface area calculated for the polygons of the APNR, and each of the buffer types. After removing the 27 beached dams from the water point layer, the process was repeated. The surface area represented by the buffers were subtracted from the surface area represented by the APNR boundary and the remaining surface area was expressed as a proportion of the area further than either 1km or 2 km from water. The presence of rivers was not included in this analysis to determine the direct effect of largely man-made water points on the system. However, rivers or drainage lines which were considered broad and sandy and which could be used for well-digging by elephants were digitized from satellite imagery and used in subsequent analyses.

**Home range size in a water saturated environment**

The home range size of all elephants were calculated using both the Minimum Convex Polygon (MCP) and the local convex hull (LoCoH) method, also known as the as the nearest neighbour convex hull method (Getz et al. 2004). While the MCP provides an estimate of the area covered by the polygon outlining the outer edge of any movement locations, LoCoH represents is a non-parametric kernel method that constructs a utilization distribution from the union of convex hulls associated with each distribution point and its k-1 nearest neighbours. The method performs better than traditional kernel methods when fitting utilization distributions to home ranges with distinct boundaries (e.g. fences, lakes). Isopleths reflect the proportional density of points within the polygon. Although the 100\% isopleth used in this report includes all data points as does the MCP, the ranges covered using LoCoH will always be smaller than those represented by MCP. The effect of age/sex group on overall home range size, for either of the methods employed, was tested using a non-parametric Kruskal Wallis Test (Fry 1993). Three of the prime bulls whose collars were deployed in the late 1990s, were not included in the statistical analysis as their home ranges were not representative of a full dataset due to premature collar failure in the experimental phase of the tracking study. Differences in wet/hot and dry/cold home ranges were tested by using a non-parametric one-tailed Wilcoxon Signed Rank Test firstly, for bulls in general and then within a particular age/sex group of elephants. A one-tailed test was used as the wet season range was thought to be larger than the dry season range (Fry 1993). All statistical analyses were conducted using GraphPad Prism 5.02 (GraphPad Software Inc. 2007).

**Elephant movements in relation to water points, control sites and rivers**

**Beached dams in relation to census data**

Elephants were counted during the annual census and the data from 2011-2013 were used to determine if elephants were visiting the areas where dams were breached during the floods, less frequently than before. As elephants usually move in response to the helicopter used during these surveys and as the marking of a position from the air will also increase the margin of accuracy of the final GPS recording, a 1km buffer was used around each of the breach dams and the number of elephant census locations that were recorded within this buffer was counted. A Friedman’s non-parametric test followed by Dunn’s Multiple Comparison Test was used to determine if the number of elephants locations in relation to the breached dams differed before (2011), during (2012) or after (2013) the floods (Fry 1993).

**Beached dams – elephant movements**

The GPS tracks of all collared elephants for which a full dataset was available from 2011-2013 was used to determine if any of the collared elephants visited the areas with the breached dams less frequently than before the floods. The number of intersections of the tracks of 13 study animals with a 50 m buffer around the location of the breached dam was counted for each of the years. Whenever a track intersected with a buffer created around a particular a water point the
intersection was considered as a ‘usage’ event. Although tracks would enter and leave such polygons, the total count of intersections probably required division by two. Dealing with division by a constant factor throughout would however, not change the outcome of the statistical analyses and were consequently left as they were recorded. A Friedman’s non-parametric test followed by Dunn’s Multiple Comparison Test was used to determine if the number of intersections in relation to the breached dams differed before (2011), during (2012) or after (2013) the floods (Fry 1993).

Elephant movements and usage of water points, control points and rivers within the APNR

An analysis was done to determine whether water points, control points or rivers were used most by the collared elephants. A buffer of 50m was constructed around each of these site types and clipped to only incorporate the APNR (Figure 3). The number of intersections of an elephants’ track (within a season and for the entire duration of that individual being collared) with a particular site type was counted. All collared elephant data was filtered to only include four hourly location fixes as some individuals’ collars recorded data at shorter intervals than others which would bias the number of intersections counted for these particular individuals. While some intersections would be missed and consequently underestimated by standardising the tracks to four hourly location intervals only, relative proportions of the usage of the various site types were of interest and would consequently be equally affected by the change in location interval and connecting track. This also meant that more study animals could be included in the statistical analysis. Only 18 animals’ data was used in the statistical analysis. These animals were selected to decrease variation between individuals in terms of home range extent, collaring duration and variances in the total number of fixes recorded within a particular season. The following criteria were used in the selection process:

- Datasets had to include more than 800 locations within a particular season (6 month period)
- A dry cycle’s data had to be followed by a consecutive wet cycle’s data within a particular year
- Data had to be obtained from consecutive years were more than one years’ data was incorporated into the analysis.
- The majority of the study animal’s total home range had to be within the APNR within a particular season. On average, the selected prime bulls spent 83% of their time in the APNR. Adult bulls spent 74%, young bulls 68% and the females spent 82% of their time in the APNR. By further selecting only those seasons within a particular bulls’ or cows’ entire collared lifespan where most of his/her time was spent in the APNR, the time periods analysed for the selected animals would have included only those months were more than 80% of their time was found within the Private Reserves.
- The same amount of seasons had to be included for animals collectively analysed within a particular age/sex group and the years chosen needed to be as close together as possible.

Two factor ANOVA was used to determine whether season, site type or the interaction between these variables was contributing most towards the observed variation in the number of intersections counted within a particular age/sex group of elephant. As neither season nor any interaction effects contributed significantly towards the observed variation, seasonal data was pooled across site types and Friedman’s Test, followed by Dunn’s Multiple Comparison Test, was used to determine whether water-, control- or river sites were most frequently used by each of the age/sex groups of elephants (Fry 1993). As the surface area covered by the 50m buffer surrounding the digitized rivers was approximately six times the surface area covered by the 50m buffers surrounding either the 807 water points or the digitized control sites (37,365 km² versus 6.321km²), elephants had six times more chance of intersecting with rivers than with water points or control sites. Irrespective of the diverse feeding opportunities offered by riverine vegetation, the north-south orientation of rivers also meant that this site type probably had a higher chance of intersection with elephant tracks compared to the other sites. Hence the Friedman’s and Multiple
Comparison Tests were repeated after dividing the number of intersections involving rivers by six in an attempt to account and consider the greater availability provided by rivers in terms of surface area alone.

**Figure 3:** The water point distribution in the APNR (top) and the digitized control sites (bottom), together with the rivers or drainage lines used in the analysis for number of elephant track intersections with a 50m buffer around each of the site types (water points, control sites and rivers).
RESULTS AND DISCUSSION

Seasons and rainfall before (2011), during (2012) and after (2013) the floods

Two seasons (wet/hot and dry/cold) of six months each were defined within a year (Figure 4). The mean monthly rainfall across the APNR peaked in January and was above the long-term average from 2011-2013 with the highest monthly recording occurring in January of 2012 (Figure 5).

Figure 4: A simplified composite climate diagram based on mean monthly rainfall and median daily temperature data from the Hoedspruit weather station. The solid line represents mean monthly rainfall and the dashed line median daily temperature. The stippled area is dry/cold season and the lined area the wet/hot season.

Figure 5: The mean monthly rainfall prior to the floods (2011), during the floods (2012) and after the floods (2013) in relation to the long-term mean.
Water availability in the APNR

The APNR is largely saturated with artificial water with approximately $\frac{2}{5}$ and $\frac{2}{3}$ of the surface area being either 1km or 2km respectively from any surface water. There was 23% more of the surface area being further than 1km away as opposed to 2km away from water. The 27 dams that were breached during the floods only made a 1% difference in surface area more than 1km or 2km away from water (Table 1 and Figure 6).

Table 1: Percentage of surface area within the APNR either 1km or 2km from of any man-made water point both before and after the 2012 floods.

<table>
<thead>
<tr>
<th></th>
<th>Within 1km from water</th>
<th>Within 2km from water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before the floods</td>
<td>43%</td>
<td>66%</td>
</tr>
<tr>
<td>After the floods</td>
<td>42%</td>
<td>65%</td>
</tr>
</tbody>
</table>

Figure 6: Existing APNR water points with 1km and 2km buffers respectively together with a number of breached dams which occurred in the 2012 floods.
Home range size in a water saturated environment

Combined home range sizes differed significantly between the different age/sex groups of elephants that were considered whether the MCP (Kruskal-Wallis = 8.69, P = 0.0337) or LoCoH (Kruskal-Wallis = 8.74, P = 0.0329) methods were used. Young males dispersing from the family unit had the largest home range sizes while females had the smallest ranges (Table 2 and Figure 7).

Table 2: Home range analysis of APNR collared elephants. Blue lines are for prime bulls, yellow for adults, orange for young and pink for females. Elephants with an asterisk were collared in 1998-1999 when the collar batteries only lasted a few months which caused insufficient data to make allowance for a seasonal breakdown of home range size.
Generally the wet/hot season range was larger than the dry/cold seasonal range for all study animals (Figure 8) with the exception of three prime bulls (Gower, WESSA and Mac). For these particular animals the results are in keeping with their musth cycles which fell over the start of the dry/cold season and which would explain their increased range in search of oestrous females during a time when limited surface water would normally restrict such large scale movements (Table 2). When comparing bulls and females in general, both sexes wet/hot season ranges were significantly larger than their dry/cold season range (One tailed-, Wilcoxon Sign Ranked Test, $W=192$, $P=0.0018$ for bulls and $W=36$, $P=0.0039$ for cows respectively). When considering the finer divisions of bulls according to age classes, only adult bulls had increased ranges during the wet/hot season months (One tailed-, Wilcoxon Sign Ranked Test, $W=15$, $P=0.0313$).

**Figure 7:** Box whisker plots with the box extending from the 25th percentile to the 75th percentile with a horizontal line at the median (50th percentile) while the whiskers extend from the smallest to the largest value for the home range sizes of various age groups of bulls and females using either the MCP or LoCoH method.

**Figure 8:** Home range size differences for the various age/sex groups for either the wet/hot- or dry/cold season using the MCP method.
On average elephants restrict their foraging distance and consequently their impacts on the vegetation, from between 15km to 17.5km from water (Young 1970). Breeding units in Kenya significantly avoided areas greater than 5km from water (Wittemeyer et al. 2007) while in Botswana breeding herds moved no further than 3.5km from rivers in the dry season and 5km in the wet season (Stokke & Du Toit 2002). The results indicate that feeding opportunities or increased socialising benefits could be driving the expansion and contraction of elephant seasonal ranges across the APNR as home range size differences were observed between the seasons despite water availability not being a limiting factor within APNR.

When considering the extent of the total home range of the different age/sex groups of elephants, most of the expansion of the range occurred during the wet/hot season months into the adjacent KNP or Private Reserves further south (Figure 9a-d). Over 300 artificial water points were provided in the KNP since the water stabilizing program was initiated in the 1930s, but waterholes have actively been removed since the mid-1990s in keeping with the KNP management objectives (Pienaar et al. 1997). Prior to borehole removal in the KNP, the majority of areas in KNP were within 5km of water sources but ongoing water source closure has ensured that most areas are now beyond the 5km range of perennial water and could even extend to 10km in the dry season (Redfern et al. 2005). These areas away from water potentially offer forage resources of greater abundance and higher selective opportunities because of decreased homogenisation of vegetation communities away from the localized impacted areas close the remaining water sources. Consequently, within the water saturated landscape of the APNR, increased competition for forage resources during the dry months could drive expansion into more favourable areas when surface water becomes freely available during the wetter months. APNR elephants with core ranges within the Private Reserves will expand their range movements during the wet/hot months into KNP when such movements are not limited by free-standing water availability. However, numerous permanent water sources within the APNR will anchor the elephants to these Reserves during the dry season when water is not freely available elsewhere and may even attract elephants with core ranges from within the KNP into the APNR during the dry months. These seasonal shifts in range could exacerbate vegetation impact as vegetation communities are most susceptible to the browsing effects by elephants during the dry season. Without attempts to diminish the number of artificial water points over time, these contractions of ranges into the APNR during the dry months may be unavoidable for elephants born within these areas whilst the water saturated environment could concurrently encourage range expansion and infiltration of elephants from within the KNP. Alternatively subtle shifts of core ranges of APNR elephants into the KNP may occur over time as a compensatory measure to increased competitive levels over limited forage resources within the APNR during the dry season.

Elephant home ranges are thought to decrease with an increase in water point density (Grainger et al. 2005). However, both the bull and cow home ranges within the APNR were found to be larger than those reported elsewhere. When comparing home range sizes with other unrestricted regions in Africa, the same trend was found albeit across smaller sample sizes for the breeding herds specifically (Table 5). As distinctions in home range sizes depending on the age of bull were found, it would be important to know the composition of different aged animals within the bull segment used in the analyses elsewhere. It would also be important to know how long the collars were fitted as we restricted our analyses to APNR elephants with repeated years of data. Nevertheless, these results are encouraging as smaller home ranges due to either the presence of fences which limit movements or because of the provision of artificial water sources could exacerbate the impact on the vegetation over time, eventually leading to a loss in spatial heterogeneity or patchiness of landscape use as areas between densely spaced water points, received near equal year-round impact (Loarie et al. 2009).
Figure 9a: LoCoH home rangers (100% isopleth) for prime bulls (from left to right and top to bottom): Benjamin, Brazen, Captain Hook, Christo, Classic, Douglas, Everest, Forty-six and General.
Figure 9a (continued): LoCoH home rangers (100% isopleth) for prime bulls (from left to right and top to bottom): Gower, Intwandamela, Mac, Matambu, Mellow, Proud and WESSA.
Figure 9b: LoCoH home rangers (100% isopleth) for adult bulls (from left to right and top to bottom): Caughley, Iain, Snap, Soshangane and Vee.
**Figure 9c:** LoCoH home rangers (100% isopleth) for young bulls (from left to right and top to bottom): Big-Al, Irving, Namaste, Striburus and Tussle.
Figure 9d: LoCoH home rangers (100% isopleth) for females (from left to right and top to bottom): Charlise, Diney, Joan, Lapajuma, Mandy, Umbabat and Yvonne.
Table 6: Home range sizes (MCP) of bulls and cows collared within the APNR in comparison with the literature.

<table>
<thead>
<tr>
<th>Group type</th>
<th>Sample size: Mean (range) in km² within South Africa*</th>
<th>Sample size: Mean (range) in km² within the APNR</th>
<th>Sample size: Mean (range) in km² other regions*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breeding herds</td>
<td>51: 595 (21-2766)</td>
<td>8: 1863 (619-3203)</td>
<td>73: 1678 (4-10 738)</td>
</tr>
</tbody>
</table>

*Van Aarde et al. 2008

Both bulls and cows’ wet season ranges were significantly larger than their dry season ranges. On closer inspection of the difference in seasonal ranges between various age groups for bulls, the increased wet season range was only found to be statistically significant for adult bulls (aged 25-35). Bulls in the prime age category (older than 35 years) experience regular annual musth cycles which could mask seasonal distinctions in range movements, depending on when particular bulls come into musth. Young bulls (15-25 years) had the largest total home ranges of all age/sex categories and large-scaled exploratory excursions by these individuals added to the variability within this age group which could also have influenced the outcome of the statistical results.

Elephant movements in relation to water points, control sites and rivers

Beached dams in relation to census data

There was no significant difference between years in the number of elephant census recordings found within a 1km buffer of the location of the 27 breached dams (Friedman’s Statistic = 3.86, P=0.125). Over the entire APNR, the breached dams coincided less with the census count of elephants during the year of the flood (2012) when compared to other years where an equal number of census recordings were found within the vicinity of the recorded breached dams (Table 3 and Figure 10).

Table 3: The frequency within a particular year with which an elephant census location was found to intersect with a 1km buffer around each of the 27 breached dams within the APNR.

<table>
<thead>
<tr>
<th>Reserve</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPNR</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>KPNR</td>
<td>5</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>UPNR</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TPNR</td>
<td>5</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>APNR</td>
<td>12</td>
<td>5</td>
<td>12</td>
</tr>
</tbody>
</table>

Beached dams – elephant movements

There was no significant difference (Friedman’s Statistic = 0.19, P=0.909) between years in the number of elephant tracks which intersected a 50m buffer surrounding the location of the 27 breached dams (Table 4).

The results indicate that the number of dams removed through the floods, are not sufficient to have influenced elephant movements in any way. To detect changes in the responses of elephants to waterhole ‘closure’, more water points need to be removed and elephant responses followed for longer tracks of time, subsequent to such actions.
Figure 10: Buffers with a 1km radius (orange circles) around the 27 dams that were breached in 2012 and the overlap with elephant census locations for 2011 (purple), 2012 (blue) and 2013 (yellow).

Table 4: The number of intersections from 13 collared elephants with complete datasets for 2011-2013 with a 50m buffer around each of the 27 breached dams within the APNR.

<table>
<thead>
<tr>
<th>ID</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>BigAl</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Classic</td>
<td>12</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Diney</td>
<td>12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gower</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Intwandamela</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Joan</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Lapajuma</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Matambu</td>
<td>18</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Proud</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Summer</td>
<td>12</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Tussle</td>
<td>0</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Umbabat</td>
<td>2</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Yvonne</td>
<td>0</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>62</td>
<td>42</td>
<td>50</td>
</tr>
</tbody>
</table>
Elephant movements and usage of water points, control points and rivers within the APNR Distinct age/sex groups of elephants used water points, control sites or rivers differently. All elephant group types, except for adult bulls, used rivers significantly more than control sites and this trend was most pronounced in prime bulls. For breeding herds rivers were also used more frequently than water points (Dunn’s Multiple Comparison Test following a Friedman Test). However, when accounting for the increased surface area of rivers (division by six), water points were used more frequently by prime and young bulls respectively (Table 5 & Figure 11). The use of the APNR relative to entire elephants’ range is depicted in Figure 12.

Table 5: The differences in site usage (water points-, control sites and rivers) by prime- (blue), adult- (yellow), young bulls (orange) and females (pink). The first Friedman Test results represent a comparison before the increased surface area of rivers have been accounted for while the second Friedman Test results were after accounting for the increased surface area of rivers. The bracketed results give the outcome of the Dunn’s Multiple Comparison Tests.

<table>
<thead>
<tr>
<th>Elephant ID</th>
<th>Water point</th>
<th>Control site</th>
<th>River</th>
<th>River divided by 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classic</td>
<td>514</td>
<td>194</td>
<td>1250</td>
<td>208</td>
</tr>
<tr>
<td>Gower</td>
<td>666</td>
<td>364</td>
<td>1467</td>
<td>245</td>
</tr>
<tr>
<td>Intwandamela</td>
<td>520</td>
<td>84</td>
<td>940</td>
<td>157</td>
</tr>
<tr>
<td>Matambu</td>
<td>616</td>
<td>143</td>
<td>815</td>
<td>136</td>
</tr>
<tr>
<td>Proud</td>
<td>442</td>
<td>297</td>
<td>1198</td>
<td>200</td>
</tr>
<tr>
<td>Friedman Statistic=10 P=0.008               **</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Friedman Statistic=7.6 P=0.0239              *</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caughley</td>
<td>331</td>
<td>150</td>
<td>992</td>
<td>165</td>
</tr>
<tr>
<td>Iain</td>
<td>288</td>
<td>158</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>Soshangane</td>
<td>340</td>
<td>228</td>
<td>1171</td>
<td>195</td>
</tr>
</tbody>
</table>
| No significant difference between site types tested with 'river' or 'river/6'
| BigAl           | 412         | 136          | 1368  | 228                |
| Namaste         | 344         | 226          | 622   | 104                |
| Striburus       | 724         | 444          | 1952  | 325                |
| Tussle          | 240         | 138          | 366   | 61                 |
| Friedman Statistic=10 P=0.0046               * |
| Friedman Statistic=7.6 P=0.0417              * |
| Joan            | 78          | 146          | 878   | 146                |
| Lapajuma        | 230         | 262          | 1094  | 182                |
| Mandy           | 490         | 392          | 748   | 125                |
| Summer          | 300         | 286          | 1502  | 250                |
| Umbabat         | 596         | 384          | 989   | 165                |
| Yvonne          | 608         | 610          | 1483  | 247                |
| Friedman Statistic=10 P=0.0081               * |
| No significant difference between site types tested with 'river/6'
| TOTAL           | 7739        | 4642         | 18855 | 3143               |
Figure 11: Box whisker plots with the box extending from the 25th percentile to the 75th percentile with a horizontal line at the median (50th percentile) while the whiskers extend from the smallest to the largest value for the number of intersections of elephant prime- (blue), adult (yellow), young bull (orange) and female tracks with water points, control sites and rivers (left) and rivers divided by six to account for differences in surface areas (right).
Figure 12: Intersections of tracks from prime- (blue), adult (yellow) and young bulls (orange) with rivers (green dots) or water points (blue dots) in the alphabetical order as listed in Table 5.
Figure 12 (continued): Intersections of tracks from young bulls (orange) and females (pink) with rivers (green dots) or water points (blue dots) in the alphabetical order as listed in Table 5.
According to the literature, elephants, with breeding herds in particular, have been found to be more attracted to river systems than to artificial water points (Smit et al. 2007; Grant et al. 2008). Before factoring into the analysis the total surface area accounted for by rivers, which would influence the encounter rate of these areas when considering the intersections of polygons with the tracks of elephants, I found that across all age/sex groups of elephants, rivers were used more so than the control sites away from any water sources. The control sites were digitized to account for possible feeding sites, independent of drinking opportunities. Although not statistically significant, the control sites were consistently less frequently used than the water points (left hand side figures—Figure 11). Given that elephants spend the majority of their time feeding with only a small proportion of their time drinking (Owen-Smith 1998), these results indicate that water sources potentially offer important socialising opportunities as apart from drinking activities. Furthermore, artificial water sources in particular, are expected to provide reduced feeding opportunities in close proximity to them because of the so-called biosphere effect (Andrew 1988). Only within breeding herds were rivers used more frequently than artificial water points (Table 5 with Figures 11). My results support other studies’ findings and indicate that rivers are relatively more important to breeding units than to other components of the population because they are not only used as drinking sources but will offer increased feeding opportunities because of the higher species diversity, greenness index and plant biomass offered along the verges. All these vegetation properties are important for females to maintain higher quality diets when compared to the bulls. Females’ higher mass specific metabolic rate and the increased demands of pregnancy and lactation necessitate them to maintain diverse diets of superior quality when compared to bulls (Stokke 1999; Greyling 2004; Shannon et al. 2006, Woolley et al. 2009).

When the relative surface area of the rivers and drainage lines were brought into consideration, water points were visited more frequently than rivers overall and the results proved to be significant for prime and young bulls (Table 5 and Figure 11—right hand side figures). As prime bulls may segregate away from areas with abundant rivers because of sexual segregation driven by differences in nutritional needs and body size differences between the sexes (Greyling 2004), these results are not surprising. Young bulls, who have been found to explore large areas more extensively than any other age/sex component for the population, are probably dependent on water points dotted across the landscape during their travels and don’t specifically follow rivers when exploring new areas. Hence, once I had accounted for the possible difference in encounter rates between water points versus rivers, the results were more in agreement with those of De Knecht et al. (2010) who indicated that within the KNP system the distance to the nearest water source, irrespective of its source, was probably of greater importance.

**RECOMMENDATIONS**

The APNR represents and extensively water-saturated landscape with 2/3 of the Reserve within 2km from any artificial water source and 2/5 thereof within 1km from water. In addition to these water sources, there are various rivers or drainage lines which either provides additional perennial or ephemeral water to water-dependent mammalian species. Although the dams that were breached during the floods may have potentially changed elephant movements in relation to them, the results indicate that more dams would need to be removed and the effect on elephants movements would need to be studied in the longer term to understand changes in their landscape use in relation to water point closure.

Despite the high density of water points in the APNR, home range sizes of elephant were found to be large and expansion into surrounding areas would help to alleviate year-round impact to the vegetation by most components of the elephant population. Bulls seem to expand their range outside of the APNR more readily when compared to females and most of these expansions occurred during the wet/hot season when surface water would also be readily available.
elsewhere. How musth cycles in older bulls and exploratory trips in younger bulls are influencing these observed range expansions in the bull segment of the population, should be studied in greater detail. However, elephants are preferentially grazers and switch to a grass-rich diet in the wetter months (Owen-Smith 1998). Furthermore, females are known to have less severe impact on the vegetation when compared to males (Greyling 2004). Hence, the abundance of water points within the APNR are not only keeping bulls within the Reserves when their impact on the woody vegetation would be greatest but might also be drawing bulls from neighbouring areas into this water-rich environment during the dry season. Cows are primarily staying within the APNR year-round but their effects during the wet season, when they are primarily feeding on grass, is probably negligible to the woody components of the vegetation.

The homogenation of the vegetation in between closely spaced water points could eventually lead to limited resources for females within the APNR which in turn could decrease their reproductive output. In addition core ranges of bulls and cows could eventually shift over time towards the more favourable feeding opportunities on offer in the KNP because of their ongoing and active removal of water points over time. Both these possibilities offer interesting research opportunities which should be considered in future as they would influence the impact of elephants on the woody vegetation within the APNR. It would be important for management to monitor the coalescences of the sacrificial zones around water points in conjunction the spatial distribution of elephants and changes in the climatic cycles over time. The changes in the extent of the sacrificial zones would provide valuable information on the relevance and importance of water point closure in future. Several studies have shown that an increased patchiness of landscape use by elephants is preferable and necessary to maintain vegetation diversity. A reduction in the 807 water points within the APNR, should be encouraged at all times, especially as the KNP has already closed more than 100 boreholes since 1998 (SANParks 2011).

The results indicate that elephants used various water sources to different degrees which not only depend on the sex of the animal but also the age category of the bull. Results indicate that while rivers offer superior feeding opportunities in addition to drinking sources, other water sources may offer important socialising opportunities in particular when compared with feeding sites in general. The importance of considering not only the type of water source but also its spatial extent and orientation relative to elephant movements have been highlighted by the study and require more in-depth consideration as they do influence their usage and preference indices.
REFERENCES


Owen_Smith 2006


