Population dynamics and elephant movements within the Associated Private Nature Reserves and adjoining Kruger National Park

Annual Progress Report
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STE Transboundary Elephant Research Programme
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1. Introduction

Save the Elephants (STE) is a publicly funded NGO, dedicated to securing a future for
elephants within their natural environment, in tolerant co-existence with mankind. To
achieve this, the organisation is actively involved in ecological and behavioural research,
education and information dissemination, and elephant-habitat conservation programmes
(www.savetheelephants.org). Research projects are running throughout Africa, in areas
that reflect the diversity of conservation issues and elephant habitat types.

The STE Transboundary Elephant Research Programme was initiated in May 2003 with
the aim of providing appropriate data and insights on an important, expanding elephant
population within a contained but recently extended protected area. The removal of
fences separating the Association of Private Nature Reserves (APNR) and the Kruger
National Park (KNP) (Fig. 1.1) was completed in 1993. A year later KNP management
placed a moratorium on the culling programme within that Park. The radical change in
circumstances raised a number of critical conservation and management issues, including:
1) how the elephant population is changing in size and structure over time; 2) how it is
distributed in space and time; 3) how observed distribution patterns reflect variation in
resources and the social landscape and 4) what impact elephants are having on this
landscape? The recent expansion of the greater conservation area to include the
Limpopo NP in Mozambique, and the revision of the KNP elephant management policy
have added additional weight to these questions. Completely addressing these issues
within a short period of time is beyond the scope of a relatively small research effort
such as the STE Transboundary programme. It would also ignore the fact that
environmental conditions change over time as do populations and population responses.
Therefore, this research programme has adopted a longer-term vision compared with
that which is traditional within the ecological (post-graduate) research community. Our
objectives, as originally stated, are:

1. to determine how many elephant bulls use the APNR;
2. to determine how many breeding herds frequent the APNR;
3. to identify the big tuskers that frequent the APNR;
4. to determine the movement of elephants within the APNR and adjacent areas;
5. to determine the changes in the density of elephants within the APNR and how this
   changes over time and whether these changes are through births, deaths or
   elephant movements to and from the KNP;
6. to establish the extent to which elephants frequent different parts of the APNR
   and KNP;
7. to determine whether food resources and/or social and safety benefits motivate
   elephant movements;
8. to quantify the impact of elephants on specific tree species.

This progress report covers the period November 2004 to November 2005 and presents
preliminary results and discussions.
Fig. 1.1. The location of conservation areas within the greater KNP – Limpopo TP complex. The Association of Private Nature Reserves (APNR) comprises the Timbavati, Umbabat, Klaserie and Balule Private Nature Reserves.
1.1. Environmental conditions

The rainfall for the austral-seasonal year July 2004 to June 2005, as measured at the elephant research office, was 420 mm. In the absence of long-term data from here, this may be compared against the mean annual rainfall (MAR) measured at Hoedspruit (513 mm, 1977-1990), a registered meteorological station ca. 27km west-south-west of the research centre. The assumption being that the latitudinal rainfall gradient evident in the Kruger NP (Gertenbach 1980) is also reflected in adjacent areas to the west. As such, locations at similar latitudes will have similar rainfall regimes. Accepting this assumption, and bearing in mind the lesser east - west altitudinal gradient (Gertenbach 1980), the 2004/2005 rainfall represents more than 80% of the mean. Consequently, it would not be considered a drought year (>75% MAR).

The ecological implications of annual rainfall relate not only to whether the year in question was more or less dry than the average, but also how the year fits into the larger temporal context. In other words, it is not only the intensity of a wet/dry year that influences ecosystem functioning, but also the duration of the wet/dry period. Gertenbach (1980) described a quasi 18-20 year rainfall cycle within the KNP, where 9-10 years of typically above average rainfall are followed by a similar period of typically below average rainfall. This pattern appears to repeat itself widely within the summer rainfall region of southern Africa (Tyson & Dyer 1975). Sufficient data are available from the Hans Hoheisen Wildlife Research Station to establish where we currently lie within the cycle (Fig. 1.2). The periodicity of the wet and dry phases was derived from Gertenbach’s (1980) data for Skukuza, which provided a phase pattern extending from 1919/1920 through 1978/1979: their established 9-10 year cycle, the mean annual rainfall for the phase and the number of years within a phase that deviate from the norm. Within the KNP, the mean annual rainfall, for any phase, is typically 13% above or below the long-term mean (Gertenbach 1980) (cf. Table 1.1). Furthermore, two to three years within a phase typically do not conform (e.g. above average annual rainfall within a dry phase). The pattern presented in Fig. 1.2 and Table 1.1 was corroborated using an annual rainfall data set from Kingfisherspruit, KNP, which spanned a similar period (1960/1-2000/1).

Two anomalies emerge in the phase pattern presented here. The first is the extended, but erratic wet period between 1970/1 to 1984/5. The annual rainfall during this period was on average only 4% greater than the long-term mean. As such it was not a distinct wet phase, and did not meet the 13% standard suggested by Gertenbach (1980). Furthermore, the five dry years were more or less evenly interspersed throughout the period, nullify any clear wet phase pattern. The standard deviation of this period’s data set was not greater than that for others, hence it is not the extent of the change in rainfall that is unusual, but rather the interspersion of wet and dry years during this phase. The second interesting period is the 1995/6 to 2000/1 wet phase. This appears exceptional in that it only lasted six years. It would appear that after this brief wet period we are now in a dry phase once again.
Fig. 1.2. The percentage deviation of Hans Hoheisen Research Station annual rainfall from the MAR (557 mm) and the three year weighted running mean of these deviations. Phases of the rainfall cycle are shown as coloured bars below the graph.

Table 1.1. Mean annual rainfall of wet and dry phases as a proportion of the long-term mean for the Hans Hoheisen station.

<table>
<thead>
<tr>
<th>Period</th>
<th>Mean %</th>
<th>Years</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 1960/1</td>
<td>120.8</td>
<td>≥6</td>
<td>incl. 1 yr &lt;MAR</td>
</tr>
<tr>
<td>1961/2 - 1969/0</td>
<td>89.0</td>
<td>9</td>
<td>incl. 3 yrs &gt;MAR</td>
</tr>
<tr>
<td>1970/1 - 1984/5</td>
<td>104.5</td>
<td>15</td>
<td>incl. 5 yrs &lt;MAR; indistinct pattern</td>
</tr>
<tr>
<td>1985/6 - 1994/5</td>
<td>78.2</td>
<td>10</td>
<td>incl. 2 yrs &gt;MAR</td>
</tr>
<tr>
<td>1995/6 - 2000/1</td>
<td>132.5</td>
<td>6</td>
<td>incl. 2 yrs &lt;MAR</td>
</tr>
<tr>
<td>2001/2 -</td>
<td>82.4</td>
<td>≥4</td>
<td>incl. 1 yr &gt;MAR</td>
</tr>
</tbody>
</table>
Seasonal rainfall patterns influence habitat conditions for large herbivores at a finer temporal scale. Dry season rainfall in particular has recently been highlighted as a potentially important determinant in the survival of some ungulates within the KNP (Owen-Smith & Ogutu 2003). Despite a promising start to the 2004/2005 wet season, each month, with the exception of November, received less rain than may be expected from the long-term mean (Fig. 1.3). The wet season was characterised by late rains. This pattern of increasing rainfall as the season progressed is the inverse of the typical trend, i.e. decreasing monthly rainfall following the early wet season peak (Dec). While the trend in below average rainfall persisted through to the dry - wet season transition period (October 2005), the current wet season has started once again with early, above average rains. The composition and phytomass of the herbaceous layer is strongly correlated with the timing and amount of rainfall. At this stage it is not clear how the seasonal rainfall pattern influenced elephant foraging behaviour, but with time we will be able to compare seasonal movement patterns across a number of years.

Fig. 1.3. Monthly rainfall (bars) for the period November 2004 to Nov 2005 as measured at the Elephant Research station. The mean annual rainfall (area plot) is based on the long-term rainfall records from Hoedspruit. Seasons are shown as shading behind months.

Daily temperatures were not exceptional (Fig. 1.4.). Minimum daily temperatures did not fall below 5 °C (range: 6 – 25 °C). Four days recorded a maximum greater than 40°C (range: 19 – 42 °C).

Fig. 1.4. Mean median, minimum and maximum daily temperature recorded at the Elephant Research station between November 2004 and November 2005.
2. Elephant identification study

2.1. Identification of elephant bulls

Individual identification records of sighted animals (bulls and cows) were recorded by collecting detailed photographs or drawings based on unique patterns of tears, nicks, holes and veins in the ears. Bulls with tusks estimated to be in excess of 50lbs were considered large tusked individuals. The date, time and location of each sighting was noted in addition to the social context, the reaction index and reproductive status of the sighted individual.

A total of 1264 sightings of bulls have been made since May 2003 until November 2005. This figure includes multiple sightings of the same animal within a month as well as sightings of bulls of which only one ear pattern was collected (incomplete identification). The complete (both ears) identification kits of 374 individual bulls were collected during the study period.

As it would be of greater interest to management, bull sightings have been divided into size and age categories and all subsequent analyses have been conducted within each of these categories. These categories have been based on various physical features and behavioural characteristics and include the following categories (please refer to Appendix 3 for a detailed description of the divisions):

- Immature bulls - the identification of immature bulls have not been the focus of the study and records have only been collected if observation time within a breeding herd has permitted this after photos of the young adult bulls and cows within the breeding herd have been collected. The lack of significant markings to the ears of immature animals has also proved problematic when it comes to re-sighting data. Sampling immature animals have therefore been biased towards those individuals with characteristic features. Nevertheless, identikits of ‘recognisable’ immature bulls will be continued as it will provide valuable information on how far and when bulls disperse from their natal herds as these bulls enter older age categories in the years to come.
- Young adults.
- Prime bulls.

Multiple sightings of an individual bull were pooled within a month to obtain a monthly re-sighting rate. Third order polynomial models were used to describe the relationship between the accumulative number of new sightings over time and the rate at which elephant bulls were re-sighted. For all categories of bulls, the regression model adequately explained the variation in new sightings and re-sightings over time (Fig. 2.1, $r^2=0.99$). By June 2004 the accumulative re-sighting rate of prime bulls had exceeded the accumulative sighting of new bulls so that re-sightings of prime bulls were more frequent than new sightings within this size category (Fig. 2.1 (c)). Results indicate that in the young- and immature bull categories, the re-sighting rates had not yet reached an asymptote. This could be expected for the immature bulls for the reasons outlined above. Although the number of identification records collected of young adult bulls exceeds those collected within any other size category of bulls, only 40% of these animals have been re-sighted since the start of this project (Table 2.1). These preliminary results therefore indicate that the majority of the bull population within the APNR is composed of young adult bulls.
Fig. 2.1. The accumulative number of re-sightings and new sightings of immature (a), young (b) and prime bulls (c) from May 2003 until November 2005.
Table 2.1. Immature, young adult and prime adult bull resightings and re-sightings calculated as a percentage of the total number of bulls identified within each size category within the APNR.

<table>
<thead>
<tr>
<th>Size category</th>
<th>IDs collected since May 2003</th>
<th>Bulls re-sighted since May 2003</th>
<th>Bulls sighted only once since May 2003</th>
<th>Re-sighting percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immature</td>
<td>100</td>
<td>28</td>
<td>72</td>
<td>28%</td>
</tr>
<tr>
<td>Young adult</td>
<td>157</td>
<td>62</td>
<td>95</td>
<td>39%</td>
</tr>
<tr>
<td>Prime</td>
<td>117</td>
<td>86</td>
<td>31</td>
<td>74%</td>
</tr>
<tr>
<td>Total</td>
<td>374</td>
<td>176</td>
<td>198</td>
<td>47%</td>
</tr>
</tbody>
</table>

2.2. Population estimates of bulls

The Jolly stochastic model (Begon 1979) was used to estimate the number of different size categories of bulls utilising the APNR on a seasonal basis. The Jolly stochastic model was applied as the basic model as it not only makes allowance for a standard error associated with the outcome of the estimate but also allows birth, death, immigration, and permanent emigration to occur and is therefore appropriate for an open system like the APNR. As animals identified during repeated sampling occasions (monthly in this case) could be followed through time and allocated to a specific ‘marking’ occasion, the method was found to be useful. The dataset was prepared in the following way:

- Data obtained from collared animals were removed from the dataset as ‘recapture’ events of these animals were not random.
- The sampling period was taken to start on May 2003 when the project was started on a full-time basis. All animals prior to this date were considered ‘unmarked’.
- All sightings of breeding units and immature males associating with them were removed from the dataset as the numbers and identikits of animals involved in these social units could not be accurately assessed.
- Data for young adult and prime bulls were analysed separately.
- All bulls from which incomplete IDs were collected (one ear’s pattern only) were removed from the dataset as identification of these animals in future sampling events was uncertain.
- Seasons were defined according to Appendix 1. Sightings within the months of April and October of each year were removed from the dataset as these periods represented transitions between seasons. Omitting transitional periods from the dataset furthermore allowed ‘recapture’ periods of equal length (five months) to be compared.

According to the model wet season population estimates for both young adult bulls and prime bulls are similar between years and are relatively higher than in the dry season (Fig. 2.2 (a) & (b)). With time, comparisons between the dry seasons of different years can be made and it will then be possible to determine whether a lower dry season population estimate represents a consistent trend between years. Due to a larger number of re-sightings within the prime bull category, the model estimates for this size category were closer to the actual number of individuals that were sighted within a season. Furthermore the standard error associated with each of the population estimates for prime bulls were smaller when compared to those of young adult bulls (Fig. 2.2 (b)). The results corroborate previous findings that the adult bull population within the APNR consists largely of young adult bulls. Although the model may not reflect absolute numbers, indications are that the overall population size for adult bulls (both young and prime bulls) can be estimated at 228 (141 + 87) for the wet season of 2003/2004; 167 (99 + 68) for the dry season of 2004 and 229 (152 + 77) for the wet season of 2004/2005 (Table 2.2).
Fig. 2.2. Population estimates obtained from the Jolly stochastic model for young adult bulls (a) and prime bulls (b) in relation to the actual number of individuals that were sighted within each of the seasons.

As the dry season of 2003 was considered the first capturing event, no population estimate is available for this time period. Likewise, a population estimate for the dry season of 2005 can only be calculated once recapture data is obtained during the wet season of 2005/2006. With time estimates of additional dry seasons will therefore become available.
Table 2.2. Population estimates (± SE) of young adult and prime bulls within the APNR according to the Jolly stochastic model.

<table>
<thead>
<tr>
<th>Season</th>
<th>Young adult bulls</th>
<th>Prime bulls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet 2003/2004</td>
<td>141 ± 41</td>
<td>87 ± 10</td>
</tr>
<tr>
<td>Dry 2004</td>
<td>99 ± 25</td>
<td>68 ± 8</td>
</tr>
<tr>
<td>Wet 2004/2005</td>
<td>152 ± 54</td>
<td>77 ± 16</td>
</tr>
</tbody>
</table>

2.3. Musth in bulls

In general the monthly proportion of musth bulls followed the rainfall cycle closely. The data collected during the initial study period (May - September 2003) can in this instance, be largely ignored as the proportion of musth bulls collected during this time would be influenced by the number of bull identikits collected at the outset of the study. Furthermore, September 2003 does not reflect the number of musth bulls present as travels abroad led to limited fieldwork being conducted during this month. The proportion of musth bulls reached a peak in April 2004 and then again in March 2005 (Fig. 2.3). In 2004 the first substantial rain fell comparatively late (January) while in 2005 the rains came early (November) which could explain the earlier musth peak in 2005 when compared to 2004. In general, the largest proportion of musth bulls was found between January and July each year. This period would be the most suitable time for bulls to come into musth as it follows a two-month time lag in a peak in the mean monthly rainfall (December-Hoedspruit data). Cows that conceive from February through to June would give birth 22 months later from December through to April during the late rainy season. By implication, these cows would have access to the most nutritious food sources when their physiological needs would be the highest such as during late pregnancy and early lactation. Their offspring would consequently have the greatest chance of survival. Preliminary observations indicate that the large, competitive bulls are coming into musth at this prime time of year as 45% of all large tusked bulls sighted within the APNR are coming into musth within these five months (February to June).

To provide some indication of how prime bulls use the APNR, bulls in this size category have been divided into resident bulls (bulls that have both their non-musth and musth cycles within the APNR) or bulls expanding their home range (Table 2.3). Bulls can either expand their range from within the KNP and enter the APNR for the duration of their musth cycle (KNP expander), or they may leave the APNR for the duration of their musth cycle (APNR expander). Classic can be described as a resident bull while Mac represents a KNP expander. It is presumed that both resident bulls and APNR expanders originally came from the APNR as they would spend the majority of their time within the private reserves. KNP expanders were probably born within the KNP and learnt to incorporate the APNR as part of their range once the fences were removed. It would be interesting to test these hypotheses by conducting genetic analyses.
Fig. 2.3. The proportion of musth bulls expressed as a percentage of the total number of bulls sighted within each month from May 2003 until November 2005. Connecting lines instead of bar charts have been used to clearly illustrate trends although the data within a particular month does not necessarily depend on that recorded during the previous month. Please note that the musth trend line is continually being updated as long as additional data is received from landowners and other interested parties which submit photographs and sighting information on prime bulls.

Table 2.3. The number of prime bulls either resident within the APNR or classified as APNR or KNP expanders in relation to being either large tusked or average tusked individuals.

<table>
<thead>
<tr>
<th></th>
<th>Resident</th>
<th>APNR expander</th>
<th>KNP expander</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large tusk size</td>
<td>7</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Average tusk size</td>
<td>23</td>
<td>38</td>
<td>27</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>48</td>
<td>39</td>
</tr>
</tbody>
</table>

The majority of prime bulls found within the private reserves presumably come from the APNR (67%). Comparatively few large tusked individuals are resident within the APNR (24%). The highest proportion of large tusked individuals are coming from the KNP (41%) while a similar proportion of average tusk size individuals are leaving the APNR for their annual musth cycle (43%). The APNR may function as an important range expanse area for competitive bulls (large tusked individuals in musth) within the KNP.

2.4. Social context of sightings
Prime bulls not in musth were sighted nearly three times more frequently in bachelor groups than on their own (Table 2.4). Only 11% of all sightings of prime bulls were within breeding herds. In contrast near equal proportions of sightings of young adult bulls not in musth were either within breeding herds or bachelor groups. Relatively few sightings
(17%) of solitary young adult males were made (Table 2.5). These results emphasize the social importance of bachelor groups to non-musth prime bulls while both the social context of breeding herds and other large mature bulls are of importance to young adult males.

Prime bulls in musth were frequently sighted on their own (56%) and rarely within bachelor groups (15%). Prime bulls in musth were seen nearly twice as frequently in the company of breeding herds when compared to sightings of this segment of the population whilst not in musth (Table 2.4). Very few sightings of young adult males in musth were made during this study (Table 2.5) which could reflect on the accuracy with which bulls have been assigned to the different size categories (Appendix 3).

Table 2.4. The number of sightings of prime bulls according to their reproductive status and in association with breeding herds, other bulls or on their own.

<table>
<thead>
<tr>
<th>Social context</th>
<th>Musth</th>
<th>Non-musth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alone</td>
<td>100</td>
<td>66</td>
</tr>
<tr>
<td>Within breeding herds</td>
<td>52</td>
<td>31</td>
</tr>
<tr>
<td>Within bachelor</td>
<td>26</td>
<td>177</td>
</tr>
</tbody>
</table>

The data for Classic has not been included in the table and has been discussed in detail elsewhere in this report (section 3.3).

Table 2.5. The number of sightings of young adult bulls according to their reproductive status and in association with breeding herds, other bulls or on their own.

<table>
<thead>
<tr>
<th>Social context</th>
<th>Musth</th>
<th>Non-musth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alone</td>
<td>1</td>
<td>55</td>
</tr>
<tr>
<td>Within breeding herds</td>
<td>2</td>
<td>130</td>
</tr>
<tr>
<td>Within bachelor</td>
<td>-</td>
<td>139</td>
</tr>
</tbody>
</table>

2.5. Identification of breeding herds

A total of 301 sightings of breeding herds were made since May 2003 until November 2005. This figure includes multiple sightings of the same herd within a month as well as sightings of herds were no identification records could be collected either due to poor visibility or rapid movement amongst the members of the herd. The identification records of 224 individual cows have been collected from 15 independent breeding herds that have been identified.

Multiple sightings of the same herd were pooled within a month to obtain a monthly re-sighting rate. A third order polynomial model was used to describe the relationship between the accumulative number of new sightings over time and the rate at which breeding herds were re-sighted. The regression model adequately explained the variation in new sightings and re-sightings over time (Fig. 2.4, $r^2 = 0.99$). By April 2004 the accumulative re-sighting rate of breeding herds had exceeded the accumulative sighting of new herds so that re-sightings of identified herds were more frequent than new sightings of herds.
Although the re-sightings of breeding herds is only at a 22% level since May 2003, this proportion more than likely under represents the actual re-sighting rate (Table 2.6). On many sighting occasions it was only possible to collect 2-3 identification records from a few individual cows for reasons outlined above. Although these individuals were then ascribed to an ‘uncategorised herd’ if they were not on record, they could have been part of an existing herd of which their particular identikits had not yet been collected and should therefore represent a re-sighting instead of a new sighting. With time, all the adult cows within the herds will be known and it will then be possible to ascribe certain individuals as belonging to particular family unit with greater ease. The fission and fusion of different family units with a change in season have also confounded the assigning of particular individuals to specific family units.

Table 2.6. The proportion of breeding herds that have been re-sighted of the total number of herds identified within the APNR.

<table>
<thead>
<tr>
<th>Total number of breeding herds identified since May 2003</th>
<th>Number of breeding herds re-sighted since May 2003</th>
<th>Number of breeding herds sighted only once since May 2003</th>
<th>Re-sighting percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>58</td>
<td>13</td>
<td>45</td>
<td>22%</td>
</tr>
</tbody>
</table>

Fig.2.4. The accumulative number of re-sightings and new sightings of breeding herds from May 2003 until November 2005.
3. Telemetry study

GPS biotelemetry collars have been fitted to 11 elephants during the course of this study: seven to bulls and four to cows; providing almost 10,000 location records over 3½ years (Table 3.1). One elephant, Benjamin, had his collar removed in November this year and not replaced, as he spends the greater proportion of his time within the radically transformed PMC mining area and consequently his movement patterns cannot be considered to reflect those of general elephant population within the conservation areas. As such there are currently 10 collars deployed. Six elephants have now been monitored for a year or more, providing a perspective on movement patterns and habitat selection across seasons.

Table 3.1. The name, age class (cf. Appendix 3) and sex of collared elephants, as well as the date the collars were first fitted and the number of data records (loci) gathered.

<table>
<thead>
<tr>
<th>Name</th>
<th>Age class</th>
<th>Sex</th>
<th>Fitted</th>
<th>Loci</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mac</td>
<td>prime adult</td>
<td>♂</td>
<td>May 2002</td>
<td>2639</td>
</tr>
<tr>
<td>Classic</td>
<td>prime adult</td>
<td>♂</td>
<td>May 2004</td>
<td>1599</td>
</tr>
<tr>
<td>Diney</td>
<td>prime adult</td>
<td>♂</td>
<td>May 2004</td>
<td>1581</td>
</tr>
<tr>
<td>Benjamin</td>
<td>prime adult</td>
<td>♂</td>
<td>Nov 2004</td>
<td>675</td>
</tr>
<tr>
<td>Alex</td>
<td>young adult</td>
<td>♂</td>
<td>Nov 2004</td>
<td>562</td>
</tr>
<tr>
<td>Joan</td>
<td>prime adult</td>
<td>♀</td>
<td>Nov 2004</td>
<td>787</td>
</tr>
<tr>
<td>Barry</td>
<td>young adult</td>
<td>♂</td>
<td>May 2005</td>
<td>855</td>
</tr>
<tr>
<td>Mandy</td>
<td>prime adult</td>
<td>♀</td>
<td>May 2005</td>
<td>869</td>
</tr>
<tr>
<td>Brazen</td>
<td>prime adult</td>
<td>♂</td>
<td>Nov 2005</td>
<td>143</td>
</tr>
<tr>
<td>Soshangane</td>
<td>young adult</td>
<td>♂</td>
<td>Nov 2005</td>
<td>153</td>
</tr>
<tr>
<td>Thandi</td>
<td>prime adult</td>
<td>♀</td>
<td>Nov 2005</td>
<td>99</td>
</tr>
</tbody>
</table>

Recently developed GPS-GSM collars were fitted for the first time this year. A review of the performance of individual collars and comparison between the GPS-satellite and GPS-GSM collars is provided in Appendix 2.

3.1. Range use patterns

The spatial distribution of collared elephants is presented in Fig. 3.1. None of those animals for which there are data spanning a full year restrict their distribution to within a single management area (Table 3.2). This highlights the merit in joint management decision making, as practised by the APNR where no single reserve appears large enough to contain a discrete elephant population. Two elephants, Benjamin and Joan move outside the conservation areas and spend a substantial amount of time north of the Olifants River.
Fig. 3.1. The seasonal distribution of collared elephants as determined by GPS telemetry.
The area occupied by the collared elephants (i.e. home range) and various range statistics are presented in Table 3.3. Given the considerable seasonal variation in environmental conditions, it is reasonable to assume that range selection and movement patterns will differ during the course of a year. The data we have gathered to date corroborate this assumption. For this reason, only those individuals that have been carrying a collar for a year or more (Mac, Classic, Diney, Benjamin, Alex and Joan) are included in the range and movement evaluations, unless stated otherwise.

Mean home range size, estimated as the minimum convex polygon (MCP) connecting extreme location points is 1 785 km² (range: 521 - 4 991 km²; SD 1 603). This however, includes the range occupied by Mac, which is more than 3x the size of any other recorded home range. Excluding Mac, the mean home range size is 1 144 km² (SD = 360). The revised mean range size is still more than 4x larger than the 272 km² estimated for the Klaserie and Timbavati elephants by de Villiers & Kok (1997) in the mid-1980's. The increased range size may be a function of improved telemetry technology (VHF in the mid-1980's and GPS in this study) which delivers more plots at a finer spatial and temporal resolution. Alternatively, it may reflect the opportunity made available to elephants to expand their range with the removal of fences between conservation areas in the 1990's.

De Villiers & Kok (1997) reported MCP home range sizes of with a mean of 288 km² (range: 115 - 465 km²) for cows and 238 km² (range: 157 - 342 km²) for bulls within the Klaserie and Timbavati PNRs. Once again our data suggest that current home ranges are substantially larger (breeding herd ⎯ x = 982 km²; bull x excl. Mac = 1 252 km²).

Most elephant home ranges are elongate in shape, with the long axis orientated north-south (cf. Table 3.3). Classic’s range is an exception, being of almost equal length and width, and orientated east-west. At this stage it is not clear whether range shape and orientation follows an environmental gradient (e.g. a north-south rainfall gradient and an east-west altitudinal gradient influencing the path of major rivers). However, given the seasonal patterns in location data (Fig. 3.1.), it appears unlikely. It is more probable that shape and orientation is a function of anthropogenic boundaries and the legacy of fencing which placed constraints on the movement of elephants. If this should prove to be the case, it will be interesting to observe whether these patterns change over time now that the fences have been removed, or whether younger animals, bulls in particular, are more inclined to adopt an east-west orientation. This may shed some light on how elephants respond to the removal of boundaries and an increase in available habitat.
Table 3.3. Descriptive statistics which define the size, shape and usage patterns of an individual elephant’s home range. These data are derived from the 8-hourly plots of the GPS-satellite collars and the 5-hourly plots of the GPS-GSM collars; with the exception of Mac, for whom daily plots were used to calculate all statistics apart from the movement stats which were based on 8-hourly plots.

<table>
<thead>
<tr>
<th></th>
<th>Mac</th>
<th>Classic</th>
<th>Benjamin</th>
<th>Alex</th>
<th>Diney</th>
<th>Joan</th>
<th>Barry</th>
<th>Mandy</th>
<th>Brazen</th>
<th>Soshangane</th>
<th>Thandi</th>
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<tr>
<td>n</td>
<td>1057</td>
<td>1573</td>
<td>666</td>
<td>548</td>
<td>1555</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>MCP</td>
<td>4990.7</td>
<td>1310.8</td>
<td>1228.4</td>
<td>1216.2</td>
<td>1443.6</td>
<td>520.5</td>
<td>760.2</td>
<td>552.7</td>
<td>79.8</td>
<td>292.9</td>
<td>119.4</td>
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<td>423.2</td>
<td>220.6</td>
<td>8919</td>
<td>4611</td>
<td>312.3</td>
<td>462.8</td>
<td>249.0</td>
<td>97.1</td>
<td>166.0</td>
<td>121.4</td>
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<td>640</td>
<td>210</td>
<td>1495</td>
<td>417</td>
<td>47.5</td>
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<td>407</td>
<td>5.9</td>
<td>26.6</td>
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<td></td>
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<td></td>
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<td>685</td>
<td>56.7</td>
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<td>44.1</td>
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<td>41.1</td>
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<td>2418</td>
<td>357</td>
<td>55.1</td>
<td>63.3</td>
<td>65.0</td>
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<td>71.0</td>
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<td>23.0</td>
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<td>22.2</td>
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<td>29.7</td>
<td>15.4</td>
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<td>6.6</td>
<td>15.7</td>
<td>7.9</td>
<td></td>
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<td>Eccentricity</td>
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<td>1.05</td>
<td>1.58</td>
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<td>1.95</td>
<td>1.37</td>
<td>2.15</td>
<td>1.92</td>
<td>1.97</td>
<td>1.21</td>
<td>1.92</td>
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<td>87.9</td>
<td>12.3</td>
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<td>26.5</td>
<td>-65.1</td>
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<td>-17.5</td>
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<td>9.77e+7</td>
<td>14.74e+7</td>
<td>20.38e+7</td>
<td>20.56e+7</td>
<td>5.42e+7</td>
<td>21.99e+7</td>
<td>8.82e+7</td>
<td>2.90e+7</td>
<td>3.23e+7</td>
<td>3.78e+7</td>
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<td>0.576</td>
<td>0.528</td>
<td>0.702</td>
<td>0.568</td>
<td>0.683</td>
<td>0.91</td>
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<td>0.01</td>
<td>0.03</td>
<td></td>
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<td>Greatest rate</td>
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<td>1.62</td>
<td>1.78</td>
<td>1.27</td>
<td>1.45</td>
<td>1.52</td>
<td>1.16</td>
<td>1.29</td>
<td>0.91</td>
<td>1.24</td>
<td>1.0</td>
</tr>
<tr>
<td>Least rate</td>
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<td>0.003</td>
<td>0.003</td>
<td>0.004</td>
<td>0.004</td>
<td>0.002</td>
<td>0.001</td>
<td>0.005</td>
<td>0.006</td>
<td>0.01</td>
<td>0.03</td>
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<td>0.27</td>
<td>0.19</td>
<td>0.23</td>
<td>0.24</td>
<td>0.19</td>
<td>0.21</td>
<td>0.22</td>
<td>0.26</td>
<td>0.22</td>
<td>0.27</td>
<td>0.22</td>
</tr>
<tr>
<td>Mean angle</td>
<td>85.5</td>
<td>83.5</td>
<td>87.9</td>
<td>94.6</td>
<td>82.7</td>
<td>76.6</td>
<td>67.4</td>
<td>79.1</td>
<td>69.2</td>
<td>55.1</td>
<td></td>
</tr>
</tbody>
</table>
| Angular deviation | 169.2 | 139.5   | 153.7    | 134.7| 149.3 | 142.6| 143.7 | 157.6 | 121.8  | 124.3      | 108.2  

**Legend:**
- n - the number of data points or loci used to calculate the statistics.
- MCP - home range area (km²) derived from a minimum convex polygon estimation, the least convex area enclosing all location records.
- Kernel probability plot - a non-parametric method which defines range use areas (km²) in terms of the greatest number of loci; the 95% probability is the home range, 50% isoline is core range.
- MCP length - the greatest length (km) of the MCP derived home range.
- JT1 Quasi axis length - primary axis length (km) of the Jennrich-Turner Bivariate Normal Home Range calculation, a simplified, elliptical estimation of home range.
- JT2 Quasi axis length - secondary axis length (km) of the Jennrich-Turner Bivariate Normal Home Range.
- Eccentricity: the ratio between the major and minor axes as determined by the Jennrich-Turner Bivariate Normal estimation, a measure of the degree to which a range is circular (1) or elliptical in shape (>1).
- Axis angle - the angle (-90° to +90°) by which the JT1 Quasi axis deviates from the y-axis, i.e. the orientation of the range relative to the north-south axis.
- R² - a measure of the dispersion of data points (mean squared distance) about the centre of activity, i.e. how evenly spread the loci are within the home range; the greater the value the more dispersed the data points.
- NNA - the R value derived from a nearest neighbour analysis test for complete spatial randomness within the MCP home range, a density estimation technique in which all animals showed a significant tendency toward clumped distribution.
- Rate - rate of movement (km hr⁻¹) between consecutive plots; plots at intervals <6hrs and > 10 hrs were ignored for the GPS-satellite collared elephants, while plots <4hrs and >6hrs were not considered for the GPS-GSM collars.
- Mean angle - the average change in direction calculated as the angular difference between consecutive plots.
- Angular deviation - the angular equivalent of the linear standard deviation, i.e. a measure of the spread of angles (0° - 180°) about the mean, or the variability in measures of change in direction.
Seasonal ranges, as defined by the 95% kernel isoline (Fig. 3.2), do not show any obvious pattern relative to one another. Wet and dry season ranges are not separated along a latitudinal gradient, they do not occur in different management areas, are not consistently discrete or overlapping (Table 3.4). One pattern that does emerge is the difference in the relative size of bull and breeding herd seasonal ranges. Amongst those animals collared for a year or more, breeding herds occupy larger wet season ranges than dry season while the inverse is true for bulls. The mean wet season range of breeding herds is 457.0 km$^2$ and the dry 220.7 km$^2$. The mean wet season range of bulls (excl. Mac, as his range is exceptionally large although consistent with the pattern) is 254.3 km$^2$; this expands to 374.4 km$^2$ in the dry season. Given the variation in individual range size a comparison of the ratio of wet to dry season ranges will provide a less biased measure of the difference. The mean wet:dry season ratio in range size for the breeding herds is 1:0.6 while that for bulls is 1:2.6. A potential, although at this stage untested, explanation for the observed difference may lie in different motivators of elephant movements. Earlier research within the APNR (Greyling 2004) has shown that breeding herds forage in such a way as to meet their inherent need for a diet of relatively high quality. In the wet season the abundance of good quality grazing would enable these herds to move over larger areas. However in the dry season they constrain their range to those areas where browse of suitable quality persists in sufficient abundance, e.g. riverine areas. In the wet season, 16.7% of Diney’s location records (n = 493) were within 500m of a major riverine area; in the dry season the proportion had increased to 29.2% (n = 884). Similarly, 19.7% of Joan’s wet season location records (n = 269) were within 500m of a major riverine area, whereas in the dry season this had increased to 40.8% (n = 354). Given their larger body size and social circumstances, bulls are less constrained by resource availability in the dry season, and possibly move over greater areas to harvest dispersed forage. Furthermore, the dry season range of bulls is influenced to a greater degree by their change in musth status than the wet season. Large bulls in particular appear to come into musth towards the end of the wet season and into the dry season (cf Fig. 2.3). Classic’s non-musth:musth range size ratio is 1:2.8.

<table>
<thead>
<tr>
<th></th>
<th>Wet season</th>
<th>Dry season</th>
<th>Wet:dry ratio</th>
<th>Overlap wet</th>
<th>Overlap dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mac</td>
<td>667.9</td>
<td>2 644.4</td>
<td>1:4.0</td>
<td>6.3</td>
<td>1.6</td>
</tr>
<tr>
<td>Classic</td>
<td>271.9</td>
<td>350.1</td>
<td>1:1.3</td>
<td>66.2</td>
<td>51.4</td>
</tr>
<tr>
<td>Diney</td>
<td>694.0</td>
<td>281.7</td>
<td>1:0.4</td>
<td>36.3</td>
<td>89.3</td>
</tr>
<tr>
<td>Benjamin</td>
<td>56.0</td>
<td>300.6</td>
<td>1:5.4</td>
<td>52.5</td>
<td>9.8</td>
</tr>
<tr>
<td>Alex</td>
<td>435.1</td>
<td>472.6</td>
<td>1:1.1</td>
<td>23.6</td>
<td>21.7</td>
</tr>
<tr>
<td>Joan</td>
<td>219.9</td>
<td>159.6</td>
<td>1:0.7</td>
<td>22.4</td>
<td>30.8</td>
</tr>
</tbody>
</table>

Table 3.4. Seasonal range size (km$^2$) as defined by the 95% kernel probability isoline. Range overlap is calculated as a percentage of both the wet and dry season ranges.
Fig. 3.2. Kernel derived seasonal ranges. The 95% and 50% probability plots reflect home range and core ranges respectively.
Home range selection is typically evaluated in terms of the animal having to meet its requisites for life and the availability of resources within the area estimated to be its range. The primary life requisites for a large herbivore such as an elephant are food of sufficient quality and quantity, and water. Vegetation types, because they are determined by the suite of plant species and their relative abundance, provide a useful surrogate measure for forage availability.

Forage resources are typically most limiting in the dry season. Habitat selection is usually considered more critical at this time of year and herbivores may use specific key resources to bridge these crunch periods (Scoones 1995; Illius & O’Connor 1999). Table 3.5 lists the proportional occurrence of different vegetation types (van Rooyen, van Rooyen & Purchase 2005) within the dry season range of collared elephants. It must be noted that this covers only that part of the seasonal range which falls within the APNR, and may present an unreliable estimate of resource selection for those animals whose dry season range falls only partially within these reserves (Mac 31%, Classic 91%, Diney 71%, Benjamin 41%, Alex 50% and Joan 13%; cf Fig 3.2). The proportional occurrence of vegetation types within both Classic and Diney’s dry season range differed highly significantly from that of the greater APNR (Classic: $\chi^2 = 390.3$, p < 0.001, df = 22; Diney: $\chi^2 = 198.4$, p < 0.001, df = 22). Both elephants selected a dry season range such that the constituent vegetation types were in proportions that differed significantly from that of the broader area available to them. Two forms of mopane woodland made up more than 50% of the area of Classic’s range. *Acacia nigrescens* - *Combretum apiculatum* mixed woodland and Phragmites river beds dominated Diney’s dry season range, accounting for more than 36% of the area. In the wet season, the breeding herd’s range included substantially more *Combretum apiculatum* - *Sclerocarya birrea* - *Strychnos madagascariensis* open woodland (10% of the area covered). Using Simpson’s diversity index (D), which summarises the number of vegetation types present and the equitability with which they are distributed, as a simple index of biotope heterogeneity, Diney’s dry season range (D = 9.1) was also more heterogeneous than that of Classic (D = 5.7).

<table>
<thead>
<tr>
<th>Vegetation Type</th>
<th>APNR</th>
<th>Alex</th>
<th>Benjamin</th>
<th>Classic</th>
<th>Diney</th>
<th>Joan</th>
<th>Mac</th>
</tr>
</thead>
<tbody>
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<td>Ficus abutilifolia - Ochna inermis rocky outcrops and ridges</td>
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<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
<td>0.9</td>
<td>0.1</td>
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<td>Combretum apiculatum - Sclerocarya birrea open woodland</td>
<td>2.7</td>
<td>5.8</td>
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<td>8.2</td>
<td>0.0</td>
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<td>2.9</td>
<td>7.2</td>
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<td>0.0</td>
<td>0.0</td>
<td>3.6</td>
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<tr>
<td>Terminalia sericea - Combretum zeyheri - Phoenicopsis reticulata - open woodland</td>
<td>7.1</td>
<td>11.0</td>
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<td>0.0</td>
<td>5.4</td>
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<td>10.4</td>
</tr>
<tr>
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<td>3.1</td>
<td>4.7</td>
<td>3.6</td>
<td>7.6</td>
<td>0.4</td>
<td>7.7</td>
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<td>8.0</td>
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<td>Acacia nigrescens - Combretum apiculatum mixed woodland</td>
<td>13.1</td>
<td>9.8</td>
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<td>10.9</td>
<td>23.8</td>
<td>36.9</td>
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<td>6.4</td>
<td>8.1</td>
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<td>0.2</td>
<td>12.9</td>
<td>29.3</td>
<td>3.5</td>
<td>20.6</td>
<td>17.4</td>
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<td>0.1</td>
<td>0.0</td>
<td>0.8</td>
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<td>0.0</td>
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<td>Euca/ divinorum - Spatholobus ciliatus short woodland on saline lowlands and floodplains</td>
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<td>0.0</td>
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<td>Acacia karroo - Euclea divinorum lowland woodland</td>
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<td>0.0</td>
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<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
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</tr>
<tr>
<td>Acacia nigrescens - Combretum hereroense open woodland</td>
<td>3.8</td>
<td>11.6</td>
<td>0.0</td>
<td>0.0</td>
<td>2.5</td>
<td>0.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Acacia gerrardii - Euclea divinorum - Spatholobus reticulata lowland savanna</td>
<td>0.5</td>
<td>1.9</td>
<td>0.0</td>
<td>0.0</td>
<td>0.2</td>
<td>0.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Acacia gerrardii - Combretum hereroense lowland savanna</td>
<td>2.4</td>
<td>6.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>2.8</td>
</tr>
<tr>
<td>Schotia brachypetala - Philonthus violaceus riparian woodland</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Phragmites australis river beds</td>
<td>9.7</td>
<td>13.6</td>
<td>7.5</td>
<td>9.3</td>
<td>12.3</td>
<td>15.3</td>
<td>10.7</td>
</tr>
<tr>
<td>Disturbed areas (old fields, air fields, habitation)</td>
<td>0.9</td>
<td>2.3</td>
<td>0.3</td>
<td>1.2</td>
<td>0.6</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Dolomite</td>
<td>0.9</td>
<td>0.1</td>
<td>0.1</td>
<td>0.6</td>
<td>1.5</td>
<td>0.0</td>
<td>1.4</td>
</tr>
</tbody>
</table>
The young adult bull, Alex, showed a pattern in seasonal range selection more comparable with that of the breeding herd than Classic. His dry season range was dominated by Phragmites river beds, *Acacia nigrescens* - *Combretum* and *Terminalia sericea* - *Combretum zeyheri* - *Pterocarpus rotundifolius* woodlands.

Dry season water availability was determined by visiting water-points between the months of June and October to record their location, size, water source and index the presence of water. A simple four point index of water availability was used: 0 being empty, 1 with water but almost empty (considered muddy and unpalatable), 2 water present and 3 full. Given the number of water points within the APNR, it was not possible to complete this in a single dry season. As the Klaserie PNR water points have already been digitised and added to a GIS database, priority was given to the Timbavati and Umababta PNRs. The exercise will be completed next dry season and water points monitored each year for the duration of the study.

Despite the fact that 48% of the water points (n = 176) were without water during the dry season (Fig. 3.3), there was almost no part of the reserve further than 3 km from surface water (Fig. 3.4). The distance a breeding herd is able to travel from water is considered to be a key limiting factor in their distribution and herds tend to remain within 3-5 km of water in the dry season (Stokke & duToit 2002; Wittemeyer, Getz & Douglas-Hamilton in prep.). Hence water is not considered to be exerting a strong influence on the distribution of elephants at the home range scale (Bailey, Gross, Laca, Rittenhouse, Coughenour, Swift & Sims 1996).

![Fig. 3.3. The proportion of monitored water points with water in the 2005 dry season. Fill is indexed as 0 - empty, 1 - little, 2 - moderate and 3 - full.](image)
Fig. 3.4. The distribution and size of water points within the Timabavati PNR. Size (m$^2$) is based on the length and width of the water point. Distances are buffers at 1, 2 and 3 km intervals around those water points with water.
3.2. Movement patterns

Elephant movement patterns, as derived from telemetry data, are defined primarily by two variables: the rate of movement and change in direction. The first variable (km hr\(^{-1}\)) is simply calculated as the distance moved between consecutive location data points, divided by the time interval. This makes allowance for minor differences in the interval between successive data points and variations in the data recording schedules of different animals. Change in the direction of movement is described by the angle (degrees) between consecutive movement paths. These angles range between 0 and 180\(^0\). We define an angle of less than 45\(^0\) as going forward (i.e. maintaining the same general direction), 45 - 135\(^0\) is considered a change in direction and an angle greater than 135\(^0\) is turning back. Rates of movement are grouped according to the quartile values. The lower quartile represents a period of restricted movement and the upper quartile periods of rapid movement. Mean quartile values derived from the six collared elephants with more than a year’s telemetry data are: lower - <0.1 km hr\(^{-1}\), upper - >0.25 km hr\(^{-1}\). Various movement types may be defined by these two variables:

1. high rate and small angle - rapid, directional movement;
2. high rate and moderate angle - may reflect large scale exploratory movements;
3. high rate and large angle - visitation;
4. low rate and small angle - movement along a path (e.g. foraging path);
5. low rate and moderate to large angle - within patch movements.

Movement types may be used to assign behaviour attributes to location data.

Mean rates of movement and turning angles, based on 8-hourly telemetry data (records excluded where the interval between consecutive plots is >10hr and <6 hrs), are presented in Table 3.5. Preliminary analyses suggest that overall rates of movement do not differ significantly between bulls and breeding herds (two-tailed t-test: p = 0.74, df = 5 856). Similarly, the overall turning angles of bulls and cows are not significantly different (two-tailed t-test: p = 0.99, df = 5 852). Fig. 3.5 shows the relative abundance of records within the main movement classes for Classic and Diney. While Classic appears to have been less inclined to undertake rapid movements, the distribution of data within the classes did not differ significantly between the bull and breeding herd.

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Rate of movement</th>
<th>Turning angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mac</td>
<td>2 279</td>
<td>0.265 ± 0.260</td>
<td>85.5 ± 56.4</td>
</tr>
<tr>
<td>Classic</td>
<td>1 522</td>
<td>0.191 ± 0.195</td>
<td>83.5 ± 52.2</td>
</tr>
<tr>
<td>Diney</td>
<td>1488</td>
<td>0.192 ± 0.144</td>
<td>82.7 ± 50.9</td>
</tr>
<tr>
<td>Benjamin</td>
<td>362</td>
<td>0.226 ± 0.226</td>
<td>87.9 ± 55.3</td>
</tr>
<tr>
<td>Alex</td>
<td>643</td>
<td>0.236 ± 0.194</td>
<td>94.6 ± 54.3</td>
</tr>
<tr>
<td>Joan</td>
<td>569</td>
<td>0.212 ± 0.172</td>
<td>92.7 ± 56.2</td>
</tr>
</tbody>
</table>
Other factors, such as ambient temperature and season (forage availability), may influence rates of movement. For example, assuming that both high and low temperatures influence movement, a piecewise linear regression with temperature (as recorded by the collar) as the independent variable accounted for 53% of the variation in Classic’s rate of movement ($R = 0.725, n = 914$). To relate time of day, the parameter recorded with location, to relative temperature within the day we recorded temperature at hourly intervals continuously for 3 or more days in each season (i.e. every three months). These data were used to derive a daily temperature profile with temperature change over time as a function of the median temperature ((min + max)/2) (Fig. 3.6.). We will now be able to relate movement data to the relative change in temperature at any given time of the day, using daily minimum/maximum data and mean monthly values as presented in Fig. 1.4. These temperature profiles need to be validated, and the exercise will be repeated again this year.

![Temperature profiles](image)

**Fig. 3.6.** Seasonal daily temperature profiles. Change in temperature is expressed as a mean percentage deviation from the daily median.
At a larger temporal scale, breeding herds (Diney and Joan) showed significant differences between wet and dry season rates of movement (Mann-Whitney tests, p <0.05). Fig. 3.7 plots the running mean of daily rates of movement (rates of movement between midday locations on consecutive days) over time for the Diney’s herd and the adult bull Classic. From this it can be seen that her dry season rates are slower than that of the wet season (dry $\bar{x} = 0.099$ km hr$^{-1}$, SD 0.075; wet $\bar{x} = 0.130$ km hr$^{-1}$, SD 0.114). With the onset of the first substantial summer rains (>20mm), the herd’s rate of movement increased. Also evident in this figure are the episodic peaks in the herd’s rate of movement. These reflect movements between range nodes (cf. Fig. 3.2): on the 4th October 2004 the herd moved between the large western node into the northern node; on the 4th December they moved from here to the eastern node; on the 30th December they moved to the southern node; on the 5th January 2005 they completed the round trip and returned to the western node. Similarly, on the 8th February 2005 the herd moved from the central region of the western node to the north-west extension; on the 18th July they repeated the move from the western node to the northern and on the 9th November returned to the western node.

Seasonal rates of were not significantly different for the large bull, Classic (Mann-Whitney test p = 0.371). However, the difference between movements during his non-musth and musth phase was highly significant (p = 0.007). Movements being more rapid during the musth than the non-musth period (musth $\bar{x} = 0.448$ km hr$^{-1}$, SD 0.363; non-musth $\bar{x} = 0.143$ km hr$^{-1}$, SD 0.099).
3.3. Discussion

Breeding herds appear to show a distinct seasonal pattern in where and how they move. In the wet season they move rapidly over a relatively large area. In the dry season their range constricts, becomes focused on riverine areas and their mean rate of movement decreases. This makes biological sense: following the first substantial rains of the wet season, and the subsequent flush of green herbaceous growth, resources are relatively abundant and of good quality. The breeding herds are therefore less constrained by the availability of forage and able to move over large areas. However, with the onset of the dry season and the senescing of the grass sward, resources become more limiting and the herds move to areas where green vegetation is most likely to persist, i.e. the riverine areas. By including a diversity of vegetation types within their dry season range and focusing on mixed microphyllous-broad leaf woodland and riverine areas, the breeding herds have a greater opportunity to achieve a degree of complementarity in their diet at this critical time.

Range use patterns amongst large bulls, such as Classic and Mac, appear to be strongly influenced by their musth cycle. This is reflected in the location and use of range nodes and movement patterns. Mac’s pattern of range use provides a clear, if somewhat extreme example. His occurrence within the southern portion of his range corresponds with his musth period, the central and northern nodes are used during his non-musth phase. Classic shows a similar pattern albeit on a smaller scale. His musth period is spent moving over a relatively large area in association with breeding herds. However, when not in musth, his distribution range shifts to the central APNR and contracts to an area approximately 36% that of his musth range (733 km²). One of the defining attributes of this non-musth range is that it lies outside the known range of breeding herds (Fig. 3.8.). Diney has passed through the area, but always as a rapid movement between nodes.

Fig. 3.8. Classic’s non-musth range (95% and 50% kernel isolines shaded green) and the distribution of collared females.
The paucity of breeding herds within the non-musth range is reflected in Classic's associations with other elephants: while 67.7% of the sightings within his non-musth range (n = 34) were in association with other bulls, there were no sightings of him in the presence of breeding herds in this area. By comparison, 30% of sightings within his musth range (n = 20) were in association with breeding herds and 25% were with other bulls in the absence of breeding herds. These patterns of association may be a consequence of the lack of breeding herds, alternatively the absence of breeding herds and the lack of opportunity to associate with them may be the motivation behind this non-musth range. The non-musth range corresponds with the distribution of mopane woodlands within the APNR (Fig. 3.9.). This vegetation type is characterised by an abundance (in space and time) of relatively poor quality forage (Dekker & Smit 1996; Lagendijk 2003). Earlier research within this area (Greyling 2004) served to highlight the differential feeding behaviour of bulls and breeding herds where bulls select a diet of high quantity but relatively poor quality and breeding herds select areas that are able to satisfy their need for relatively high quality forage. Hence the scarcity of breeding herds within the non-musth range may be a consequence of their dietary requirements and foraging behaviour. Large bulls, such as Classic, may retreat into this area during their non-musth period to minimise competition for resources, build up condition and avoid confrontation with other bulls accompanying breeding herds. The pooled APNR elephant census data for the period 1994 to 2004 shows that the ratio of breeding herds to bulls is substantially lower within the non-musth area (1:1.1) compared with rest of the APNR (1:5.1). This same census data shows the density of bulls within the non-musth range (0.44 km$^{-2}$) to be almost twice that outside this area (0.23 km$^{-2}$) (census data excludes Lillydale, Kempiana, Springvalley and Morgenzon properties). Breeding herds show the inverse relationship: 0.76 km$^{-2}$ within the non-musth area and 1.1 km$^{-2}$ outside.

Fig. 3.9. The location of Classic’s non-musth range (95% kernel isoline in green) relative to distribution of vegetation types within the APNR. Colophospermum mopane woodlands are coloured red.
Classic's slower rate of movement and moderate to large turning angles within his non-musth range (non-musth: $\bar{x}$ rate of movement = 0.14 km hr$^{-1}$, $\bar{x}$ turning angle = 83.5$^\circ$) fit our expectation of within patch foraging behaviour in this area, while the rapid rate and moderate to small angles outside this area (musth: $\bar{x}$ rate of movement = 0.40 km hr$^{-1}$, $\bar{x}$ turning angle = 79.3$^\circ$) are consistent with the expectation of rapid directional movements and exploratory behaviour outside. Rates of movement and turning angles differ significantly between his non-musth and musth phases (Mann-Whitney test; rate of movement $p < 0.001$; turning angles $p = 0.03$).

Not all collared bulls follow this pattern of musth and non-musth ranges. The young adult bull Alex has not been observed in musth (sightings $n = 23$) and spent the majority of his time in association with breeding herds (45.5% with breeding herds, 36% with bulls only and 18.2% alone). There were no two consecutive sighting of him in association with same herd. He appears to follow a pattern of movement that places him within the area of the breeding herds throughout the year, and then to move regularly between herds.

Ganswindt, Rasmussen, Heistermann & Hodges (2004) describe two reproductive states in a bull elephant: sexually active (no sign of musth but in association with breeding herds) and musth; with a transitory phase linking these two. Our preliminary data suggest that individuals may adopt either one of these, but don't appear to move between them in the course of a year. Large bulls, such as Classic and Mac have discrete musth and non-musth phases. They are spatially separated and when not in musth do not associate with breeding herds. Their musth period is timed to maximise its benefit (cf. section 2.3). They appear to adopt a competitive approach to reproduction. Younger bulls, such as Alex, do not exhibit a protracted or distinct musth phase and do not retire from the area used by breeding herds. If reproductively active, they appear to follow an opportunistic reproductive strategy. Our resightings data corroborates this hypothesis: 39.4% of our sightings of prime bulls ($n = 452$) were animals in musth, less than 1% of young adult bull sightings ($n = 327$) were animals in musth. Only 11.3% of non-musth prime bull sightings ($n = 274$) were associations with breeding herds, while 40.1% of non-musth young adult bull sightings ($324$) were animals associating with breeding herds. The bulls may change their reproductive strategy as they age, as young adults they remain in the vicinity of the breeding herds, taking advantage to the forage opportunities these areas have to offer and if reproductively active are so in an opportunistic way. As they grow older and larger they may shift towards a more competitive reproductive strategy, timing their musth cycle to optimise is benefits and competing with other large bulls at this time. When not in musth, these bulls retire to areas not generally utilised by breeding herds, using their greater body size to advantage with the abundance of poor quality forage to build up condition in preparation for the next competitive musth phase.
4. Vegetation impact study

4.1. Rationale

A questionnaire survey conducted in 2003 revealed that landowners within the APNR had expressed their concern about the impact of elephants on especially *Sclerocarya birrea* (Marula) and *Acacia nigrescens* (Knob thorn) trees. This report looks at the wire netting of specific trees to evaluate the effectiveness of this method in preventing the bark stripping of the monitored specimens. This technique has been applied very successfully by Save the Elephants in East Africa to prevent the bark-stripping of *Acacia* spp. (Gordon 2003). If this relatively simple technique effectively deters elephants from bark-stripping mature trees then it could be of importance for the following reasons:

- Various large trees around camps and lodges are of aesthetic importance to landowners and managers. Protecting these individuals would ensure the maintenance of the aesthetic features of the landscape.
- Protecting numerous trees within a relatively small area would create localised woodland refugia that would maintain the structural diversity of the landscape and prevent biodiversity loss at a larger scale.
- Woodland refugia may function as important seed reserves for future recolonisation of other areas.

4.2. Methods

Wire netting of trees

Trees, defined as single stemmed woody plants, more than 2 m tall were considered suitable for treatment with wire netting. During surveys *S. birrea* trees were sexed by searching for fruit kernels beneath the trees in the dry season or by looking for fruit on the tree during summer surveys. Bird wire (13mm mesh, 1.8m tall) was wrapped around the tree trunk about 50cm off the ground to a height of approximately 230cm. On average 1.25m of wire was used per tree. The ends of the netting were stapled on the tree trunk with 25mm wire fencing staples.

Study sites and treatment monitoring

Two study sites have been established within the APNR. On the Vlakgezicht property in the Timbavati a selection of 64 trees have been monitored since July 2004. In November-December 2004 this study site was extended to include an additional 51 trees. In October 2005 a further 129 trees were incorporated into the monitoring programme. This report will focus on the entire Vlakgezicht monitoring site which predominately consists of *S. birrea* trees.

On Ntsiri, in the Umbabat Private Nature Reserve 100 trees have been monitored since November 2004. This study site consists of a near equal proportion of *S. birrea* and *A. nigrescens* trees. The results of the Ntsiri study site were discussed in a recent report (Henley & Henley 2005).

In 2006 a large study site will be established on the Joubertshoop property which will be incorporated into the Klaserie Private Nature Reserve. This property offers a unique opportunity to conduct baseline monitoring before the fences are dropped and elephants
move into the area. On Joubertshoop we hope to be testing a variety of mitigation methods (wire netting, bees and chilli repellents) over time.

Fig 4.1. Vlakgezicht study site with the location of trees included in the monitoring programme as well as the type of treatment that was applied to them.
The following data was collected at each sample site:

**Location**: GPS derived co-ordinates

**Species** (and sex if marula)

**Date**

**Age of impact**: Recent or current season impact was distinguished from old impact by the pinky fleshy colour of the exposed stem in the former

- 1 month (recent)
- 4-5 months (within the past dry/wet season)
- 12 months (within the rainfall cycle)
- > 12 months (old)

**Stem diameter at breast height** - a standard index of the size of the tree

**Impact** - extent of bark stripping - proportion of circumference stripped of bark within the following classes: 0%, <1%, 1-5%, 5-10%, 10-25%, 25-50%, 50-75%, 75-90%, 90-99%, 100%

- height of tusk entry points
- the type of impact i.e. the extent to which primary branches were broken, whether the main stem had been broken or whether the tree had been pushed over or uprooted. If the tree was uprooted or the main stem had been broken within the past season and the tree was still alive then the impact was placed into the 90-99% category. If the woody plant had subsequently died then the impact was scored at 100%.

**Treatment applied** - none, wire-netting only, wire-netting and stone packing around the base of the tree.

**Photographs** taken

**Additional notes**: the presence of old impact together with more recent impact, any healing that has subsequently occurred, the condition of the treatment method and whether it has deteriorated (wire rusted or broken).

**Results and discussion**

The majority of the trees that were monitored had either been bark stripped or had some primary branches broken (Figure 4.2).

![Pie chart showing impact contributions of monitored trees](image)

**Fig 4.2.** Relative impact contributions of all the monitored trees.
Female trees appeared to be bark-stripped more frequently than male specimens. Most bark stripping events, irrespective of the sex of the plant or when the bark stripping event had occurred, took place in the lower impact categories (< 50%). The main stem and primary branches of male trees were more frequently broken than in female trees, especially within the high impact categories (> 50%). Only female trees were found to be pushed over or uprooted (Fig. 4.3). Pushing over trees is probably a consequence of elephants trying to access fruit during the wet season. The sex ratio of male: female *S. birrea* trees was almost equal (1: 0.9). The different sexes appeared to be grouped in clumps (Figure 4.4).

![Bar graph showing the extent of bark-stripping, primary branch or main stem breakage, and uprooting for male and female *S. birrea* trees.](image)

**Fig 4.3.** The numbers of *S. birrea* trees of a particular sex belonging to a specific bark stripping (a), primary branch or main stem breakage (b) or uprooting (c) category.
Trees according to sex and type
- Female
- Male
- Unknown sex or Albizia spp., Lannea spp. or Loncocarpus spp.

House 1
House 2
Dam 1
Dam 2

✓ Road or dry riverbed

Fig 4.4. Location of monitored trees according to sex and type. Some *S. birrea* trees could not be sexed as they had died more than a year ago.
The majority of trees, irrespective of the species, were moderately bark-stripped (10-25%) while most trees weren’t bark-stripped (Fig. 4.5). *Sclerocarya birrea* can grow bark over the exposed stem which then appears to have a different texture and colour than the old exposed stem and which can be described as healed/recovered specimens. Healing of *S. birrea* does not seem to occur in the low impact categories (<5%) and the high impact categories (90-99%).

![Fig 4.5. The number of plants (all species) which had been bark stripped and the proportion of *S. birrea* of these which were recovering from the incident.](image)

The majority of all bark stripping events appear to have occurred more than one year ago (Figure 4.6).

![Fig 4.6. The number of trees bark stripped according to the age at which this type of feeding event occurred.](image)
Most trees were found to have a diameter of 30-49 cm at breast height. Relatively few
trees were found in the small (0-9) and large (70-79) size categories (Fig 4.7). A
relatively large number of trees with a DBH of 20-29 was heavily impacted upon (90-
100%).

Fig 4.7. The frequency at which trees of specific size classes were found to have
particular categories of impact.

The mean tusk entry height was 121.9 cm while the median height was found to be 119.5
cm. The range of tusk entry heights varied from 20 cm above the ground to as high as
250 cm (Figure 4.8).

Fig. 4.8. Box whisker plot of tusk entry height extending from the 25th percentile to
the 75th percentile with a horizontal line at the median (50th percentile). The whiskers
depict the range of the data that was collected.
Although the incidence of debarking appears to be relatively high, in only a few cases debarking was found to be extensive. To date, three trees with wire netting were investigated by elephants but weren’t bark-stripped since being treated. The inspection of treated trees by elephant were judged from the tracks and the stretching of the eyes of the bird wire attached to the tree as no fresh debarking events could be detected. One untreated tree was recently (within the past month) heavily impacted upon (100%) when all its primary branches were removed. The technique of tree protection thus appears to be effective.

All *S. birrea* trees recover from primary branch breakage events. More than half (56%) of all plants with broken main stems showed signs of regrowth (Fig 4.9). Horizontal, dead plants were impacted upon more than a year ago which made the direct cause of their death difficult to ascertain (uprooting by elephants, fire, strong winds or attack by insects with old age). Even though all uprooted *S. birrea* trees were females and weren’t treated with wire netting, it is still not possible to determine whether wire netting prevents tree felling as no recent untreated tree felling events had occurred. Only two *S. birrea* seedlings were found within the entire study site. The dearth of young trees needs further investigation to determine what factors may be influencing seedling survival and regeneration and consequent recruitment into older age classes.

Figure 4.9. The locality of trees according to the extent of debarking, tree felling or mortality.

All vegetation study sites will be revisited at the end of the wet season to monitor the incidences of bark-stripping, tree felling and the effectiveness of the treatment with wire netting.
5. Mortality study

Monitoring mortalities serves two purposes in this project. Firstly it contributes toward an understanding of the role risk plays a factor motivating elephant movements. Secondly it enables us to keep the register of known individual current and correctly interpret resightings data (or the lack thereof).

Three natural mortalities were recorded this year and one shooting of a problem animal. The natural mortalities were:
- an adult female on Klaserie PNR;
- a neonate on Timbavati PNR;
- an unsexed adult on Timbavati PNR.

Three mortalities from an estimated population of 892 (2005 annual aerial census) represents a mortality rate of 0.34%. This is down from the past two years (Fig 5.1.) and below the mean of 0.46% for the past 14 years.

![Chart showing mortality rate over time for three reserves of the APNR: the Klaserie Umbabat and Timbavati PNRs.](chart)

Rates of natural mortality appear to be very low; substantially lower than the 3.2% reported in the adjacent Kruger NP (Whyte 2001). As a key demographic parameter and potential determinant of range use, the spatial, temporal and demographic patterns in mortality merit further investigation in future.
6. Miscellaneous

Education and extension are an important component of any research programme and one which we are prepared to invest a substantial amount of effort. Since November 2004 we have given 79 presentations on our research programme. This includes four presentations to landowners, five to lodge managers and staff and 67 to 301 visitors to the APNR.

More than 20 guests participated in two collaring safaris.

Fifteen articles have appeared in the popular press since November 2004, dealing with the STE Transboundary Research programme. This includes two in international newspapers, le Monde and the Canadian Globe & Mail, and a short piece in National Geographic Magazine. Other articles have appeared in The Star, The Citizen, Laevelder and the Kruger Park Times newspapers, as well as African Wildlife and the South African magazines. We also hosted BBC radio for a few days.

In February this year we gave a presentation entitled: “Tracking elephants across boundaries: new tools for biotelemetry”, at symposium co-sponsored by Fauna and Flora International and the Vodacom Foundation. We also participated in an elephant workshop at Wits University in June, where both researchers gave presentations. Finally, we attended a STE research meeting in Samburu GR, Kenya which drew STE members from both Africa and the UK.

A recent meeting with representatives of Fauna & Flora International and Resource Africa resulted in us being invited to participate in a workshop at Cambridge early in the new year. It is hoped that our research programme will serve as a pilot study for the development of pattern recognition software to be used in wildlife research projects based on individual recognition.

The review of the Kruger NP elephant management policy has been a key issue the past year. Given our circumstances, we have been invited to participate and comment on numerous occasions. Michelle submitted two review papers as contributions to workshops dealing specifically with this issue in the past year: “A neighbour’s perspective on the new management policy of the Kruger NP” submitted to the SANParks scientific workshop in March and “Considering more than elephants” which was presented at the Elephants Alive workshop.

During the course of this year, we peer-reviewed three scientific manuscripts, one from the Journal of Mammology and two from African Zoology. We have recently been asked to review another two manuscripts, one submitted to the South African Journal of Wildlife Research and the other to African Zoology.
7. Conclusion

The objectives of this research programme may be summarised as follows:

a) to determine how many elephants use APNR, large bulls and breeding herds in particular (objectives 1, 2 and 3);
b) to determine how elephants distribute themselves within the APNR and adjacent KNP, and how their movement patterns reflect changes in distribution (objectives 4, 5 and 6);
c) to identify environmental correlates associated with observed distribution and movement patterns, and the influence of social and safety circumstances on their movements (objective 7);
d) to evaluate the impact of elephants on priority tree species (objective 8) and investigate mitigation measures designed to reduce elephant damage to individual trees.

These reflect the long-term vision of this research programme. Many of the patterns and processes being investigated can only be identified with any confidence once they have been repeated over a number of years. However, two and a half years into the study we can evaluate our initial progress towards meeting these objectives.

The identification and resighting of large bulls appears to have reached a point where meaningful data on population size may be estimated. It is expected that we will be in a similar position with the breeding herds within the next year. The younger adult bulls are more fluid in their social dynamics and movement patterns and will take longer to come to terms with.

The greatest value in these data lies in their estimation of seasonal changes in the elephant population. In this way they will complement the annual aerial census which provides a snapshot of the population at one point in time, which is then be used to identify population trends from year to year. The elephant identification study is also beginning to show its value in determining individual turn over within the APNR during the course of the year. A count of \( x \) elephants at any one point in time, be it annual or seasonal, does not provide information on the absolute number of elephants using the area throughout the year. The patterns of resighting known individuals is providing greater insight.

As far as the second group of objectives are concerned, the telemetry data has shown the size of range areas to be substantially larger than expected based on previous research with the APNR. It is clear that elephants distribute themselves across management units within the APNR. The nodal nature of range use and movement patterns within and between these is also apparent from the telemetry data. Seasonal movements need to be evaluated over a number of years before patterns can be reliably identified.

The telemetry data are also beginning to provide a preliminary understanding of environmental correlates and habitat selection patterns, and the role of musth and the social landscape in determining the movements of elephant bulls. At this point in time we only have telemetry data spanning two or more years for Mac, and the extent of his movements may be exceptional and not a true reflection of the norm amongst large bulls.
Within the next year we will have opportunity to see if Classic, Diney, Joan and Alex repeat the patterns observed in the past year.

The vegetation study has provided some insight into elephant impact on marulas and a baseline which we will monitor for the duration of the study. It is planned expand this part of the research programme in the new year, with the possibility of collaborating with post-graduate students investigating other aspects of the elephant:ungulate:tree dynamic.

In terms of STE’s mission, progress may be evaluated more broadly in terms of the project’s contribution toward 1) a greater understanding of elephant ecology; 2) its contribution to informed and appropriate elephant management and 3) the generation of an appreciation for elephants and wilderness within general public. Our study is highlighting the significance of bull retirement areas and the social landscape as a determinant of elephant range selection and movements. We have also initiated possibly the only long-term study of elephants, based on a register of known individuals in southern Africa. This will serve as an important research resource in years to come. We have actively participated in the national elephant management debate and kept managers within the APNR informed of our findings, preliminary as they may be. Finally, through our presentations to lodge staff, visitors, teachers and students, as well as popular publications emanating from the research programme we have sought to bring relevant information to the attention of general public and enthuse people.

Over the next year we will continue to develop the register of known elephants and it is our expectation that in this time we will see a drop off in the number of new adult cow sightings and greater clarity on the structure and dynamics of breeding herds. We intend to continue fitting GPS-telemetry collars to elephants, expanding the size of our sampled population. There is a possibility that we will extend the study area to include transboundary movements between the Kruger NP and the Limpopo NP, and fit collars to elephants in the north-east of the KNP. The vegetation study will be expanded considerable, with the inclusion of the Joubertshoop property into the monitoring sites, and we will test the efficacy of other mitigation measures such as chilli pepper and bees.
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References


Appendix 1. Climatic seasons defined

Long-term rainfall data from the Kruger NP 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, the definition of seasons was based on data from weather stations in and around the APNR that span a period of 20 years or more. These were Ingwelala (1983 - 2004), Hoedspruit (1977 - 2004) and Kingfisherspruit, KNP (1957 - 2003).

The aim is to derive an objective definition of ecologically meaningful seasons. Current conditions do not exist in isolation, and as such consideration is given to the influence of the preceding months conditions. Furthermore, it is to be expected that there is a substantial amount of spatial variation in conditions such as rainfall and as such is based on change in relative conditions (%). Nonetheless, absolute values provide a useful benchmark against which present conditions may be compared (e.g. a general rule of thumb amongst rangeland scientists is that 15-20mm is the minimum amount of rain required to fall during a single event to initiate grass growth in the early wet season) and so the absolute amount of rainfall is also considered.
**Dry season:**  
May → September
- Mean monthly rainfall is <5% (typically <2%) of the mean annual total.
- Each month receives ≤10 mm of rain (September in the Kingfisherspruit area is an exception).
- The first month of this season receives <½ (typically ⅓) the rainfall of the preceding month’s mean.
- The total seasonal rainfall accounts for <10% of mean annual total.

**Dry-wet transitional period:** October
- Mean monthly rainfall is 5-10% of the mean annual total.
- Each month receives ≤25 mm of rain.
- At least one rainfall event totalling ≥15mm.
- The total monthly rainfall is a substantial increase (>2x, typically 3-4x) over the preceding month’s mean.

**Wet Season:**  
November → March
- Mean monthly rainfall is ≥10% of the mean annual total.
- Each month receives ≥50mm of rain. Monthly rainfall may decrease towards the end of the season (>40mm), however due to the preceding month’s high rainfall soil moisture remains relatively high.
- The total seasonal rainfall accounts for >75% of mean annual total.

**Wet-dry transition period:** April
- Mean monthly rainfall is ≤10% of the mean annual total.
- Each month receives ≤50 mm of rain.
- The total monthly rainfall is a substantial decrease (≤½) over that of the preceding month.
Appendix 2. Telemetry collar review

A performance summary of the deployed GPS telemetry collars is presented in Table A2.1.

Table A2.1. Currently deployed collars. Records are the total number of data points recorded by this collar; schedule refers to the interval at which the collar is currently programmed to record data; download interval is the average number of days between data downloads; errors is the number of GPS errors (90-180) and failed data recordings; life expectancy refers to the remaining life expectancy (days) of the collar based on the collar type, number of batteries, number of data records and errors (assumed equivalent of 3 records).

<table>
<thead>
<tr>
<th>Type</th>
<th>Records</th>
<th>Schedule</th>
<th>Download interval</th>
<th>Errors</th>
<th>Life expectancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mac</td>
<td>176</td>
<td>24 hr</td>
<td>daily</td>
<td>136</td>
<td>640 days</td>
</tr>
<tr>
<td>Classic</td>
<td>1599</td>
<td>8 hr</td>
<td>daily</td>
<td>80</td>
<td>53 days</td>
</tr>
<tr>
<td>Diney</td>
<td>1581</td>
<td>8 hr</td>
<td>daily</td>
<td>86</td>
<td>54 days</td>
</tr>
<tr>
<td>Alex</td>
<td>675</td>
<td>8 hr</td>
<td>daily</td>
<td>59</td>
<td>0 - removed</td>
</tr>
<tr>
<td>Joan</td>
<td>787</td>
<td>8 hr</td>
<td>daily</td>
<td>361</td>
<td>210 days</td>
</tr>
<tr>
<td>Barry</td>
<td>870</td>
<td>5 hr</td>
<td>daily</td>
<td>55</td>
<td>2 909 days</td>
</tr>
<tr>
<td>Mandy</td>
<td>921</td>
<td>5 hr</td>
<td>daily</td>
<td>45</td>
<td>2 905 days</td>
</tr>
<tr>
<td>Brazen</td>
<td>195</td>
<td>5 hr</td>
<td>daily</td>
<td>10</td>
<td>3 078 days</td>
</tr>
<tr>
<td>Soshangane</td>
<td>582</td>
<td>5 hr</td>
<td>daily</td>
<td>3</td>
<td>3 002 days</td>
</tr>
<tr>
<td>Thandi</td>
<td>149(^1)</td>
<td>5 hr</td>
<td>1.6 days</td>
<td>2</td>
<td>3 080 days(^1)</td>
</tr>
</tbody>
</table>

\(^1\)last download 10/11/05; other collars 21/11/05
\(^2\)based on an 8 hr interval, not the current 24 hr
\(^3\)assuming similar data recording history as Brazen

Two GPS collar types are currently available, the GPS-satellite collars that were first fitted to two bull elephants green hunted in the Timbavati PNR in November 1998, and GPS-GSM collars that were fitted for the first time this year. The principle difference between these being the device used to relay the GPS derived location data. The GPS-satellite collar data are transferred by means of a mobile global satellite communication platform utilising 2-way satellite communication (the Inmarsat-3 suite of geostationary communication satellites). GPS-GSM collars rely on a cell phone to relay data between the collar and the researcher. The purchase and running costs associated with a GPS-GSM collar are substantially lower (almost half) than that of a GPS-satellite collar. Furthermore, because their components draw less energy, the GPS-GSM collars are expected to deliver 10x as many data points for an equal number of embedded batteries. The principle constraint associated with the GPS-GSM collar is the need for cellular coverage to download data.

Despite being fitted with telemetry collars 6 months earlier, Alex and Joan delivered a similar number of location records as Barry and Mandy. Furthermore, their collars are only expected to last another 1.5 and 7 months respectively, compared with 97 months for Barry and Mandy, if current schedules are maintained. This is due to two factors: firstly the inherent longevity of the collars and secondly the reliability of these collars. The differential drain on battery power means that although Alex and Joan’s collars are fitted with 10 D-cell batteries, and Barry and Mandy’s with six, their GPS-satellite collars are expected to deliver approximately 2 500 data points, compared with Barry and Mandy’s GPS-GSM collar’s expected 15 000 data points.
Two GPS-satellite collars, fitted to Classic and Diney, have performed well. They are delivering 20.0 and 18.4 location records for each error reading respectively. The other GPS-satellite collars have been less reliable, delivering between 0.9 and 11.4 location records for each error reading. Bearing in mind that the GPS unit is designed to make three attempts to communicate with the satellites, each 90/180 record or no reading is assumed to draw three times as much power as a successful reading. This may be overemphasising the power drained by error readings as it doesn’t take into account the energy used by the satellite phone to relay data (substantially greater than that of the cell phone). Nonetheless, the high proportion of error recordings is substantially reducing the expected lifespan of the GPS-satellite collars. The GPS-GSM collars recorded an average of 29.9 successful location points for each error (range: 14.3 - 51.0), once deployed.

The primary constraint with GPS-GSM collars is the patchy cell coverage within the APNR and the effect this has on data downloading. Table A2.2 summarises the performance of the current GPS-GSM collars and Fig. A2.1. plots the locations of data points which did and did not download data.

Table A2.2. GPS-GSM collar performance. Download events are data points that downloaded immediately. Records stored are data points that downloaded at a later stage. Runs are the groups of stored data points downloaded in a single event. On average 4.8 data points are recorded each day.

<table>
<thead>
<tr>
<th></th>
<th>Download events</th>
<th>Records stored</th>
<th>No. runs</th>
<th>Mean records per run</th>
<th>Max records per run</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barry</td>
<td>335</td>
<td>781</td>
<td>82</td>
<td>9.5</td>
<td>316</td>
</tr>
<tr>
<td>Brazen</td>
<td>66</td>
<td>147</td>
<td>28</td>
<td>5.3</td>
<td>22</td>
</tr>
<tr>
<td>Mandy</td>
<td>562</td>
<td>368</td>
<td>101</td>
<td>3.6</td>
<td>30</td>
</tr>
<tr>
<td>Soshangane</td>
<td>114</td>
<td>138</td>
<td>34</td>
<td>4.1</td>
<td>15</td>
</tr>
<tr>
<td>Thandi</td>
<td>34</td>
<td>220</td>
<td>20</td>
<td>11.0</td>
<td>154</td>
</tr>
</tbody>
</table>

![Fig. A2.1. The Location of GPS-GSM collar location records which downloaded immediately and which were stored and downloaded at a later stage (missed download).](image)
The GPS-GSM collars are currently recording data at five hourly intervals. The reason for this is two fold: firstly to extend the lifespan of these collars so that we will be able to build up a sufficient number of collars deployed concurrently. At the present rate of five new collars per year, and bearing in mind that four GPS-satellite collars will be due for replacement within the next year, it will take us two years to get 15 or more collars in place. At the current data recording interval the collars should theoretically last for almost another eight years. If the GPS-GSM collars are all changed to an hourly schedule in two years time, these collars should last another 3.2 years. This means we will have the next two years to develop models of elephant range selection and movements at an intermediate scale (landscape system - Senft, Coughenour, Bailey, Rittenhouse, Sala & Swift 1987). These models and the new questions they generate can be evaluated at a finer resolution (e.g. feeding site - Bailey, Gross, Laca, Rittenhouse, Coughenour, Swift & Sims 1996) thereafter. The second motivation for a five hourly schedule is that every five day period delivers at least one location record for ever hour of the day at no extra cost to the lifespan of the batteries, enabling us to investigate habitat selection patterns within the course of the day, as well as seasonal and inter-annual patterns (cf. Fig. A2.2). The GPS-satellite collars do not make allowance for this eccentric recording schedule.

![Spider plot of location data](image)

Fig. A2.2. A spider plot of the percentage location data recorded at different times of the day. Joan and Alex are fitted with GPS-satellite collars and Mandy and Barry with GPS-GSM collars.

It is our opinion that in future we only deploy GPS-GSM collars within the APNR. These collars:
- are cheaper to purchase and run;
- are lighter, for the same number of embedded batteries;
- last longer;
- are typically more reliable, having proportionally fewer error readings;
- record data at shorter intervals, spanning all hours of the day.

Their erratic pattern of data downloading means that we will not always be able to revisit collared animals on demand. However the average interval between data downloads is sufficiently short to facilitate regular resightings of these animals and we feel that the extra effort required to sight these animals is more than compensated by the opportunity to increase the collared elephant sample size.
### Appendix 3. Criteria for categorising bulls into various size categories

<table>
<thead>
<tr>
<th>Size category</th>
<th>Behavioural characteristics</th>
<th>Physical attributes</th>
<th>Age categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immature bulls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Juvenile</td>
<td>Small bulls physiologically dependent on their mothers</td>
<td>All bulls within this category are smaller than large, mature females within the herd.</td>
<td>Bulls within this category would include most bulls younger than 17 years old.</td>
</tr>
<tr>
<td>- Sub-adult</td>
<td>Bulls that have been weaned but which are still in close association with the family unit (psychologically depend on their mothers)</td>
<td>Tusks are either visible as buds or are splayed rather than convergent.</td>
<td>Juveniles would be between 1-3 years of age.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frontal head shape is narrow and square and similar to young females.</td>
<td>Sub-adults would be aged between 4-10 years.</td>
</tr>
<tr>
<td>Young adult</td>
<td>Young adults spend time on the periphery of the breeding herd which they accompany. These breeding herds may or may not be their natal herd.</td>
<td>All bulls within this category have reached the same height or are larger than mature females within the breeding herd.</td>
<td>Bulls within this category would be between 17 years old and into their early thirties.</td>
</tr>
<tr>
<td></td>
<td>Young adult bulls are also frequently found within bachelor groups or could be temporarily solitary.</td>
<td>The tusks begin to take their adult configuration i.e. convergent, straight or asymmetrical. Tusks are still not thick set at the base as with prime bulls.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bulls may start to experience short, sporadic musth cycles from about 25 years of age.</td>
<td>The head shape is slowly taking more of an hour glass shape although the sockets from which the tusks protrude are still narrow and not in line with temporal protrusions (eye sockets and temporal glands) when viewed from the front.</td>
<td></td>
</tr>
</tbody>
</table>

Note that the top triangle is broader than the bottom one.
<table>
<thead>
<tr>
<th>Prime</th>
<th>Senescing/retired</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulls within this category would have distinct musth and non-musth periods. Musth periods are predictable for each animal and can last 2-4 months depending on the body condition of the bull. Musth periods are spent in search of breeding females while non-musth periods are spent on their own or mostly within bachelor groups in areas distinct from those occupied during musth.</td>
<td>Bulls older than 50 years will still experience regular musth cycles.</td>
</tr>
<tr>
<td>Bulls will no longer experience musth and will retire to areas with soft vegetation such as riverine areas.</td>
<td>Bulls within this category range in age from 35 to approximately 55 years of age.</td>
</tr>
<tr>
<td>Bulls have an overall huge body size which can be up to twice the size of adult females.</td>
<td>Retired bulls can be anywhere between 55 and 65 years old.</td>
</tr>
<tr>
<td>The shoulder height and back length increases steadily and becomes hollower between the shoulder blades and the pelvic area.</td>
<td>Tusk sockets appear to become limp and elongated in retired bulls.</td>
</tr>
<tr>
<td>The tusks are usually thick set at the base.</td>
<td></td>
</tr>
<tr>
<td>The head has a distinct hourglass shape which is wide at the eyes and base of the tusks and is generally broad with visible temple depressions.</td>
<td></td>
</tr>
<tr>
<td>The ears are held lower on the head and the back is usually considerably hollow. As the last set of molars come into wear from 45 years of age and could take 15 years to wear down, a loss in body condition with accompanying deep temporal depressions and an overall gaunt appearance may only become visible in the very last few years of the bull’s life.</td>
<td></td>
</tr>
<tr>
<td>Tusks are sometimes large and long.</td>
<td></td>
</tr>
</tbody>
</table>