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SANParks[1] and SAEON[2]

Co-workers, photograph taken by Mr Nardus du Plessis (2015).

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Executive Summary

The *Aloe dichotoma* (Quiver tree) is the iconic plant species of Augrabies Falls National Park (AFNP). It is the most south-eastern distributed population in a conservation area in Southern Africa. Quiver trees are listed under CITES Appendix II, but it is not currently listed under the IUCN as a protected species. However, it is declared as a protected plant species in the Northern Cape. Some researchers have proposed that the quiver trees could be used as an indicator of climatic change. However, there are also other threats to this iconic plant species such as: poaching for ornamental uses, loss of habitat due to cultivation of grapes and possible impact of herbivory. The main aim for this report was:

- To record the distribution pattern of quiver trees in AFNP,
- To assess the population structure of populations or sub-populations in AFNP,
- To measure the physical damage that has been inflicted on individual trees according to height classes in AFNP

Various methods used by different researchers since 2005 are discussed and assessed.

Plan going forward:

1. To collaborate with SAEON Arid Node and DENC towards producing a scientific paper.
2. Analyse the current mega-data set using various statistical techniques.
3. Propose a monitoring action plan in collaboration with Park Management, DENC and SAEON (Arid Node).
4. Conduct a reconnaissance survey of the quiver tree populations on the south facing granite steep midslopes.
5. Continue with the survey and photographing of individual quiver trees marked by Ellis (2011).

Introduction

Aloe plant species form a conspicuous part of the South African landscape and many people appreciate their striking beauty. At the same time, studies in Southern Africa, that use indicator species of both animal and plant species to show that species are dying or shifting their ranges because of climatic changes in their native environment, have mainly focused on the succulent tree *Aloe dichotoma* (Foden *et al*. 2005). *Aloe dichotoma* (Quiver tree) often occurs as a single plant species growing in a water-stressed environment characterised by rocky areas in arid parts of Namaqualand and Bushmanland. Results from bioclimatic modelling (Foden *et al*. 2005) of this species suggests that it may already be shifting its range southwards as climate changes have begun to affect their central populations detrimentally (Foden *et al*. 2005). In addition to the above mentioned threat about its current distribution pattern, the iconic plant species *Aloe dichotoma* trees of Augrabies Falls National Park (AFNP) have evidence of physical damage. This is an alarming concern because unlike many other plant species in arid regions, *Aloe dichotoma* is limited to re-sprouting successfully after damage; therefore when adults die, their replacement must come from seedlings. According to Foden *et al*. (2005) the Spearman Rank Order Correlations indicate that canopy and stem damage positively correlate with high population mortality. It should also be noted that populations with high mortality rates are undergoing long term water stress, which normally starts with leaf shedding because of unfavourable climatic conditions (Foden *et al*. 2005). The study of Foden *et al*. (2005) also indicated that a higher mortality rate is likely on lower slopes or plains with hotter microhabitats than on steeper south facing hills. Repeated photography that was used by Hoffman and Kaleme according to Foden *et al*. (2005) at a site close to Calvinia, indicated an increase of 108% over 98 years (photos 1904 Marloth and 2002), however, in the Pofadder region a decline of more than 52% in these populations (Plains 80% decline) (Acocks 1948 and 2002) were noted. Populations with high mortality rates experienced extreme water stress, which Foden *et al*. (2005) speculated was due to a pole ward range shift for the long-lived, drought-tolerant, succulent in response to climate change. Foden *et al*. (2005) also indicated that in 7 out of 8 population sites showed a decrease or lack of recruitment and no signs of any new populations were recorded. Interestingly, the cultivation of this plant species thrives far south in the Karoo Botanical Garden at Worcester and planted populations have become self-propagating!

“The quiver trees are part of the family Asphodelaceae. In Afrikaans it is called ‘kokerboom’. The species name *dichotoma* means forked and refers to the branches that start to fork halfway up the tapering trunk. The height of the quiver tree is 3-5 meters. The leaves have a blue-green colour and the leaves are arranged in terminal rosettes. In juveniles the leaves are arranged vertically. The leaves are oblong and narrow and the leave margins have fine teeth. The bark has razor sharp golden scales, but the pith is soft and spongy. The branches are smooth and covered in a white powder, to reflect the sun’s rays. The crown is rounded. The flowers have a canary yellow colour and produces large amounts of nectar. The flowering season is during winter (Wolfaardt 2007)”.

According to Powell (2004) it takes a quiver tree 50 years before it starts to reproduce seeds for the first time and the lifespan is +/- 250 years. Therefore it is estimated that it will take 18-21 consecutive years of favourable climatic conditions for a quiver tree to rehabilitate (Powell 2004).

Quiver trees are listed under CITES Appendix II, but are not currently listed under the IUCN as a protected species. However, it is declared as a protected plant species in the Northern Cape. **It is also important to note that quiver trees are significant ornamental trees, which are being**

poached from their natural habitat (no literature on this). Therefore this could also be a reason for the decrease in some of the populations. The impact of cultivation, for grape production, of the slightly undulating granite plains is also not mentioned in the literature, however around the Orange River it plays a major role in the decrease of this specific plant species and habitat for the quiver trees.

These iconic plant species of Augrabies Falls National Park (AFNP) are currently the most south-eastern distributed population in a conservation area in Southern Africa (Figure 1).

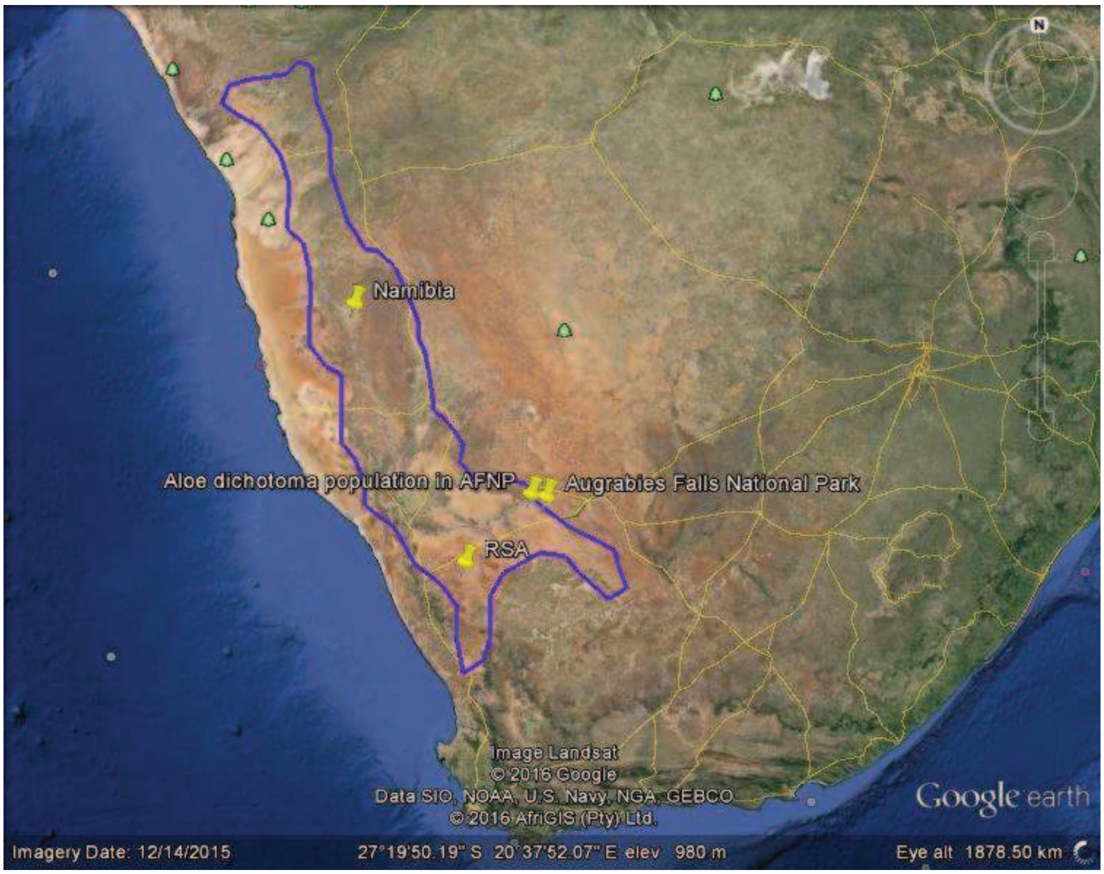

Figure 1: *Aloe dichotoma* (Quiver tree) distribution in Southern Africa (adapted from Foden *et al*. 2005) note the location of Augrabies Falls National Park.

Historical background

The main aim of the Hendricks & Bezuidenhout (2005) document, was to assess the ecological condition of the *Aloe dichotoma* population in the Park. With the following objectives:

- To record the distribution pattern of quiver trees in AFNP,
- To assess the population structure of populations or sub-populations in AFNP,
- To measure the physical damage that has been inflicted on individual trees according to height classes in AFNP (Hendricks & Bezuidenhout 2005).

In 2005 two Nature Conservation students, Johmandie Giliomee and Andri Cornelius initiated a monitoring programme for the quiver trees (*Aloe dichotoma*) of AFNP. The Giliomee (2005) project covered the impact that fauna has on the quiver trees and the Cornelius (2005) project was about the distribution and population structure of the quiver trees of AFNP. These studies were followed up and used as a template for the studies of Wolfaardt (2007) and Heimstadt (2009) (Table 1). Unfortunately this focus was broken by the study of Heimstadt (2009), who sampled only 407 quiver trees in Zeekoeisteek but also extended his study to the nearby Bullrevieren farm, to act as a control with no large wildlife. Subsequently two other studies with different methods were conducted by Herbst & Bezuidenhout (2010) and Ellis (2011) (Table 2).

Table 1: Summary of related monitoring on quiver trees that was conducted in Augrabies Falls National Park.

Date	Researchers	Method	Study site	Report available	Results
2005	Hendricks & Bezuidenhout	1.GPS location of all individual quiver trees (including their individual heights), 2. Distribution map. 3. Divide individual trees into three life histories in accordance to its height as follows: seedlings (< 1m), juveniles (1-2m) and adults (>2m). 4. Measure the percentage physical damage per individual tree.	Zeekoeisteek farm (8 500 ha).	Hendricks, H.H.H & Bezuidenhout H. 2005. Measuring the impacts on the distribution and population structure of *Aloe dichotoma* in Augrabies Falls National Park (AFNP). Methods proposed for students. Internal report, Scientific Services, SANParks, Kimberley.	No results
27 May to 23 September 2005	Giliomee Johmandie	1. Survey was started at Lekkerwater gate. 2. GPS point of each tree, the height, the physical damage according to height classes, type of damage, animals tracks, beehives and weaver nests.	Zeekoeisteek farm (8 500 ha). Bought by SANParks in 1999. Sheep farm.	Giliomee, J. 2005. *The damage impact of selected fauna species on Aloe dichotoma in the Augrabies Falls National Park* . SANParks, Augrabies.	1. Total of 1 459 quiver trees were recorded. 2. Tracks recorded 3. Sociable weaver nests. 4. Honeybee. 5. 315 dead quiver trees. 6. 114 trees not damage
27 May to 23 September 2005	Andri Cornelius	1. Survey was started at Lekkerwater gate. 2. GPS point of each tree, the height, the physical damage according to height classes, type of damage, animals tracks, beehives and weaver nests.	Zeekoeisteek farm (8 500 ha). Bought by SANParks in 1999. Sheep farm.	Cornelius, A.J. 2005. Die verspreiding en populasiestruktuur van *Aloe dichotoma* in Augrabies waterval Nasionale Park. Interne verslag vir diploma en SANParke.	1. 1 460 quiver trees recorded, 2. 30 Sub-populations; In 25 of these sub-populations no recruit young seedlings. 3. 1 145 trees alive. 4. 315 dead.
7 June to 16 October 2007	Lize Wolfaardt	1. Method used of Giliomee and Cornelius (2005).	Zeekoeisteek section (Giraffe and springbok was re-introduce in 2003/4 from northern section and VaalbosNP)	Wolfaardt, L. 2007. Impact of fauna on the Quiver tree (*Aloe dichotoma*) in Augrabies Falls National Park. Unpublished report for the Nelson Mandela Metropolitan University (SAARSVELD) and SANParks.	1. 1717 Quiver trees were recorded. 2. 73% (1261 Quiver trees) recorded alive 3. 27% (456 quiver trees) were dead. 4. 18% (315 quiver trees) not damage at all. 5. 55% (946 quiver trees) damage to the plant.
First eight months of 2009	Marco Heimstadt	1. Method used of Giliomee and Cornelius (2005).	Zeekoeisteek section and Farm Bullrevieren	Heimstadt, M. 2009. *Aloe dichotoma* and its plight in Augrabies Falls National Park. National Diploma: Nature Conservation, Cape Peninsula University of Technology. Internal report SANParks, Augrabies Falls National Park.	1. Zeekoeisteek 407 trees recorded. 2. 242 dead. 3. 6 trees not damaged. 4. Of the living trees 41 adults, 80 juveniles and 44 seedlings. 5. 12 fungus infections.

Table 2: Summary of other studies that have been conducted on quiver trees in Augrabies Falls National Park.

Date	Researchers	Method	Study site	Report available	Results
First eight months of 2009	Marco Heimstadt	1. Method used of Giliomee and Cornelius (2005). 2. Additional control plots on the farm Bullrevieren, which is bordering AFNP.	Zeekoeisteek section and Farm Bullrevieren	Heimstadt, M. 2009. *Aloe dichotoma* and its plight in Augrabies Falls National Park. National Diploma: Nature Conservation, Cape Peninsula University of Technology. Internal report SANParks, Augrabies Falls National Park.	1. A total of 830 trees were recorded. 2. Zeekoeisteek 407 trees of which 242 dead, only 6 trees not damaged. 3. Bullrevieren 220 trees were recorded with 24 trees dead. 4. Second plot Bullrevieren 203 of which 14 dead, 18 trees no physical damage.
10 to 12 August 2010	Marna Herbst, Hugo Bezuidenhout, Steven Smith, Nardus du Plessis, Elsabe Swart and Conrad Geldenhuys	1. New method. 2. A grid of 50m in width were walked and all trees counted. 3. Age structure noted as well as an index of damaged assigned until a total of 100 trees were assessed. 4. GPS coordinates were captured for each corner of the quadrant surveyed.	Zeekoeisteek (S28° 32' 03.3 E20° 00' 55.5), Bullrevieren Control 1 (S28° 36' 31.4 E20° 09' 12.8) and Control 2 (adjacent farm) (S28° 46' 44.2 E20° 07' 05.5).	Herbst, M. & Bezuidenhout, H. 2010. Evaluation of wildlife impact on quiver trees (*Aloe dichotoma*) in the Augrabies Falls National Park. Internal report for Scientific Services, SANParks, Kimberley.	1. The Zeekoeisteek population can be considered the healthiest site from a demographic point of view. 2. The most juveniles in relation to adults occur at this plot (1:6.67:9). 3. The high rate of physical damage is of concern only in the Zeekoeisteek population.
2011 & 2012	Graeme Ellis	1. New method. 2. A sample of a 100 *Aloe dichotoma* were selected. 3. Individuals from all 5 categories (juvenile 1, juvenile 2, adult 1, adult 2 and senescing). 4. Each of the selected individuals has a tag. 5. A GPS location. 6. Photographs of individual.	Zeekoeisteek area	Ellis, G. 2011. Report on the implementation of a monitoring project on the Aloe dichotoma in the Augrabies Falls National Park. Ellis, G. 2012. Report on the July 2012 monitoring of *Aloe dichotoma* in the Augrabies Falls National Park. Both internal report for Scientific Services, SANParks.	1. Total of 100 trees. 2. 71 herbivory damage, 10 dead, 39 trees not browsed (Ellis 2012).
2013	Graeme Ellis, Marna Herbst & Michele Hofmeyr	1. A sample of a 100 *Aloe dichotoma* were selected. 2. Individuals from all 5 categories (juvenile 1, juvenile 2, adult 1, adult 2 and senescing). 3. Each of the selected individuals has a tag. 4. A GPS location. 5. Photographs of individual.	Zeekoeisteek area	Ellis, G. Herbst, M. & Hofmeyer, M. 2013. Report on the September 2013 monitoring of *Aloe dichotoma* in the Augrabies Falls National Park. Internal report for Scientific Services, SANParks.	1. Total of 100 trees. Most of the preliminary results and observations suggest that a significant amount of disturbance, natural or animal induced, has happened in this population of *A.dichotoma* since monitoring began in 2011. A large portion of the damage does seem to be caused by herbivores.

i) Brief overview of researchers, years, methods, study area and results of past quiver tree studies in AFNP

Hendricks & Bezuidenhout (2005)

Hendricks & Bezuidenhout in 2005 proposed a study in the Zeekoeisteek section of AFNP to assess the quiver tree populations and conditions (Table 1). They suggested that a GPS location of all the individual quiver trees (including their individual heights) be recorded and constructed a distribution map using the ArcView software package. Quiver tree populations were divided into sub-populations on the assumption that a sub-population is a group of individuals less than 500m away from the nearest neighbour. Therefore the distance between sub-populations is greater than 500m but the distance between nearest neighbour individuals with a sub-population is less than 500m. Part of the proposal was to construct (table) frequency size class distributions of 1 m intervals for the entire quiver tree population and define sub-populations. Divide individual trees into three life histories in accordance to its height as follows: seedlings (< 1m), juveniles (1-2m) and adults (>2m). Measure the percentage physical damage per individual tree. Calculate the percentage seedlings and juveniles for each sub-population representing a surrogate for population health status because of the importance of recruitment for population viability. Percent seedlings represents a ratio of non-reproductive individuals (% seedlings (<2m)) against reproductive individuals (adults (>2m)). A scatter plot of log of the number of seedlings and juveniles (>2m) against the log of the number of adults (>2m) is performed to investigate the relationship between reproductive and non-reproductive individuals in the *Aloe dichotoma* sub-populations. A higher % of seedlings and juveniles (>2m) in a sub-population is assumed to be a sign of better health condition. To measure the physical damage of the individual trees according to height classes, damage is used at a specific height class as a surrogate for which animals are potentially responsible for impacting on individual trees (Figure 2).

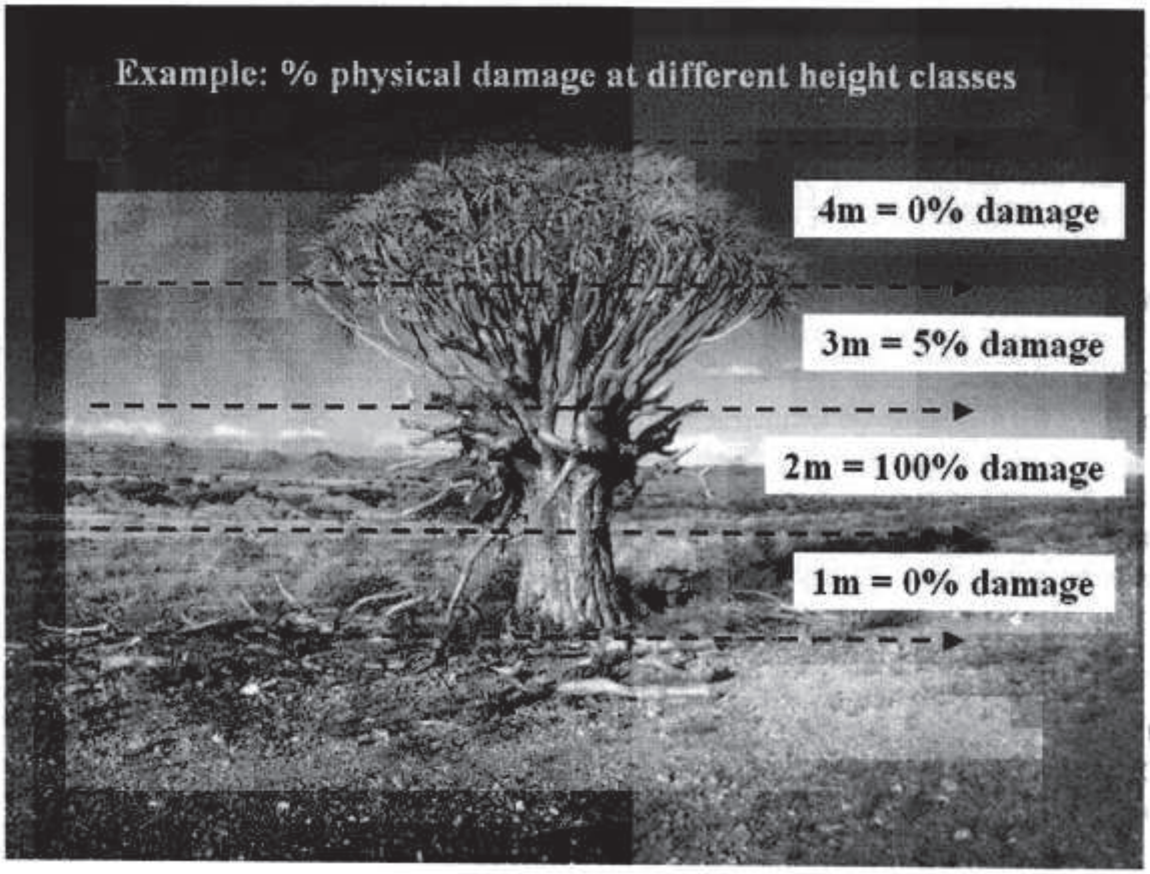

Figure 2: Percentage physical damage at different height classes proposed by Hendricks & Bezuidenhout (2005).

Giliomee (2005) & Cornelius (2005)

In 2005 two students Johmandie Giliomee and Andri Cornelius surveyed the named section Zeekoeisteek (8 500 ha) bought by SANParks in 1999. The farm was utilised for sheep farming before it was included into AFNP. The field work was conducted from the 27th May to 23rd September 2005 (Table 1). They started there survey at Lekkerwater gate and continued to the Af en Toe gate, keeping to the left side of the new tourist route. Each sub-population was recorded by starting with the outermost quiver trees and walking in an anti-clockwise circle gradually decreasing to the centre of the sub-population. GPS points of each tree, height, physical damage according to height classes, type of damage, animals' tracks, beehives and weaver nests were recorded. The results of this study was the following: A total of 1 460 quiver trees were recorded, 30 sub-populations; In 25 of these sub-populations there was no recruitment of young seedlings; 1 145 trees were alive and 315 were dead; 22% of total number of trees was dead and of these dead trees 39% were adult trees, 36% juvenile trees and 3% seedlings. Tracks of the following species were recorded: Gemsbok (3 individual quiver tree visited), Springbok (4), Eland (4) and Giraffe (57). Sociable weaver nests were recorded in 3 trees and honeybees in 3 trees. 315 dead quiver trees were recorded of which 144 were pushed over and139 growth points were broken off. 32 natural causes; 23 trees severely damage but re-sprouted; 114 trees not damaged. Also noted that Giraffe and Springbok was re-introduced in 2003/4 from the northern section and Vaalbos National Park (Wolfaardt 2007).

Wolfaardt (2007)

In 2007 Lize Wolfaardt monitored the same population using the same methods that was described by Giliomee (2005) and Cornelius (2005). Results of the study conducted by Wolfaardt (2007) indicated that 1 717 Quiver trees were recorded in the Zeekoeisteek section of AFNP (Table 1). The increase in the number of quiver trees recorded could be that different perceptions of what is an individual quiver tree and also possible double counting since she could not remember which trees were counted during the survey dates 7th June to 16th October 2007. “Several quiver trees found at the same spot were counted as more than one tree if they were separate from the ground. It was difficult to remember which trees were already recorded (Wolfaardt 2007)”. 73% (1 261 Quiver trees) of the 1 717 quiver trees recorded were alive and 27% (456 quiver trees) were dead. 18% (315 quiver trees) of the population had no damage at all. 55% (946 quiver trees) had some form of damage to the plant. The damage ranges from serious damage to parts of the plant to fungal infections.

Heimstadt (2009)

From January to August 2009 Marco Heimstadt monitored a section of Zeekoeisteek and used the same method that was described by Giliomee (2005) and Cornelius (2005). Additional work was conducted on the adjacent farm Bullrevieren (Table 1). To further identify or to exclude some herbivores as culprits, control plots were used in areas where some or all the animals that are present in the park were excluded from the area. These control plots were on the farm Bullrevieren, which is adjacent to AFNP. The control plots were also used to confirm that the impact in the park was due to animals and not other factors like wind (Bezuidenhout *pers.com*. 2009). Heimstadt (2009) recorded 830 quiver trees in total. In the Zeekoeisteek monitoring plot 407 quiver trees were recorded of which 242 were dead and only 6 trees were not damaged. The living quiver trees could be separated into 41 adults, 80 juveniles and 44 seedlings and 12 of these trees were infected by fungus. At Bullrevieren 220 trees were recorded with 24 trees dead. Of the living trees recorded, 56 were adults, 122 juveniles and 18 seedlings. On the second plot on Bullrevieren, 203 trees were recorded, of which 14 were dead and 18 trees had no physical damage. Of the living trees recorded, 56 were adults, 133 juveniles and 18 seedlings. In the Zeekoeisteek area 59 % of the quiver trees were dead. If compared with the data in the control plot on the farm Bullrevieren BR/09/01 (control plot 1) 11 % were dead, the only large herbivores are springbok and ostrich, and on control plot BR/09/02 (control plot 2) 7 % were dead, gemsbok and kudus are present at this control plot. He concluded that this high mortality rate of quiver trees at the Zeekoeisteek section is due to faunal impact other than ostrich, springbok, kudu or gemsbok.

Herbst & Bezuidenhout (2010)

The Research and Development Support Scientists (Elsabe Swart and Conrad Geldenhuys) of the Department of Environment and Nature Conservation (DENC) Northern Cape have initiated a research project on the quiver trees of the Northern Cape Province. Zeekoeisteek and Bullrevieren plots (Heimstadt 2009) were visited by a group of scientists during 10th till 12th August 2010 (Herbst & Bezuidenhout 2010). The method used was similar to that was used by DENC (Swart *pers. com*. 2010). A grid of 50m in width were walked and all trees counted, with age structure noted as well as an index of damaged assigned until a total of 100 trees were assessed. GPS coordinates were captured for each corner of the quadrant surveyed and the area of the quadrant was calculated (Table 2). The results from this study indicated that the Zeekoeisteek population was the healthiest site from a demographic point of view. The most juveniles in relation to adults occurred at this plot (1: 6.67: 9). However the rate of physical damage was a concern in the Zeekoeisteek population.

Ellis (2011, 2012 & Ellis *et al*. 2013)

In 2011 Graeme Ellis conducted a survey of 110 *Aloe dichotoma* trees in the Zeekoeisteek section. Quiver tree individuals from 5 categories (juvenile 1, juvenile 2, adult 1, adult 2 and senescing) were sampled. Each of the selected individuals were tagged with a unique number (Ak01-Ak100) on an aluminium disc attached to the tree. A GPS location and a photograph of each individual was taken. The results from Ellis (2012) indicated that 71 trees showed signs of herbivory damage, 10 were dead, and 39 trees were not damaged. Different feeding events at different heights by various wildlife species were recorded. Most of the preliminary results and observations suggest that a significant amount of disturbance, natural or animal induced, has happened in this population of *Aloe dichotoma*. A large portion of the damage does seem to be caused by herbivores.

"Of the 100 trees monitored, 67 experienced some form of herbivory damage, while 42 trees experienced some level of new herbivory (within the last year). Remembering that 23 trees are dead, 35 trees experienced no new browsing. The majority of these fell into the younger age categories (1-3). Damage was recorded when broken branches were encountered in the canopy that was attributed to a browsing event. However, on many of the younger plants (categories 1 and 2) 40% displayed some level of leaf utilisation which was not recorded as herbivore damage. 77% of the plants monitored had 50% or more of the overall damage attributed to herbivory (new and old) (Ellis, Herbst & Hofmeyer 2013)".

"In order to record the height of new damage, an average height to new damage was taken. Of the77 live plants, 42 experienced new herbivore damage. Of these trees, 23 had damage to their canopy at or below 250cm. A measure of 250cm has been taken as a value which antelope feeding events realistically won't occur above. The remaining 19 trees had damage above this with a max height recorded at 450cm. This would strongly suggest that there are definitely different feeding events performed by different species within the *Aloe* population (Ellis *et al*. 2013)".

An interesting angle to consider expressing the effects of browsers on these plants is to look at the average number of rosettes per plant in each live category compared across years. A slight increase in average number of rosettes in live category 1 individuals would be the seedlings' response to rosette removal. It has been observed that many small rosettes emerge from the break site (Ellis 2011, Ellis 2012). If no herbivory was present in the population, this number should be a single rosette for category 1, a characteristic of this age classes. What is disturbing is the decrease in average rosette number for categories 3 and 4 between 2011 and 2012. The 2013 figures don't deviate too much from the previous year's bar the age class 5 average. This is almost certainly as a result of the senescing process (Ellis *et al*. 2013).

A single toppled plant, alive, was selected in 2011 to be monitored. This plant was dead in the 2012 monitoring and another 4 trees, of live category 2 had been toppled. 50% of these had since died and a further 4 have been toppled and are still alive. Very little evidence of browsing occurred on these toppled individuals which suggest toppling is not necessarily associated with browsing (Ellis *et al*. 2013).

Density transects were walked through the centre of the population. Different length and area transects were walked explaining the slight differences in densities (Indi/ha) in the respective years. Having moved from less than one dead for each live plant to 2 dead for each live plant is cause for concerns. The percentage dead of counted plants (live and dead) has increased by 10% between 2011 – 2012 and 26% between 2011 – 2013. These increases, taking into account the short time period lapsed, is a considerable increase in the number of dead plants within this population (Ellis *et al*. 2013).

Most of the preliminary results and observations suggest that a significant amount of disturbance, natural or animal induced, has happened in this population of *Aloe dichotoma* since monitoring began in 2011 (Figure 2A). A large portion of the damage does seem to be caused by herbivores. With three monitoring sessions completed, this negative trend is of great concern and management interventions are needed. Three Camera traps were installed in the population in an attempt to shed light on who utilises the aloes and how. Surprisingly very few photos of Giraffe were gathered. Kudu, Eland, Gemsbok, Springbuck and Ostrich were regularly captured in the population. This further supports the data that a number of species are to blame for these levels of disturbance and damage recorded.

A decision was taken to erect a complete exclosure around a large part of the aloe population (Figure 5). 61 of the 100 trees fall inside this exclosure, while the remaining 39 fall outside at varying distances from the fence. This project may need to be amended to include a comparative part looking at the recovery of those individuals now protected. In principle, if an animal encounters a fence while foraging, they will probably spend more time in that immediate area than if they were able to move through the area freely. Whether the pressure increases on those individuals falling outside the exclosure and whether those closer to the fence are worst effected needs to be investigated (Ellis *et al*. 2013)."

Figure 2A: Tree No. A63 – Ellis (2011, 2012 and Ellis *et al*. 2013).

Additional important notes from past conducted research.

Wolfaardt (2007) and Giliomee (2005): **Porcupines** gnaw on the bark of trees and are known to ringbark selective trees. The porcupines are destructive feeders and damage more than they can eat (Skinner & Smithers 1990). The trees selected were young quiver trees. Giliomee (2005) found three **sociable weaver** (*Philetairus socius*) nests in her study site. All three nests were in adult trees. Two **honeybee hives** were found. One of the quiver trees was already dead and the other one was an adult tree that was still growing and therefore bee hives do not have an impact on the survival of the species. Giliomee (2005) found four bee hives. All four trees were still alive and the same conclusion was made by Wolfaardt (2007). Some example of a tree that was **seriously infected** with a fungus is shown in Figures 3 & 4. These funguses have a major impact on the health of the population. Some branches die due to these funguses.

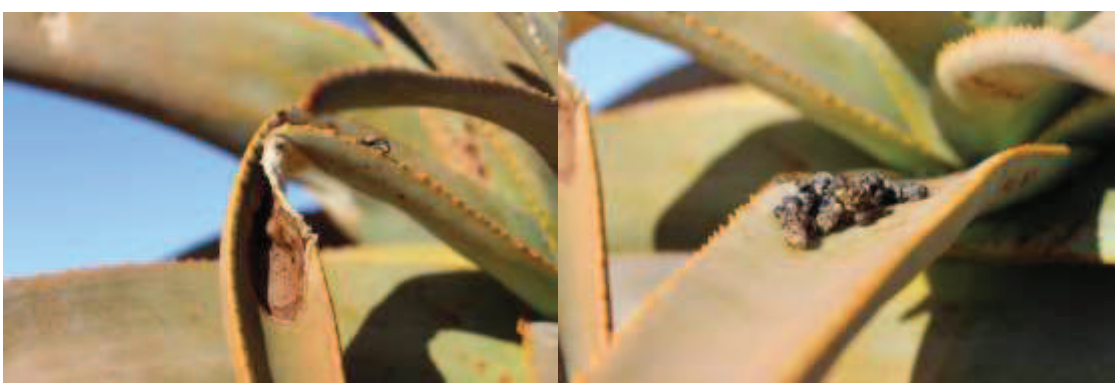

Figure 3: (Picture left) Infected leave Figure 4: (picture right) possible reason for infection (Photos Nardus du Plessis 2015).

Study site

Majority of these studies, with the exception of Heimstadt's study (2009), were conducted in AFNP. The area was restricted to the Zeekoeisteek farm / area (2007 – 2012) (Fig 5) but in 2015 two new sites were surveyed (Figure 6) (Tables 1 & 2).

Figure 5: Locality of Zeekoeisteek area (purple line) and location of exclosure plot in Zeekoeisteek area (blue line).

Methods

A proposed method by Dr Helga van der Merwe of the SAEON Arid Node, Kimberley (*pers comm*. 2015) for conducting surveys where trees occur at high densities, was tested. Mr Pauw, was also part of the survey, ensuring that the methodology used was similar to that used for their assessment of quiver tree populations elsewhere in the Northern Cape. Their method is based on Foden (2002) and is similar to the methods used by DENC (2010), which were also derived from Foden (2002). For this survey the method was adapted to enable us to conduct a survey within three days. The idea of trying to use the same method as other researchers outside AFNP, will allow us to compare results over time in different areas of the arid Northern Cape Province. The quiver tree populations of AFNP must not be seen in isolation but rather as part of a broader quiver tree population within the Northern Cape.

The following environmental parameters were also recorded for each of the three study sites:

Location, Date, Survey no, GPS reading, Altitude, Aspect: N, E, S, W, Dominant plant species, Total cover (%) of plot, Slope: Level (0-3°), Gentle (>3-8°), Moderate (>8-16°), Steep (>16-26°), Very steep (>26°), Slope position: (1) Crest, (2) Tallus slope, (3) Mid-slope, (4) Foot-slope, (5) Plain/Valley floor; Geomorphology: Convex, Concave, Flat, Geology; Topographical position: Valley, Sandy plain, Plateau, Koppie, Ridge; % Stone: Sizes: Gravel (<10mm), Small stones (>10 – 50mm), Stones (>50 – 200mm), Boulders (>200mm); Soil texture: Sand, Clay, Loam, Soil colour; Drainage: Good, Poor; Erosion: None, Water marks, Sheet erosion, Rill erosion, Dongas, Deposition; Wind: Erosion, Deposition, Shifting sand; Trampling: None, Slight, Moderate, Heavy; Litter on soil surface: Yes, No;

Soil compaction; Small mammals; Water points. Average canopy cover and height for the tree, shrub and herbaceous layers of the total plot area were estimated.

For the three localities Zeekoeisteek (exclosure site), Daberas and Coppenhagen the same method was used with various adaptations (Table 3).

A. Population structure / demography studies (similar to Foden 2002, DENC 2010 methods):

Zeekoeisteek (exclosure site)

1. A belt transect was used (Mueller-Dombois & Ellenberg 1974).
2. GPS reading was taken at the start of transect and at the end of the transect line and then again starting and end of transect line with second transect.
3. The belt transect of 1 000m length with 4 m width was conducted and then 200m apart the next belt transect was conducted again 1 000m in length, 4 m width.
4. All the quiver trees in this transect were counted and recorded as dead or alive.
5. Photograph of quiver tree individuals in the different height classes were taken with the measuring stick for Volcalc purposes (Barrett & Brown 2012).
6. 40 Marked (Ellis 2012) Quiver trees were randomly surveyed recording the following:
    - i) Height of the tree (measuring stick)
    - ii) Canopy diameter of the tree (measuring stick)
    - iii) Height of first branch
    - iv) Basal circumference
    - v) Number of live heads
    - vi) Number of dead heads
    - vii) Number of dead trunks
    - viii) Infection and if possible what caused the infection (notes)
    - ix) Stem damage (Yes or No)
    - x) Leaf damage (Yes or No)

Daberas

1. A belt transect was used (Mueller-Dombois & Ellenberg 1974).

2. GPS reading was taken at the start of transect and at the end of transect line and then again starting and end of transect line with second transect.
3. The belt transect of 1 000m length with 4 m width was conducted and then 200m apart the next belt transect was conducted again 1 000m in length, 4 m width.
4. All the quiver trees in this transect were counted and recorded dead or alive.
5. Photographs of quiver tree individuals in different height classes were taken with the measuring stick for Volcalc purposes (Barrett & Brown 2012).
6. 40 Quiver trees were randomly surveyed recording the following:
   i) Height of the tree (measuring stick)
   ii) Canopy diameter of the tree (measuring stick)
   iii) Height of first branch
   iv) Basal circumference
   v) Number of live heads
   vi) Number of dead heads
   vii) Number of dead trunks
   viii) Infection and if possible what caused the infection (notes)
   ix) Stem damage (Yes or No)
   x) Leaf damage (Yes or No)

Coppenhagen

The Coppenhagen site is currently fenced out of the Park (Table 3 & Figure 6) and is also different to the two other sites. The geology is Quarts porphyry outcrop which differs from the other two sites which were located on the slightly undulating Blouputs granite rocks. Due to the nature of the outcrop the method was slightly adapted.

1. A belt transect was used (Mueller-Dombois & Ellenberg 1974).
2. GPS reading was taken at the start of transect and at the end of transect line. This was done for the other two transects also.
3. The belt transect of 200m length with 4 m width was done and then 20m apart the next transect and then another 20m and another transect.
4. All the quiver trees in this transect were counted and recorded as dead or alive.

5. Photographs of quiver tree individuals in different height classes were taken with the measuring stick for Volcalc purposes (Barrett & Brown 2012).

6. All the trees that were noted on this outcrop were recorded totalling 72 individuals. Only the height was recorded for 32 of these individuals,

7. 40 Quiver trees were randomly surveyed recording the following:

- i) Height of the tree (measuring stick)
- ii) Canopy diameter of the tree (measuring stick)
- iii) Basal circumferences (measuring tape)
- iv) Height of first branch
- v) Number of live heads
- vi) Number of dead heads
- vii) Number of dead trunks
- viii) Infection and if possible what caused the infection (notes)
- ix) Stem damage (Yes or No)
- x) Leaf damage (Yes or No)

The following detail was recorded about the measurements mentioned above:

1. Total height – measured from the basal foot on the upper side of slope and parallel with the main stem.
2. Canopy diameter - measured in a plane at right angle from the direction where the height measurement and the associated photograph is taken.
3. Basal circumferences - measured at the base (usually thickest part of the main stem), but above the basal spreading foot or roots if present.
4. Height at first branching – measured on the top side where the branches separate.
5. Number of live heads.
6. Number of dead heads - heads without leaves or of which leaves are desiccated and shrivelled.
7. Number of dead trunks - breakages where several heads have/may have been lost.
8. Leaf infection – yes or no and if possible potential reason
9. Stem damage - rating from 0 for no scarring, 1 for slight damage, 2 for moderate damage and 3 for severe damage. Note the damage source if discernible.
10. Leaf damage - rating from 0 for no scarring, 1 for slight damage, 2 for moderate damage and 3 for severe damage. Note the damage source if discernible.
11. Other comments

12. Dead individuals:

    12.1. standing or lying,

    12.2. height if erect,

    12.3. canopy diameter, if canopy still intact,

    12.4. basal circumference of trunk

    12.5. height at first branching if tree still intact,

    12.6. additional comments.

B. Population density and percentage mortality:

1. Count all individuals in a 1000m x 4m belt transect that bisects the densest part of the population (and the demographic survey plot) and spanned to topographic gradients.
2. Where populations are small, break transect into shorter non-overlapping lines (total area = 4000m²).
3. Dead trees: indicated standing or lying.

C. Equipment necessary:

1. 100m rope
2. Pole to measure height
3. 2m long pole to assist in measuring the width of the belt transect
4. GPS
5. Camera
6. Field forms, writing equipment, clip board etc.

Results and discussion

During the surveys conducted in 2015, it was observed that three different landscape units provide a suitable habitat for quiver trees populations.

The following three landscape units were noted:

i) Undulating Blouputs granite midslope plateau (Two sites)

ii) Quarts Porphyry outcrop closely associated with the Daberas granodiorite (One site)

iii) Zeekoeisteek granite steep midslope southern aspect of hills (Reid *et al*. 2014).

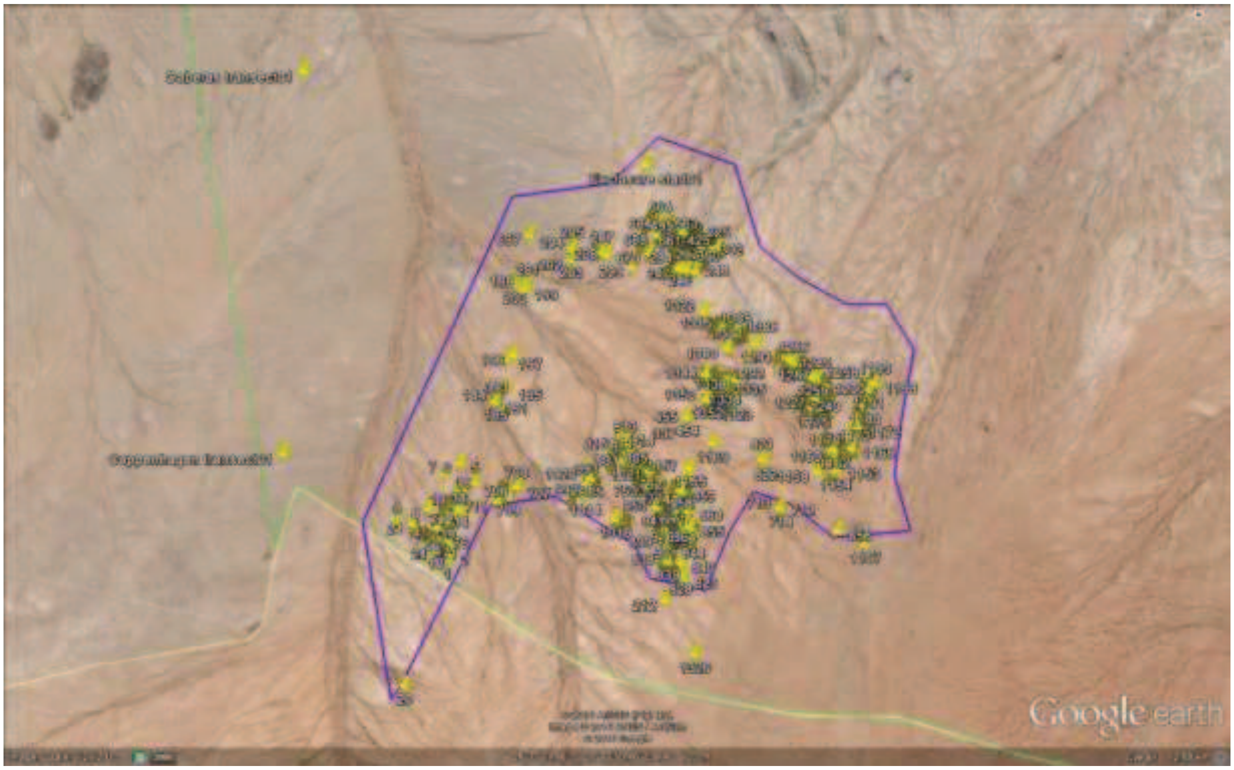

Figure 6: Location of monitoring plots in Zeekoeisteek in relation to Coppenhagen and Daberas sites and also the individuals that were recorded by Giliomee (2005), Cornelius (2005) and Wolfaardt (2007).

Table 3: GPS points for the three sites that were surveyed (Zeekoeisteek, Daberas and Coppenhagen) as well as one known site and one potential site.

Location	South	East
Zeekoeisteek (exclosure site)	28,52887	20,01582
Daberas	28.52077	19.97530
Coppenhagen	28.56002	19.97500
Nelshoop	28.58619	20.14841
Pauw site	28.48947	20.05411

Two possible quiver tree populations, which were identified from satellite imagery (Google Earth), on relatively steep slope southern aspect hills, were not surveyed (Table 3, Figures 7 & 8). The population at Nelshoop have been confirmed on the ground, but not the Pauw site.

Figure 7: Possible location of quiver trees close to Nelshoop (28°35'10.30"S 020° 8'54.31"E and second population 28°34'46.52"S & 20° 8'8.55"E).

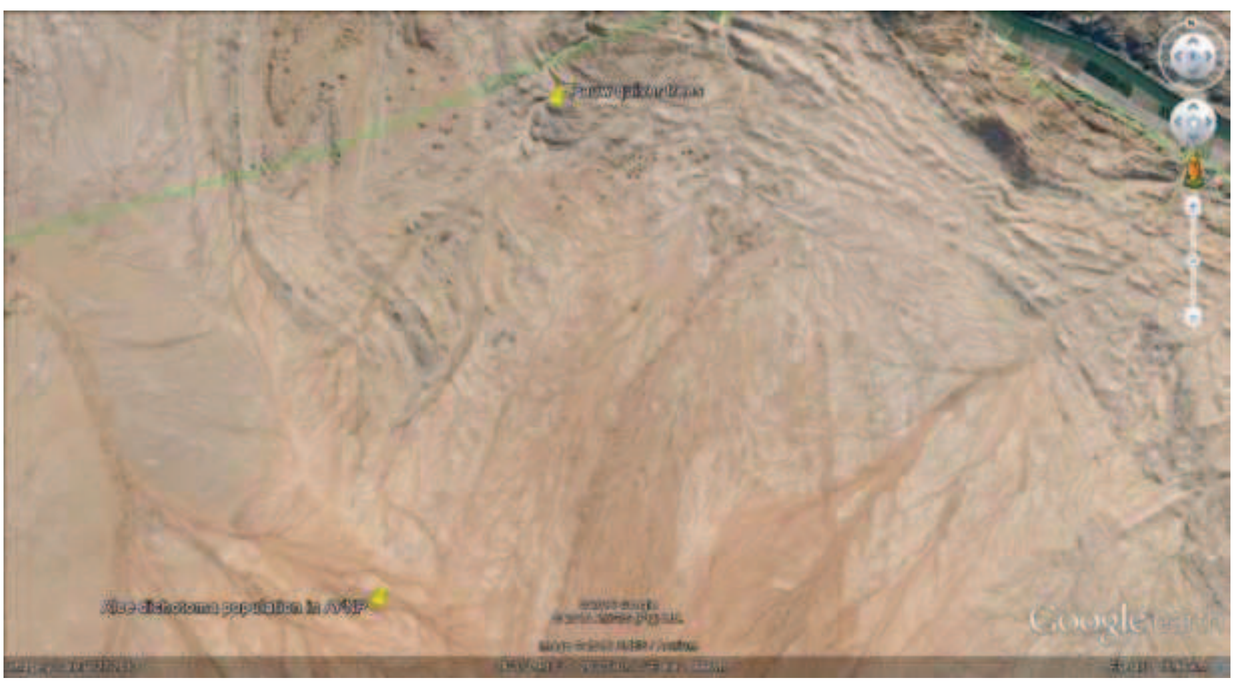

Figure 8: Possible location of quiver trees which is called the Pauw quiver trees (28°29'22.15"S & 20° 3'14.85"E).

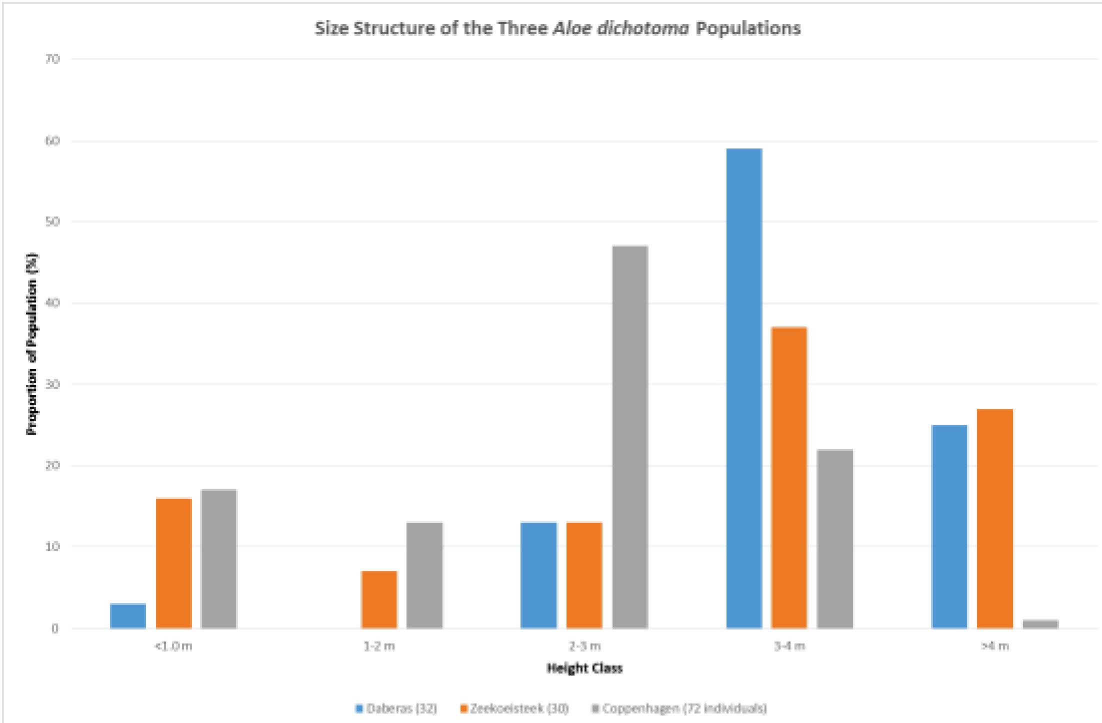

Figure 9: Results of the different sites with percentage of quiver trees (y) in different height classes (x).

Figure 9 shows that the Zeekoeisteek and Coppenhagen populations both have a fair proportion of seedlings and juveniles, which indicates a healthy population. However, it is a concern that the Daberas population has a smaller proportion of seedlings and no juveniles. The reason for the lack of recruitment and establishment should be investigated further, as the population will decrease if it cannot replace itself.

It is not apparent why the Coppenhagen population has such a high proportion of individuals in the height class 2-3 m and progressively lower proportions in the classes 3-4 m and >4 m compared to the Daberas and Zeekoeisteek populations. This could be due to the age of the population (Coppenhagen could be younger) or due to environmental variables. One possibility is that the quartz rich, shallow soil at Coppenhagen could limit the growth of the trees past a certain height, while this is not a factor in the other populations. Further analysis of this dataset may provide a better indication, but more directed research is needed to establish this for certain.

The results of the density for the different sites are: Zeekoeisteek 8 individuals per hectare, Daberas 5.6 individuals per hectare and Coppenhagen 5.4 individuals per hectare.

Table 4: Although different methods were used, some of these results could be compared. Damage (%) is for the all quiver trees that are still alive.

Researchers	Total	Alive (%)	Damage (%)	Dead (%)
Giliomee, J. 2005. Cornelius 2005.	1459	78	92	22
Wolfaardt, L. 2007.	1717	73	55	27
Heimstadt, M. 2009.	407	41	39	59
Herbst, M. & Bezuidenhout, H. 2010.	100	38	50	62
Ellis, G. 2012.	100	90	71	10
Bezuidenhout *et al*. 2015	Total	Alive (%)	Damage (%)	Dead (%)
Daberas	40	80	75	20
Zeekoeisteek	40	75	58	25
Coppenhagen	40	100	63	0

The term damage unfortunately was not standardised between the different researchers and therefore we could over - or under estimate damage to the quiver trees.

Table 5: Results of the quiver trees studies per seedling, juvenile and adult percentage of living individuals.

	Seedling (%)	Juvenile (%)	Adult (%)	Living individuals
Giliomee, J. 2005. Cornelius 2005.	3	36	39	1138
Wolfaardt, L. 2007.	13	58	29	1253
Heimstadt, M. 2009.	27	48	25	165
BR/09/01	9	62	29	196
BR/09/02	1	22	77	189
Herbst, M. & Bezuidenhout, H. 2010.	0	29	71	72
BR/09/01	9	20	71	65
BR/09/02	0	8	92	93
Ellis, G. 2012.	-	-	-	
Bezuidenhout *et al* 2015				
Daberas	3	0	97	32
Zeekoeisteek	16	7	77	30
Coppenhagen	17	13	70	40

Concluding remarks

A lot of work has been conducted on the quiver tree populations of AFNP. Unfortunately the methods were changed a couple of times. However, there is still the potential to use some of these data sets to form a strong guideline for future research in and outside AFNP. As stated before SANParks must not see the quiver tree as only occurring inside the park and isolated. These quiver tree populations inside the Park are part of a much larger outside mega-population and by all indications, could be an indicator or key plant species to the proposed or potential climate change. For both the long term monitoring of the population in AFNP as well as comparability with other datasets for the mega-population, it is therefore imperative that a standardised method is used henceforth.

Plan going forward:

1. To collaborate with SAEON Arid Node and DENC towards producing a scientific paper.
2. Analysis the current mega-data set with different statistical techniques.
3. Proposed a monitoring action plan in collaboration with Park Management, DENC and SAEON (Arid Node).
4. Reconnaissance survey of the Zeekoeisteek granite steeper midslope south facing aspects quiver tree populations in the Park.
5. Continue with survey and photograph of individual quiver trees marked by Ellis (2011).

References

Barrett, A.S. & Brown L.R. 2012. A novel method for estimating tree dimensions and calculating canopy. *African Journal of Range & Forage Science*, DOI:10.2989/10220119.2012.727471.

Foden, W., Midgley, G., Hughes, G., Bond, W., Thuiller, W., Hoffman, T., Rebelo, T., Kaleme, P. & Hannah, H. 2005. *A climate driven range shift in Aloe dichotoma (the Kokerboom): Detecting and monitoring climate change impacts in arid ecosystems*. A Threatened Species Programme, Climate Change and Conservation Project of SANBI.

Giliomee, J. 2005. *The damage impact of selected fauna species on Aloe dichotoma in the Augrabies Falls National Park*. SANParks, Augrabies.

Hendricks, H.H.H & Bezuidenhout H. 2005. Measuring the impacts on the distribution and population structure of *Aloe dichotoma* in Augrabies Falls National Park (AFNP). Methods proposed for students. *Internal report, Scientific Services*, SANParks, Kimberley.

Mueller-Dombois, D. & Ellenberg H. 1974. *Aims and Methods of Vegetation Ecology*. John Wiley & Sons. United States.

Powell, E. 2004. *Oorsig van die Noord-Kaap se Kokerbome, Aloe dichotoma*. Departemant van Toerisme, Omgewing en Bewaring. Kimberley

Cornelius, A.J. 2005. Die verspreiding en populasiestruktuur van *Aloe dichotoma* in Augrabies waterval Nasionale Park. *Interne verslag vir diploma en SANParke*.

Ellis, G. 2011. Report on the implementation of a monitoring project on the Aloe dichotoma in the Augrabies Falls National Park. *Internal report for Scientific Services*, SANParks.

Ellis, G. 2012. Report on the July 2012 monitoring of *Aloe dichotoma* in the Augrabies Falls National Park. *Internal report for Scientific Services*, SANParks.

Ellis, G. Herbst, M. & Hofmeyer, M. 2013. Report on the September 2013 monitoring of *Aloe dichotoma* in the Augrabies Falls National Park. *Internal report for Scientific Services*, SANParks.

Herbst, M. & Bezuidenhout, H. 2010. Evaluation of wildlife impact on quiver trees (*Aloe dichotoma*) in the Augrabies Falls National Park. *Internal report for Scientific Services*, SANParks, Kimberley.

Wolfaardt, L. 2007. Impact of fauna on the Quiver tree (*Aloe dichotoma*) in Augrabies Falls National Park. *Unpublished report* for the Nelson Mandela Metropolitan University (SAARSVELD) and SANParks.

Heimstadt, M. 2009. *Aloe dichotoma* and its plight in Augrabies Falls National Park. National Diploma: Nature Conservation, Cape Peninsula University of Technology. *Internal report* SANParks, Augrabies Falls National Park.

Reid, J.L., Mathee, H.L.M., Praekelt, H.E. & Collison, W.P. 2014. Geological map (1: 100 000) of Augrabies Falls National Park. Department of Geology, University of Free State.