THE BIOLOGY, ECOLOGY AND CONSERVATION OF *EUPHORBIA GROENEWALDII* AN ENDANGERED SUCCULENT OF THE LIMPOPO PROVINCE

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DECLARATION

I declare that the dissertation hereby submitted to the University of Limpopo for the degree of Master of Science has not previously been submitted by me for a degree at this or any other university, that it is my own work in design and in execution, and that all material contained therein has been duly acknowledged.

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PREFACE

The study was carried out through the Department of Biodiversity in the School of Molecular and Life Sciences, University of Limpopo from January 2007 to May 2010, under the supervision of Professors D. Engelbrecht and M. Potgieter of the Department of Biodiversity at the University of Limpopo with assistance by Professor E. Witkowski of the School of Animal, Plant and Environmental Sciences at the University of the Witwatersrand. This study represents original work by the author and where the work of other authors has been used, they are duly acknowledged in the text and listed as references.

Chapter 1 consists of a general introduction discussing the broad characteristics and status of various members of the family *Euphorbiaceae*. The southern African representatives of the family are briefly introduced emphasising *Euphorbia groenewaldii.* The rationale and the objectives of the study are outlined. Chapter 2 of this dissertation was written as a research paper with the relevant tables and figures appearing at the end of the chapter. The intrinsic and extrinsic (biotic and abiotic) factors affecting *E. groenewaldii* are reviewed in Chapter 2, with the aim of developing a conservation management programme that will ensure the species' continued survival. Chapter 3 compares population size differences in two different studies; reassesses the present conservation management of *E. groenewaldii* and re-evaluates its conservation status. Chapter 4 presents a summary of the findings of the previous chapters and includes recommendations on *E. groenewaldii's* conservation management. Due to the format of this dissertation, a certain amount of duplication of information has resulted.

ABSTRACT

Several South African *Euphorbia* species are threatened with extinction, yet only a few have been studied in sufficient detail to develop a conservation management plan based on sound scientific principles. The focus of this study was on one of the highly threatened dwarf Euphorbias, namely *Euphorbia groenewaldii*. Apart from a report on the species distribution and estimated population numbers by Raal (1986), virtually nothing is known about this attractive succulent species. Conservation and management of threatened species requires a thorough understanding of their biology, ecological requirements and spatial distribution which should form the basis of a monitoring programme that must be conducted at regular intervals.

Euphorbia groenewaldii is endemic to six rocky schist and quartzite ridges in the vicinity of Polokwane, the capital of South Africa's Limpopo Province. The species' small global range, small number of populations and small population sizes in some instances, render the species susceptible to anthropogenic and environmental stochasticity.

Biotic and abiotic features were investigated to determine their influences, as well as, the threats (trampling, anthills, herbivory and number of senescent plants) facing *Euphorbia groenewaldii*. Canopy area was used to determine the stage (age) and size structure of each population. Biotic features and natural environmental components considered were percentage cover of grass, forbs, dead vegetation, stones, fixed rock and bare ground. The percentage cover, of all the biotic features (grass, forbs and dead material) and environmental components (stones, fixed rock and bare ground), most preferred by *E. groenewaldii* is close to 25% in the direct vicinity of the individual plant. *Euphorbia groenewaldii* select areas with fixed rock more than in any other biotic feature or environmental component. This could be for protection from, or a result of, trampling by large herbivores, or that it's most preferred mineral substance is found within this geology.

Abiotic features considered in this study were; fire, aspect, slope degree, slope position and soil. The *E. groenewaldii* population as a whole prefers to grow on the

northern aspects. Furthermore, with threats affecting all the populations, it is forced to grow in the middle of steeper slopes.

Currently the only fire ‘regime’ is a natural or accidental occurring fire. The area where *E. groenewaldii* grows belongs to the local government and is open to public traffic. If a regular (once a year) cold-fire regime for *E. groenewaldii* can be put in place and, if possible, coincide with rainfall events it could help the release of more seeds and help with a more constant rate of seedling recruitment for this species. Such a fire event was witnessed during the study period and subsequent new growth and seedling appearances were recorded.

Threats that were noted and considered were mostly of a biotic nature (absence of fire being the exception) and included trampling, herbivory and termite mounds. Other threats not included are urban expansion and mining/quarrying activities. These types of threats are real and more extensive, and if not monitored could completely destroy a population in a very short time period.

Trampling is a significant threat facing this species, particularly at the Melkboomfontein population, where 31% of the population shows physical signs of trampling by livestock; mainly cattle. Herbivory is also a threat to *E. groenewaldii* and causes significant damage (15% over the total population according to the statistical analysis). There is also a significant difference in the effect anthills have on *E. groenewaldii* as opposed to the other threats, which have almost no effect on its population size.

In addition to the above, surveys were conducted to determine the species’ present extent of occurrence and area of occupancy to obtain population size estimates and densities. The results were compared with data of a study by Raal in 1986. The results of this study showed a dramatic decline in population numbers. Possible reasons for the reduction include habitat loss, better survey techniques (that provided better predictions of population density) and a more comprehensive survey and data analysis in this study, and a failure to implement the conservation management plan proposed by Raal (1986). It is estimated that the total number of individuals in all the populations comprise approximately 26 500 individual plants, with all occurring in an area of less than 4 km^2 (excluding the Dalmada populations). The small extent of occurrence suggests that *E. groenewaldii* populations require urgent protection.

An investigation of morphological differences between *E. groenewaldii* and *E. tortirama* was conducted. This investigation attempted to find external morphological differences by looking at the flower peduncles, colour of bracts and spine shields. Analysis of these data showed differences in the length of the peduncles (longer in *E. groenewaldii* than in *E. tortirama*); colour of bracts (colourless in *E. groenewaldii* as opposed to the reddish-pink bracts of *E. tortirama*) and the continuation (*E. groenewaldii*) and non-continuation (*E. tortirama*) of spine shields.

In 1986, *Euphorbia groenewaldii's* conservation status was considered endangered; it is still the case today. However, the IUCN status of *E. groenewaldii* was re-evaluated on the current data gathered, which has placed *E. groenewaldii* in the Critically Endangered category. This is mainly due to the small extent of occurrence (approximately 4 km^2) of the species (less than the 100 km^2 which according to the IUCN Redlist Categories and Criteria, 2006, criteria B, classifies species as critically endangered).

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CHAPTER 1
INTRODUCTION

1. GENERAL INTRODUCTION

The rich biodiversity of the southern African sub-region is well documented (Siegfried & Brooke, 1994). In fact, the World Conservation Monitoring Centre recognized South Africa as the third most biologically rich country in the world after Brazil and Indonesia (WCMC, 1992). South Africa, as a signatory to the Convention on Biological Diversity, has committed itself to establish an inventory of its fauna and flora through research and recording. To conserve biodiversity it is necessary to establish what one hope to conserve and to describe the spatial and temporal distribution and abundance of biota. Biological diversity, also known as biodiversity, can be defined in various ways, for it is the very basis of human survival and economic well-being. Biodiversity also encompasses all life forms, ecosystems and ecological processes, and it also acknowledges the hierarchy at genetic, taxon and ecosystem levels (Savard *et al.*, 2000). For Savard *et al.* (2000), the term biodiversity is used in a very broad manner meaning the variability of life (composition, structure and function).

It is estimated that the total number of species on earth varies between 5 million and more than 50 million, with a conservative estimated figure of 13.6 million species (Singh, 2002). Out of these, only approximately 1.7 million species have been described and awarded scientific names (Spellerberg, 1996). This suggests that our knowledge of the Earth's biodiversity is remarkably incomplete. Gibbs (2001) noted that mankind is presently entering another of the earth's mass extinction phases in terms of the earth's biodiversity, with about half of the habitable surface of the earth being changed by humans who are impairing and destroying ecosystems. Although the extinction of species is a natural phenomenon, according to Singh (2002), and an integral part of evolution, it is anthropogenic activities (habitat destruction, over-exploitation, invasive alien species, habitat degradation and climate change) that accelerate the rate of extinction which exceeds the background rate of extinction at present. Central to all the above-mentioned threats to biodiversity is an ever increasing human population.

The root cause of many extinctions can be linked to anthropogenic processes (Walker, 1992). It is estimated that the present mass extinction may be complete within as little as 200 years, and estimates suggest that about 20% of all species are expected to be lost within 30 years and 50% or more by the end of the twenty-first century (Singh, 2002).

Extinction of a species is usually initiated by a decline in its numbers until it ceases to exist. Extinction is induced by either an environmental change or a challenge that exceeds the adaptive capacity of individuals and it then has no safe place to retreat to. Thus it seems reasonable to affirm that the probability of extinction increases steadily as effective population size decreases (Given, 1994).

A well-known example of human influence on the extinction of a plant species in the wild is the Saint Helena Olive (*Nesiota elliptica (Roxb.) Hook.f.*). This small tree was endemic to the island of Saint Helena in the south Pacific ocean. It became very rare in the 19th century, as a consequence of habitat loss, and by 1875 only about 15 trees were recorded growing on the northern side of Diana's Peak. The last wild Saint Helena Olive died on 11 October 1994, but the species continued to survive in cultivation until December 2003. This is despite numerous conservation efforts (Maas, 2010).

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2. WHY IS CONSERVATION IMPORTANT?

The world is currently in the midst of a biodiversity crisis with an estimated 2-25% of all species at risk of extinction due to anthropogenic causes (Singh, 2002). This has become a major problem in terms of saving our animal and plant diversity (Cullen *et al.*, 2001). Furthermore, the importance of future processes, such as altered dynamics of species interactions under global change scenarios, urban and infrastructure development and habitat reduction and fragmentation, may increase in the future (Burgman, 2002). It is therefore very important to conserve biodiversity, whether it includes rare, endangered or common species, in order to guarantee the ongoing existence of species, habitats, biological communities, interactions between species and ecosystems, and ultimately humankind (Spellerberg, 1996).

All plants, animals, communities, ecosystems, biological processes and biological interactions form part of the biodiversity of this planet and are of fundamental importance because we depend on our natural resources for our survival and future existence. Conservation of biodiversity incorporates aspects like preservation, restoration and enhancement of the environment and controlled utilization of our natural resources (Given, 1994).

Conservation of a species is often viewed as a trade-off between the economic value that the species holds for humanity and the possible ecosystem services a species fulfils. The decline of a certain species may set off significant ecological changes, such as changes in ecological interactions and population dynamics, causing instability in the community as well as disruption of linkages which could result in the loss of other species (Venette *et al.*, 2001).

Caughley (1994) describes two paradigms for the conservation of rare and/or endemic species, namely; the small-population paradigm and the declining-population paradigm. The declining-population paradigm predominates in conservation studies.

2.1 Small-Population Paradigm

This paradigm, according to Caughley (1994), deals mainly with the aspects or problems of population dynamics and population genetics that is faced by small populations with the possibility of going extinct as a result of its small population size. This paradigm can be examined in theory and could be implemented in conserving rare and endangered species. The small-population paradigm has also assisted in the design of nature reserves.

There are concepts that are relevant to this paradigm, like metapopulation dynamics, genetics, minimum viable population (MVP) and population viability analysis (PVA) (Caughley, 1994).

2.1.1 Metapopulation Dynamics

Recently a broader and more inclusive concept of the population came into use that includes both dispersal and spatial variation in habitat type and quality (Krohne, 2001). This concept of metapopulation is a collection of subpopulations interconnected by dispersal. This type of population structure can apply to groups of populations that live in a landscape with habitats that vary in quality and occur in discrete patches (Schemske *et al.*, 1994).

Some patches may be located in optimal habitats and support large populations that may exceed the carrying capacity and force some individuals to disperse to other patches in search of space and resources (Given, 1994). Successful dispersal to other patches depends on the distance between patches and the nature of the corridor linking these patches. Less than optimal patches could hold smaller populations or on occasion go extinct (Krohne, 2001). Subpopulations are not in equilibrium and may go extinct on a regular basis (Stewart & Hutchings, 1996). A metapopulation persists because of the interactions between patches that will prevent the extinction of the whole metapopulation and not because it achieves a state of equilibrium (Schemske *et al.*, 1994).

Stewart and Hutchings (1996) stated that the dynamics of a metapopulation will depend mostly on the quality of the habitat supporting the subpopulations as well as the quantitative aspects of the subpopulation’s dispersal among them. The quality and size of the habitat determine the extinction probability of a subpopulation and its carrying capacity. Krohne (2001) is of the opinion that the dispersal rate of a subpopulation will be determined by the species’ vagility and the distance separating the subpopulations. For example, the forest herb, *Primula vulgaris* Huds., that cannot survive in a mature forest with low light intensities and so colonizes gaps left by dead trees or by some disturbance. The result of this is that the metapopulation consists of a chain of populations increasing and decreasing in forest gaps of various ages.

2.1.2 Genetics

A species with a small population size will need to cope with long term environmental changes by changing its genetic composition so that it can adapt to environmental changes for the continuous survival of the population (Given, 1994). Species lose habitat as a result of urbanisation and development, for instance the addition of roads, quarries, housing and pipelines. Habitat loss involves four phenomena: a reduction in habitat area, area fragmentation, habitat deterioration within the patches and habitat deterioration between the patches (Sih *et al.,* 2000).

When an endangered species' habitat is fragmented and has deteriorated into patches because of destruction, there will be plants that have survived outside the destroyed area (Marom, 2006). These individual plants of the endangered species may not survive long due to fragmentation and exist in too many small populations to persist and will have a good chance of going extinct (Marom, 2006). A consequence of a small population size is that relatives will increasingly interbreed and hence face the risk of genetic drift and inbreeding. This will cause a population to decline and ultimately go extinct. Following this, the population with lower genetic variation can have a smaller chance to survive if the environment changes (Krohne, 2001).

Marom (2006) questioned the correctness of genetic approaches towards conservation studies of rare plants. According to them studies on genetics have thus far failed to indicate how the resultant research is practical for assisting in the recovery of threatened plant species. These approaches are only relevant for assisting in maintaining genetic variation during *ex situ* cultivation and reintroduction and to studies where genes have been identified as a key cause of a population decline. Genetic diversity of a species and all its subpopulations may also be conserved as is, because some populations may be genetically unique and they should be conserved as such.

2.1.3 Minimum viable population (MVP)

In conservation biology the question of what composes a MVP embraces the concept that the concerned population should be large enough to prevent the effects of inbreeding depression and to retain genetic diversity (Gray, 1996). What is the critical minimum size at which a population will risk imminent extinction? This is a very important question to ask when maintaining either a single-site or a dispersed population of an endangered species, as well as when protecting species distributed across fragmented natural populations (Stewart & Hutchings, 1996).

According to Stewart & Hutchings (1996), there are a few points that must be remembered when considering MVP estimates: Firstly, an MVP can only be defined in the context of the probability of population survival over a defined time period. Second, estimates will undoubtedly vary between species and possibly between populations, thus there is no unique number that can be applied universally. Thirdly, MVP refers to the risk of extinction from genetic causes. The risk of environmental stochasticity (randomness) can also be added but are often harder to estimate. Finally, figures that have been widely quoted and adopted by conservation managers are often little more than subjective guidelines.

2.1.4 Population viability analysis (PVA)

Over time plants change form, grow, produce flowers and fruit, become senescent, and die (Given, 1994). The same goes for ecosystems and populations that undergo change and are in constant flux (Given, 1994). Populations and ecosystems are vulnerable to change in different ways and rates through time (Given, 1994).

A PVA is an assessment that usually predicts the probability of a population becoming extinct within a certain time period, given a set of assumptions about the factors that will affect a species, as well as have a specific management regime (Possingham, 1996). The information obtained through a PVA will provide a framework for the planning of the maintenance of a population and consider the following factors (Given, 1994):

i) The fragmentation of habitat or loss of habitat quality, e.g. through edge effect, can lead to fragmentation of populations and their decline.
ii) The reduction in population distribution and effective size may lead to extinction.
iii) The increased variation in population growth rate can lead to extinction. Many fluctuations in population size with frequent peaks and crashes will increase the extinction risk for a population.

iv) Inbreeding depression coupled with decreased genetic variation may lead to increased risk of extinction.
v) In very small populations there is an increased possibility of chance loss of genetic material through genetic drift.
vi) The effect of human policies and activities must be considered e.g. interest in species and habitats change.

Given (1994), Possingham (1996) and Pfab (1997) noted that population viability analysis is a widely used tool in threatened animal species studies and to a much lesser extent in plant, especially threatened plant, studies.

2.2 Declining-Population Paradigm

When designing a management strategy that will help recover an endangered species, it is essential to identify agents responsible for the decline of a population (Peery *et al.*, 2004). Caughley (1994) proposed a framework which identifies such factors, which is collectively known as the Declining-Population Paradigm. The main principal of the Declining-Population Paradigm is that the reduction of the range of a species and the decline in the number of its individuals has a physical cause that may be identified and solved with experience and skill. The problem with this paradigm is that it is not grounded on a sound theoretical basis. It is embedded in pragmatic approaches with which it provides most of the means by which practical conservation problems might be solved. The declining-population paradigm comprises mainly case-by-case ecological investigations and recovery operations that are more often than not short on scientific rigour, which helps little with advancing the understanding of the processes of extinction. There are however two areas of theory that this paradigm does cover: i) the causes of extinction and ii) the means by which the causes or agents that cause declines in a population may be identified (Caughley, 1994).

The causes of a small population size that may lead to extinction can be sub-divided into two categories: natural and man-induced causes (Pfab, 1997). The agents of decline in small populations (especially man-induced agents) may be classed under four headings (Caughley, 1994):

i) Overkill. For example, harvesting and collecting at above the maximum sustainable yield. The most susceptible species are those with a low intrinsic rate of increase.
ii) Habitat destruction and fragmentation. For example, a habitat could be degraded by agents, such as a change in the fire regime; grazing by livestock (e.g. a boom in a herbivore population and the effect of overgrazing on a vulnerable species can be seen in the years following the boom) (Bradshaw, 1981), or grazing on a plant in specific times of its life cycle (when the plant produces flowers, seeds or seedlings) (Ward, 1981; Harvey & Meredith, 1981); and cutting down a patch of forest or draining a wetland (Caughley, 1994).
iii) Impact of introduced species. For example, the introduction of alien species, either intentionally or unintentionally by people, that eliminate native species by competing with and preying upon them and destroying their habitat (Marom, 2006). Invasive species may also have very little effect on the indigenous plants, depending on what effects their displacement or co-existence have on rare and endangered plants (Marom, 2006). An example of where invasive species do have an effect on rare and endangered plants is found on the Island of Hawaii where an alien grass species, *Panicum maximum*, has been the cause of the extinction of a rare and endemic fern, *Marsilea villosa* (Wester, 1994).
iv) Chains of extinction. For example, extinctions taking place after another species on which it relied upon also went extinct. Orchid species requiring specific pollinators are good examples of this phenomenon. If either one becomes extinct, the other one will follow because the orchid provides food for the pollinator and the pollinator helps with the fertilization and future existence of the orchid.

To use this paradigm in the field and correctly identify the agents of decline, there are a minimum of four approaches that one could follow (Peery *et al.,* 2004):

i) A demographic response can be modelled for each potential cause and compared with independently collected population data. This approach is mostly exploratory because it does not include clear information on the causes of decline and because modelled mechanisms are rarely confirmed.

ii) Rates of decline can be compared among populations experiencing different environmental conditions. This could be a powerful approach, but endangered species are regularly restricted to one or a few populations that result in small sample sizes. Besides, different factors may limit different populations.

iii) The timing of a population decline can be related to the timing of changes in candidate limiting factors. This approach is powerful but not always feasible because accurate population data for periods prior to a decline are rarely available.

iv) Developing a series of competing predictions about the effects of each factor on the behaviour, habitat use, demography and trophic interactions of a species of interest and then designing field studies to test the predictions. This approach is called the multiple competing hypotheses (MCH), and is perhaps the most general approach for diagnosing the cause of population decline and can incorporate elements from other approaches in the predictions.

More effort is needed when it comes to rare and endangered plant conservation. All conservation paradigms must be considered and even evaluated for the best possible strategy in conserving rare and endangered plants.

3. THE FAMILY EUPHORBIACEAE

3.1 General background

The botanical name *Euphorbia* derives from Euphorbus, the Greek physician of King Juba II of Numidia (52-50 BC-23 AD). He is reported to have used a certain plant, possibly Resin Spurge *Euphorbia resinifera* A. Berger., as a herbal remedy when the king suffered from a swollen belly. Carolus Linnaeus assigned the name *Euphorbia* to the entire genus in honour of the physician (White *et al.*, 1941).

The *Euphorbia* represents a diverse genus of plants belonging to the spurge family (Euphorbiaceae) (White *et al.*, 1941). The genus *Euphorbia* is distributed worldwide and varies in habitat preference from dwarf succulents to trees as tall as 20 m.

These spurges achieve their greatest diversity in the arid areas of Africa and Madagascar where many of them are cactus-like succulents; most of these are rare and threatened by human encroachment (Berry *et al*., 2006). It is comprised of approximately 2160 species, which makes the genus one of the largest genera in the plant kingdom (White *et al.*, 1941). It is estimated that about 10% of the world's *Euphorbia* species can be found in South Africa (Fourie, 1983). *Euphorbias* can be found in all the major biomes in South Africa (Becker, pers. comm.) and can reach extreme densities in places like the Eastern Cape's Noorsveld, e.g.. *Euphorbia coerulescens* Haw., and along the western coast of South Africa as far north as the Richtersveld region (Van Jaarsveld *et al.*, 2006). The accelerated rate of extinction of species discussed earlier also threatens several members of the *Euphorbiaceae.* Several members of this family have extremely small ranges and narrow habitat requirements and are threatened as a result of various factors. These include, amongst others, *Euphorbia barnardii* A.C. White, R.A. Dyer & B. Sloane, *Euphorbia clivicola* R.A. Dyer, *Euphorbia perangusta* R.A. Dyer, and this is but a few species from the northern regions of South Africa (Hilton-Taylor, 1996).

The International Union for the Conservation of Nature's (IUCN) Red List of Threatened Species lists 171 species of the genus *Euphorbia* as species of conservation concern (IUCN, 2007). Of these 171 species, 51 (29%) are listed in the upper conservation categories of endangered or critically endangered (IUCN, 2007). Africa has the dubious distinction of representing 72 (42%) of the 171 threatened *Euphorbias* worldwide, of which 25 (15%) species are listed as endangered or critically endangered (IUCN, 2007). One of the major reasons for the endangered status of so many *Euphorbias* is habitat destruction. Ever increasing human populations require more land which leads to more habitat destruction. Associated with habitat destruction are a range of factors associated with human activities, e.g. collector pressure, trampling by livestock and humans, destruction by vehicles (recreational and commercial), development (Pfab & Witkowski, 2000) and pollution (Knowles & Witkowski, 2000).

Nearly 30% of South Africa's *Euphorbias* are listed in the Red Data List of Southern African Plants (SANBI, 2009) but not all of them are listed in the IUCN Red List of

Threatened Species. Most of these Red Data listed species are poorly known and very little information is available on their biology, ecological requirements and environmental factors influencing their spatial and temporal distribution (Pfab & Witkowski, 1997). Historically, most species were only managed and monitored in terms of population increases and decreases (Raal, 1986; Pfab, 1997).

Only a few South African *Euphorbia* species have been studied in sufficient detail to develop a conservation management plan based on sound scientific principles. Pfab and Witkowski (1999a, 1999b & 2000) studied the critically endangered *Euphorbia clivicola,* whereas Knowles and Witkowski (2000) studied the population biology and ecology of the endangered *Euphorbia barnardii* and made recommendations for its effective management. Several other Red Data listed *Euphorbia* species are almost entirely unknown and are only known from distribution records or historic monitoring records of the Transvaal Provincial Administration, for example *Euphorbia grandialata* R.A. Dyer, *E. groenewaldii* R.A. Dyer*, Euphorbia louwii* L.C. Leach*, E. perangusta* R.A. Dyer*, Euphorbia restricta* R.A. Dyer*, Euphorbia rowlandii* R.A. Dyer*, Euphorbia tortirama* R.A. Dyer *and Euphorbia waterbergensis* R.A. Dyer (White *et al.*, 1941; Act No. 7 of 2003).

From the above information it is evident that several members of the genus are in dire need of conservation efforts. However, our attempts at conserving these species are hampered by a lack of knowledge about their general biology and ecological requirements (Witkowski & Liston, 1997). Moreover, their potential for providing novel compounds for medicinal purposes is virtually unknown.

The focus of this study will be on one of the dwarf *Euphorbia* species, namely *Euphorbia groenewaldii*. Apart from a report on the species distribution and estimated population numbers by Raal (1986), virtually nothing is known about this attractive succulent species.

3.2 *Euphorbia groenewaldii*

3.2.1 General background and description

Euphorbia groenewaldii was discovered by Dr. F. van der Merwe in 1936 and requested to name the plant in honour of his friend, B.H. Groenewald (White *et al.*, 1941).

Euphorbia groenewaldii was originally described from a stony hillside near Polokwane (White *et al.*, 1941), and subsequently the species has been discovered on a number of small gravel ridges in the Diep River valley. The species originally comprised six known populations, but Raal (1986) believed that one population is extinct as it could not be relocated during routine monitoring surveys in the early 1980s. The six populations reported by Raal (1986) were found on the farms Rietpol 858LS (presumed extinct), Spits 994LS, Majebeskraal 1002 LS (Ronsma), Melkboomfontein 919LS, De Put 918LS (Masele), Kalkfontein 1001LS and Tweefontein 915LS – Geluk 998LS (Dalmada) (Figure 1.1 to 1.5). It should be noted that due to sub-urban development the Tweefontein-Geluk population is comprised of several isolated subpopulations.

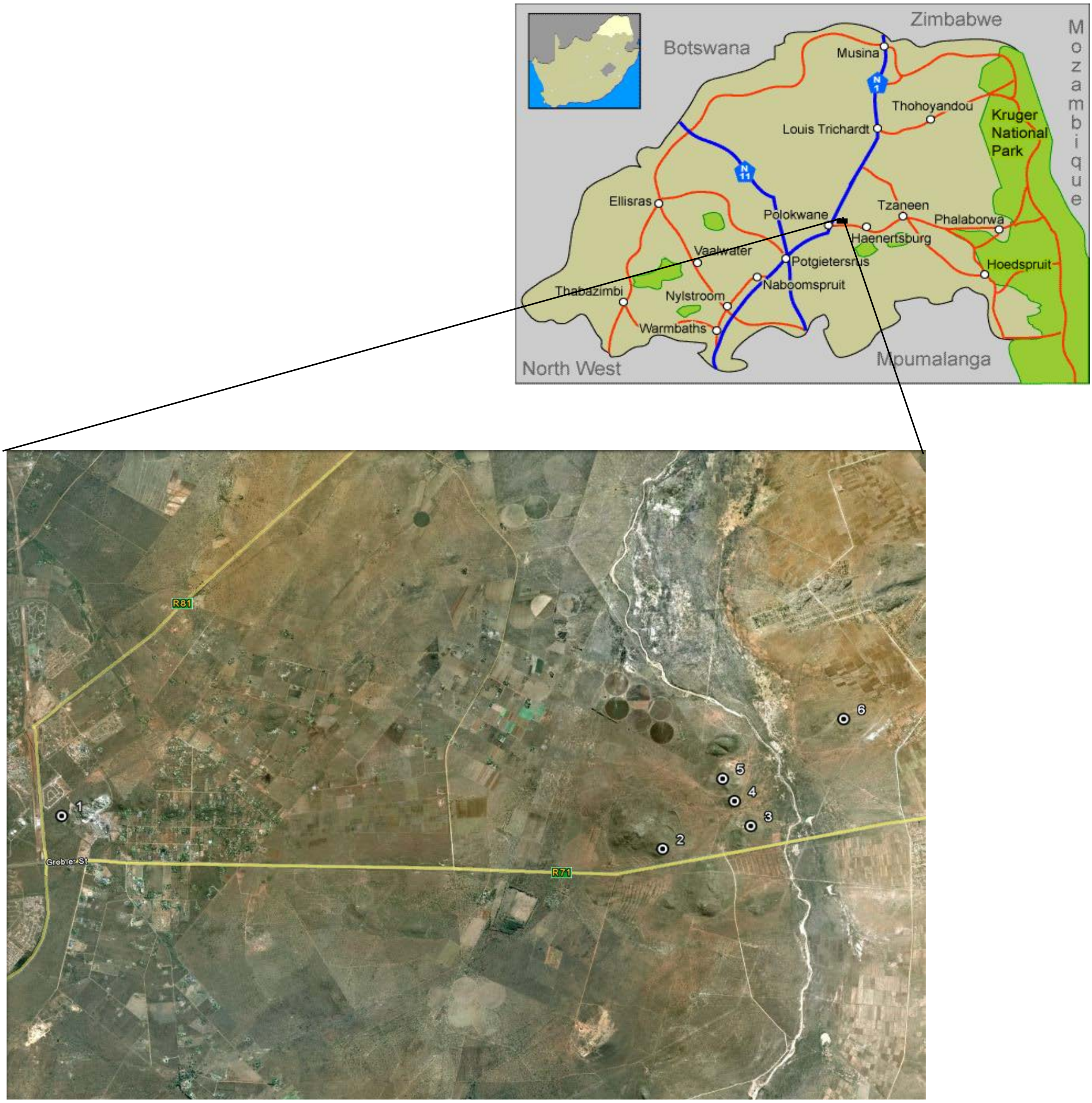

Figure 1.1: Population localities of *E. groenewaldii* (Google Earth, 2010; Howard, 2011).

1. Tweefontein 915LS-Geluk 998LS: GPS Coordinates: S23° 53’ 29.1”; E29° 30’ 46.2”
2. Kalkfontein 1001LS: GPS Coordinates: S23° 53’ 47.6”; E29° 36’ 38.4”
3. Majebeskraal 1002LS: GPS Coordinates: S23° 53’ 34.8”; E29° 37’ 30.8”
4. Spits 994LS: GPS Coordinates: S23° 53’ 20.9”; E29° 37’ 21.2”
5. De Put 918LS: GPS Coordinates: S23° 53’ 08.3”; E29° 37’ 14.1”
6. Melkboomfontein 919LS: GPS Coordinates: S23° 52’ 34.7”; E29° 38’ 25.4”

Figure 1.2: Views from Kalkfontein 1001 LS. Looking west towards the Tweefontein-Geluk populations.

Figure 1.3: Views from Kalkfontein 1001 LS. Looking north towards De Put (Masele).

Figure 1.4: Views from Kalkfontein 1001 LS. Looking north-east towards Spits and Melkboomfontein.

Figure 1.5: Views from Kalkfontein 1001 LS. Looking east towards Majebeskraal (Ronsma).

R.A. Dyer in White *et al.* (1941) described *E. groenewaldii* as a dwarf, spiny succulent plant (Fig. 1.6) with the main root and stem forming a large subterranean tuberous body. The root can be as long as 18 cm and 7 cm thick and is usually un-branched, terminating in a tap root. The tap root may also give rise to secondary roots, some of which grow near the surface of the soil. The stem crowns the root and is distinguished from it by horizontally extended impressions from which old branches have fallen, and producing from its narrow apex three to seven branches. The length of the branches varies from 25—70 mm and may have a thickness (branch diameter) of 12.5 to 20 mm (excluding the tubercular projections). The colour of the branches are bluish-green, occasionally with lighter green markings. They are three-angled, spirally twisted in a clockwise or anti-clockwise direction and are simple or occasionally with one to two lateral branches from near the base. The angles (of tubercles) are more or less compressed, and owing to the twist, slightly folded upwards. It has prominent tubercles (5—10 mm) and is slender with a pair of spines and a rudimentary leaf at the apex. Spines are slender, 3—10 mm long, separate or somewhat united at the base and with or without a pair of minute prickles at their base. Spine shields are discontinuous, triangular above the base of the spines or extending to the flowering eye. Only a few cymes are produced and they occur on old and young branches, and three cyathia (rarely twice-branched that will give four to five cyathia) grows from each cyme's eye. The first (middle) cyathium is male or bisexual, and the others are bisexual, and are produced in the ad- and ab-axial positions. Peduncles are 4—10 mm long and stout. The involucre is cup-shaped, 5—7 mm in diameter, with five glands and five small fringed lobes at the point where the spine joins the stem. Only a few cymes are produced, and consist of three cyathia. The seed capsules are triangular in shape, and sessile on the stems.

Figure 1.6: A 20 cm diameter *Euphorbia groenewaldii* plant in a typical rocky habitat.

3.2.2 The conservation status of *Euphorbia groenewaldii*

Raal (1986) indicated that *E. groenewaldii* is a rare species because of its small geographical range, seemingly specific habitat requirements and due to the likely possibility of it going extinct if no intervention of some sort (ie. a conservation plan) is initiated and implemented. However, according to Stewart and Hutchings (1996), rarity in itself does not necessarily mean that a species is in danger of extinction as some naturally rare species have attributes that provide them with the ability to persist in small populations. Rarity has a spatial, numerical and ecological dimension namely; size of the geographical range (spatial); habitat specificity (ecological), and population size (numerical) (Table 1.1) (Rabinowitz, 1981).

Rare and endangered endemic plant species are defined as plants that occur in small populations or even as a single population, with specific habitat requirements, and can therefore be confined to a small or single locality as well as a few widespread localities (Kruckeberg & Rabinowitz, 1985). *Euphorbia groenewaldii*, an endemic dwarf member of the Euphorbiaceae, fits most of the above-mentioned criteria. For example it has a small geographical range and narrow habitat specificity (Raal, 1986).

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Table 1.1: Seven forms of rarity (Kruckerberg & Rabinowitz, 1985).

	Geographical Range			
	Large		Small	
Local Pop. Size	Wide habitat use	Narrow habitat use	Wide habitat use	Narrow habitat use
Large, dominant somewhere	Common and locally abundant over a large range in several habitats	Locally abundant over a large range in a specific habitat	Locally abundant in several habitats over a small range	Locally abundant in over a small range in a specific habitat ***– E. groenewaldii***
Small, dominant	Constantly sparse over a large range in several habitats	Constantly sparse over a large range in a specific habitats	Constantly sparse over a small range in several habitats	Constantly sparse over a small range in a specific habitats

Conservation and management of threatened species require a thorough understanding of their spatial distribution that should form the basis of a monitoring programme conducted at regular intervals (Bradshaw, 1981; Palmer, 1987; Schemske *et al*., 1994). As mentioned above, our knowledge of *E. groenewaldii* is limited to Raal's (1986) reproductive assessments and monitoring surveys. Raal (1986) stated that with the exception of the Rietpol population, which could not be located during surveys in the early 1980s, all the remaining populations of the species were stable.

In Raal's (1986) conservation plan for the species he initially indicated that it is endangered based on a small geographical range but later concluded that the species is vulnerable as his results suggested that there are a large number of individuals in the populations. Hilton-Taylor (1996) (using the criteria of the IUCN Version 2.3 in 1994) concluded after his review of *E. groenewaldii,* that the status of

E. groenewaldii must be upgraded to endangered. However, the system used by Hilton-Taylor (1996) did not make use of specific criteria (see below) for each category and was based on the qualitative data available at that time (The Threatened Species Program, 2006). Since Hilton-Taylor's (1996) assessment, the criteria for assessing a species' conservation status have changed.

According to the World Conservation Union (2006) there are five quantitative criteria which are used to determine whether a taxon is threatened, and if threatened, which category of threat it falls in (Critically Endangered, Endangered or Vulnerable). The five criteria are:

A. Declining population (past, present and/or projected)
B. Geographic range size, and fragmentation, decline or fluctuations
C. Small population size and fragmentation, decline or fluctuations
D. Very small population or very restricted distribution
E. Quantitative analysis of extinction risk (e.g. Population Viability Analysis)

These criteria are supported by the biological indicators of populations that are threatened with extinction, such as a rapid population decline or a very small population size. The criteria also include sub-criteria that must be used to more specifically justify the listing of a taxon in a particular category. For example, if a taxon is listed as Vulnerable (C2a(i)), it will be placed in the Vulnerable category because its population is fewer than 10 000 mature individuals (criterion C), the population is undergoing a continuing decline and all its mature individuals are in one subpopulation (sub-criterion a(i) of criterion C2).

The World Conservation Union (2006) recognizes the following categories of threat:

Extinct (EX)

A taxon is extinct when there is no reasonable doubt that the last individual has died. A taxon is presumed extinct when exhaustive surveys in known and/or expected habitat at appropriate times (diurnal, seasonal, annual) and throughout its historic range have failed to record an individual.

Extinct in the Wild (EW)

A taxon is extinct in the wild when it is known only to survive in cultivation, in captivity or as a naturalized population (or populations) well outside its past range. A taxon is presumed extinct in the wild when exhaustive surveys in known and/or expected habitats at appropriate times (diurnal, seasonal, annual) and throughout its historic range have failed to record an individual.

Critically Endangered (CR)

A taxon is critically endangered when the best available evidence indicates that it meets any of the criteria A to E for critically endangered, and is considered to be facing an extremely high risk of extinction in the wild.

Endangered (EN)

A taxon is endangered when the best available evidence indicates that it meets any of the criteria A to E for critically endangered, and is considered to be facing a very high risk of extinction in the wild.

Vulnerable (VU)

A taxon is vulnerable when the best available evidence indicates that it meets any of the criteria A to E (see pg. 18) for critically endangered, and is considered to be facing a high risk of extinction in the wild.

Near Threatened (NT)

A taxon is near threatened when it has been evaluated against the criteria but does not qualify for critically endangered, endangered or vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future.

Least Concern (LC)

A taxon is near threatened when it has been evaluated against the criteria and does not qualify for critically endangered, endangered, vulnerable or near threatened. Widespread and abundant taxa are included in this category.

Data Deficient (DD)

A taxon is data deficient when there is inadequate information to make a direct or indirect assessment of its risk of extinction based on its distribution and/or population status. A taxon in this category may be well-studied, and its biology well-known, but appropriate data on abundance and/or distribution are lacking. Data Deficient is therefore not a category of threat. Listing of taxa in this category indicates that more information is required and acknowledges the possibility that future research will show that threatened classification is appropriate.

Not Evaluated (NE)

A taxon is Not Evaluated when it has not yet been evaluated against any of the criteria.

The abovementioned five criteria only hold fast for the three categories of Critically Endangered, Endangered or Vulnerable and each criterion has a list of sub-criteria that has to be met in order to place a species in the relevant category. Meeting the sub-criteria is only possible if one understands the terminology and format in which this system works (A list of sub-criteria for each of the five main criterions can be found in Chapter 3). It is critical to understand the terminology in the sub-criteria in order to follow the correct measures when determining the status of a species for conservation purposes (Primack, 1993).

A recent conservation status reassessment conducted by the South African National Biodiversity Institute's (SANBI) Threatened Plants Program (TPP) concluded that the *Euphorbia groenewaldii* status should remain Endangered as determined by Hilton-Taylor (1996) (J. Victor, TPP, SANBI, pers. comm.; SANBI, 2009). The assessment conducted by SANBI was based on very little field data, and comprised only of collecting material for genetic analyses (Victor, pers. comm.). Ms. Victor works at Biosystematics Research and Biodiversity Collections at SANBI and she is Deputy director of research. Historic distribution records based on herbarium specimens were super-imposed on digital land cover and vegetation maps after which possible habitat disturbance were searched for on these maps (Victor, pers. comm.). Based on this, the distribution range and population sizes of the species were estimated.

3.3 Rationale for selecting *Euphorbia groenewaldii*

Rare and endemic plant taxa are much more susceptible to extinction than other taxa because of the many unique attributes that they have (Primack, 1993). For example, they may:

1) have a small range,
2) comprise one or only a few populations,
3) have low population densities, and
4) have specific habitat requirements.

Rare species generally have narrow or fragmented distribution ranges. Moreover, they are sometimes threatened by stochastic events due to their low local population densities, narrow habitat specificity or their inability to consistently reproduce (Huenneke, 1991). Then there is the vulnerability towards environmental (stochastic variation in the environment; ie. rainfall and temperature) and demographic (stochastic variation in the demographic rates ie. reproductivity and mortality) variability (Millar & Libby, 1991; Pfab, 1997). There are two types of genetic variation that are important when dealing with small populations (Millar & Libby, 1991).

i) The degree of homozygosity within individuals in a population, i.e. the proportion of an individual's loci that contain homozygous rather than heterozygous alleles. Many deleterious alleles are only harmful in the homozygous form.
ii) The ratio of monomorphism/polymorphism within a population. This relates to how many different alleles of the same gene exist in the gene pool of a population. Polymorphism may be particularly important at loci involved in the immune response. Small populations tend to exhibit reduced genetic variation as inbreeding leads to loss of genetic variation.

The above mentioned attributes also apply to *E. groenewaldii.* All five populations occur in a very small area of only a few square kilometres and population sizes vary from a few thousand to several hundred thousand individuals (see Chapter 3) (Raal, 1986).

*Euphorbia groenewaldii'*s small global range, small number of populations and in some instances small population sizes render the species susceptible to anthropogenic and environmental stochasticity. Moreover, the species is popular with collectors which place additional pressure on existing populations (Raal, 1986).

The above mentioned factors resulted in the species being listed as endangered by Hilton-Taylor (1996) and the most recent IUCN assessment conducted by SANBI (P. Winter, systematist, SANBI, and J. Victor, pers. comm.). *Euphorbia groenewaldii* is also listed as a Schedule II species by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) since 1975 (UNEP-WCMC, 2009). The National Environmental Management: Biodiversity Act (Act No. 10 of 2004) does not list the protection of specific species, but do have sections (chapter 4 regulation 51 to 59) that provide the protection to threatened ecosystems and species. At a provincial level the species is listed as an especially protected species in the Limpopo Environmental Management Act (LEMA), Act 7 of 2003. The aforementioned Act states that no person, whether the plant is protected or not, may without a permit collect the plant (Act No. 7 of 2003).

Witkowski *et al.* (1997) highlighted the lack of information on the biology, ecology and the status of threatened plant species in the northern regions of South Africa and advocated that more research and conservation efforts should be directed towards this region. After 1994 a lot of attention was given to reconstruction and development; conservation programmes received comparatively very little attention (Witkowski *et al.*, 1997). As a developing country South Africa has to balance social and economic development with environmental protection, often at the cost of the environment.

4. POPULATION BIOLOGY

Population biology is the study of a group of living organisms present at the same place and time (Feldhamer *et al.*, 1999).

According to Pfab (1997), data that are normally collected for population biology studies of threatened plant species should comprise one or more of the following:

i) A measure of vitality of individual plants,

ii) The size- and age structure of the population, including the distances between plants and between populations,

iii) The regeneration capacity of individual plants, including the number of flowers, fruit and seeds, seed dispersal, seed predation (both pre- and post-dispersal), seed viability/longevity and germination cues, seedling establishment and rates of growth, pollination success, and a measure of any vegetative reproduction.

This type of data and approach to population biology of threatened species can help to identify the causes that may lead to its decline (Pfab, 1997). Some investigations under the topic of reproductive biology (Pavlik *et al.*, 1993) and regenerative capacity (Lamont *et al.*, 1993) of rare and threatened plant species have shown that one of the biggest factors of decline is a lack of available and effective pollinators. The lack of pollinators cause a drop in ovules being fertilized and fewer seeds produced.

5. POPULATION ECOLOGY

Population ecology examines interactions that occur between organisms and their environment (Mader, 1998; Krohne, 2001). The following are typical questions that need to be addressed in population ecology studies (Mader, 1998; Krohne, 2001).

a) What are the characteristics of a population?
b) Which population parameters can be measured?
c) How do populations differ in aspects such as density and age distribution?
d) How do populations expand?
e) What are the patterns of population increase/decrease?
f) How are the populations numbers controlled?
g) What factors determine the limits of population size?

The ecological data that are usually collected of rare and threatened plant species includes various biotic (Mader, 1998) and abiotic factors (Krohne, 2001). Biotic, meaning of or related to life, are living factors, like plants, animals, fungi, protist and bacteria. Abiotic, meaning not alive, are nonliving factors that affect living organisms. Environmental factors such habitat (pond, lake, ocean, desert, and mountain) or weather such as temperature, cloud cover, rain, snow, hurricanes, etc. are abiotic factors (Given, 1994).

When one considers and understands biotic aspects in the environment, it allows one to identify the extrinsic and ultimate causes that may contribute to the decline of a population. Informed decisions can then be made that support proper recommendations for management and conservation strategies (Pfab, 1997). Biotic factors that regulate mechanisms on population densities are divided into density-dependant factors and density-independent factors (usually associated with abiotic events) (Krohne, 2001). Density-dependant factors are those effects that increase or decrease the density of a population. These include extrinsic factors such as over-storey and under-storey shading, litter thickness, vegetation physiognomy and species composition, grazing and browsing impacts, disease, alien plant infestations, and human impacts (Witkowski *et al.,* 1997). Density-independent factors are those that affect the size of a population independent or regardless of the population density (Krohne, 2001).

Grazing, as example of a biotic factor, can cause damage to the plant that could have a major effect on a population of a rare and threatened species by resulting in a decline in population density. Grazing could also have an indirect effect on rare and threatened species. Examples include *Haworthia koelmaniorum* (vulnerable species) (Witkowski *et al.*, 1997) and the endangered *Euphorbia perangusta* (Raal, 1988), both of which are threatened by cattle trampling (Pfab, 1997).

In the case of under-storey shading and litter thickness, seedlings compete for space to germinate and to grow. An example of this is of two perennial grasses, *Pseudoroegneria spicata* and *Pascopyrum smithii*, in the north-western United States that are suppressed by litter from two Eurasian forbs (*Euphorbia esula* and *Centaurea maculosa*) that hinder their germination and growth. These effects may ultimately, without management and conservation strategies, reduce the population density of these grasses which may threaten their long-term survival (Olson & Wallander, 2002).

Abiotic factors are sub-divided into physical resources and limiting factors. Physical resources are abiotic factors that an organism needs to assimilate in order to live and prosper. This would include light energy, water, and carbon dioxide for photosynthesis. Physical factors which determine the presence and absence of a species, it is called a limiting factor (Krohne, 2001). Limiting factors, are physical factors that delimit a zone in which life is possible for each type of organism, are climate changes (temperature), geology, geomorphology, soil types, soil chemical composition (pH and salinity), slope and aspect, and a fire regime (Witkowski *et al.,* 1997).

In assessing plant growth, cognisance has to be taken of the soil pH because it has an important influence on the growth of the plant. Soil pH affects the nutrient availability and toxicity and the microbial activity in addition to extending a direct effect on the protoplasm of plant root cells (Medinski, 2007).

A typical example that the influence of an abiotic factor, such as temperature, may have on the distribution of a species is that of the Saguaro cactus (*Cereus giganteus*), a Sonoran Desert species. It was shown that its range limits was exactly determined by a specific set of temperature requirements. The Saguaro cactus dies if it is exposed to temperatures below freezing for more that 36 hours, but if it thaws before 36 hours has passed it will survive. This resulted in the species occurring in a restricted area where there is no record of subfreezing temperatures for longer than 36 hours (Krohne, 2001).

6. CONCLUSION

The ultimate aim of conservation biology is to maintain the evolutionary potential of species by maintaining natural levels of diversity, including genetic, species and ecosystem diversity. The primary conservation goal should be to establish and maintain self-sustaining populations whenever possible, and when necessary using ecological manipulations to minimize inbreeding and maximize genetic variability within populations, for example artificial pollination (Barrett & Kohn, 1991). From the foregoing, it is evident that the success of any conservation management plan depends on a thorough understanding of the species' biological and ecological requirements, breeding system, pollinators, and life-history. Hamrick *et al.* (1991) suggested that any species' recovery or management plan drawn up without considering this information may be subject to error.

In assessing the type of plant species that should be conserved, rare and endemic species always comes to mind. One of the biggest problems with the conservation of rare and endemic species is the lack of manpower (Spellerberg, 1992) and the appropriate financial backing (Witkowski *et al.*, 1997) to conserve these types of species. This is particularly relevant to developing countries such as South Africa. The lack of knowledge regarding the biological and ecological requirements of *E. groenewaldii* is a major concern, and research into these aspects should be undertaken as a matter of urgency. This information will be invaluable for the development of a conservation and management plan for the species. In the absence of detailed knowledge regarding the biological and ecological requirements of poorly known species, Pfab (1997) suggested that results obtained from studies on closely related species could be used as an interim measure to develop conservation management plans for such species.

7. PROJECT AIM

To study the biology and ecological requirements of *Euphorbia groenewaldii,* and to establish its spatial distribution in order to develop a comprehensive conservation management plan for the species.

8. PROJECT OBJECTIVES

The objectives of this study were to determine the:

- Distribution and size (number of plants in the area) of the remaining populations of *E. groenewaldii*.
- Stage (age) and size structure of the populations.
- Dynamics of the populations; that is whether the numbers are increasing or decreasing in relation to Raal's (1986) data.
- Biotic features of the habitat of *E. groenewaldii*.
- Abiotic features of the habitat of *E. groenewaldii*.

- Threats to the populations such as disturbances, harvesting, trampling, herbivory, pollution and invasive alien plants.

A further strategic objective included to:

- Develop a management and conservation plan for the species.

CHAPTER 2

POPULATION BIOLOGY AND ECOLOGY OF *EUPHORBIA GROENEWALDII*

1. INTRODUCTION

Euphorbia groenewaldii is protected by the Limpopo Environmental Management Act (Act No. 7 of 2003), through which threatened and protected species may not be taken out of the wild/natural environment. It is also listed in the Red Data List (SANBI, 2011) as "Endangered" due to *E. groenewaldii*'s small global range. Additionally, it is listed in Schedule II of the Convention for the International Trade of Rare and Endangered Species of Fauna and Flora (CITES) (CITES, 2011). According to CITES (2011), this means that *E. groenewaldii* can be traded with, if the correct legal steps are followed. A permit from the national government is applied for first, hand in hand with CITES regulations (CITES, 2011), through which an evaluation process (purpose for taking out plants, is it for trading purposes and is it viable for the population to be interfered with) will take place. However, despite its red data listing, legal protection (CITES Schedule II, Act No. 7 of 2003), and the conservation management plan provided by Raal (1986), it seems little has been done currently to ensure the long-term conservation of this species.

1.1 Existing threats

No biological threats such as genetic deficiencies or diseases have been documented. Anthropogenic factors exert significant pressure on the continued existence and population expansion of *E. groenewaldii*. The following anthropogenic factors were identified by Raal (1986) as threats to this species:

- **Brick work factory:** It destroyed a large section of the Tweefontein-Geluk (Chapter 1: Fig. 1.1) population (S23° 53' 29.1"; E29° 30' 46.2") and it is still continuing to expand into the remaining habitat of *E. groenewaldii*.
- **Urban expansion:** The Mothiba's kraal (S23° 52' 34.7"; E29° 38' 25.4") settlement (Chapter 1: Fig. 1.4) is expanding westwards into the range of the Melkboomfontein population. The resultant expansion footprint covers the whole of the population.

- **Collector's pressure:** There is evidence of the illegal removal of the plants (found plants that were dug out), either to be used as pot plants or, to probably a more serious degree, for the international trade (Euphorbias, 2010).

Non-anthropogenic threats (Raal, 1986) were:

- **Trampling:** There is a significant amount of trampling by livestock where this species occurs.
- **Herbivory:** Fruits, flowers and even branches of *E. groenewaldii* are consumed by animals (domesticated or wild) and insects, which could impede the regeneration and reproduction of the species.
- **Fire:** A fire which is too hot can destroy the whole plant.

Several ecological and environmental factors impact on the survival of an endemic plant such as *E. groenewaldii*. Strategies to minimize factors affecting species survival are obtained by considering species conservation in the context of landscape. For a successful conservation plan assessing the spatial dynamics and the significance of habitat fragmentation is required. Rare taxa such as *E. groenewaldii* occuring mainly on schist outcrops, discrete and highly variable in extent and isolation, require this approach. Such qualities make this landscape an excellent arena for studying the spatial dimensions of plant ecology and conservation (Wolf, 2001).

1.2 Rationale for selecting *E. groenewaldii*

The rationale for selecting *Euphorbia groenewaldii* was to investigate its current status in terms of distribution and population densities. The real threats that could cause this dwarf succulent's population numbers to decline were identified. Possible declining numbers were assessed. Additional data was collected to develop understanding of what was necessary to conserve and protect *E. groenewaldii*.

The extrinsic and intrinsic causes affecting *E. groenewaldii* conservation were firstly investigated. Extrinsic causes could include biotic factors, such as herbivory, alien plant invaders, diseases and the human element (Pfab, 1997). The abiotic factors involve *ex situ* and *in situ* conservation methods, as well as factors such as habitat type, fire regime, climate and soil.

Intrinsic causes involve interesting biological factors that may cause a decline in the population. For example: plant size reduction, reduced flowering, a deficiency in pollinators (Harvey & Meredith, 1981), pre-dispersal of seed, fruit predation (Ward, 1988), and even the failure of germination or seedling establishment (Pfab, 1997).

2. OBJECTIVES

Based on the above, the objectives of this chapter are to:

1. Determine the stage (seedling, juvenile and adult), and size structure of each population.
2. Identify biotic features, such as grass -, forb -, and dead material cover present in *E. groenewaldii*'s habitat.
3. Identify the abiotic features that play a role in the existence of *E. groenewaldii.* These include: fire damage/effect, soil chemistry, and preferred slope and aspect of habitat.
4. Assess and quantify present threats facing the different populations.

3. MATERIALS AND METHODS

3.1 Site Description

Geomorphology: Aspect, Slope and Altitude

The populations of *Euphorbia groenewaldii* occur between 1250 m and 1380 m above sea level (Google Earth, 2010). According to Raal (1986), plants occur in pockets ranging from deep to shallow, gritty, sandy loam soil. Figure 2.1 (Google Earth, 2010) indicates the geographical area occupied by this species.

3.1.1 Geology

A 1: 250 000 geological map (Geological Series, 1985) indicates that the habitat of this species falls within the Murchison Sequence, specifically the Mothiba Formation. The geology of the Mothiba Formation is made up of talc-chlorite and amphibole-chlorite schist, amphibolite and serpentine iron formation (Mucina & Rutherford, 2006).

The geology of the study area is varied and includes basement granite and gneiss; classic sediments of the Pretoria Group (Vaalian); and ultramafic and mafic metavolcanics of the Pietersburg Group (Swazian). There are shallow and skeletal soils which includes Mispah and Glenrosa soil forms (Mucina & Rutherford, 2006).

3.1.2 Climate

Climatic data from 1960 to 1990, a 30 year period, for the study area was obtained from the South African Weather Service. The mean daily temperature is lowest during June and July, and drop to -4 ºC in June. Mean minimum temperatures for June and July are 5 ºC and 4 ºC, respectively (Fig. 2.2). The average daily maximum temperature during June and July is 20 ºC (Fig. 2.2). The mean daily temperature is highest during January and February, and can rise to 36 ºC in February. Mean maximum temperatures for January and February are 28 ºC (Fig. 2.2). During the months of January and February the average daily minimum temperature is 17 ºC (Fig. 2.2).

The dry season starts in May and lasts until September. The driest month is July with a mean monthly rainfall of only 3 mm (Fig. 2.2). The region receives its highest rainfall from November to January, with an average of 85 mm, 81 mm and 82 mm per month, respectively (Fig. 2.2). The long term (1960-1990) mean rainfall per annum for Polokwane is 478 mm (South African Weather Service, 2003).

3.1.3 Vegetation

Euphorbia groenewaldii is mostly restricted to the Polokwane Plateau Bushveld (PPB), but is also closely associated with the Mamabolo Mountain Bushveld (MMB) vegetation type (Mucina & Rutherford, 2006). The PPB vegetation type consists of low to tall, open to closed sour grassland that is interspersed by short, open to sparse *Acacia caffra* or *Ormocarpum trichocarpum* dominated woodland, as well as succulent trees such as *Aloe marlothii*. The MMB is characterized by rocky hills or domes with moderate to steep slopes and small trees and shrubs. These rock domes and slabs are sparsely vegetated with xerophytic or resurrection plants and several succulents. The vegetation is characterized by tall trees such as *Sclerocarya birrea* and *Combretum molle,* as well as by succulent trees including *Euphorbia cooperi, Euphorbia ingens* and *Aloe marlothii* (Mucina and Rutherford, 2006).

3.2 Population size and distribution

The distribution of *E. groenewaldii*, as indicated by Raal (1986), was used as a base to locate the different populations. Initial surveys showed that *E. groenewaldii* is a small-sized plant and that most populations cover a large area. The following two sets of definitions were used to help formulate and choose the best sampling method for all *E. groenewaldii* populations.

- Extent of Occurrence (EOO)
  The area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon, excluding cases of vagrancy (Standards and Petitions Working Group, 2006; World Conservation Union, 2006).

- Area of Occupancy (AOO)
  The area within it's 'extent of occurrence' that is occupied by a taxon, excluding cases of vagrancy will be the AOO. The measure reflects the fact that a taxon will not usually occur throughout the area of its extent of occurrence, which may contain unsuitable or unoccupied habitats (Standards and Petitions Working Group, 2006; World Conservation Union, 2006).

The EOO was determined after all the AOO for each population of *Euphorbia groenewaldii* was determined.

Each population area of occupancy was determined using a global positioning system (GPS) by walking outward from roughly the centre of a population in each of the eight major magnetic directions until the last plant was found. All these points were then connected as accurately as possible by walking from one of the eight major magnetic directions' end point (where the last plant was found) to the next end point of the following major magnetic direction, while looking for *E. groenewaldii* plants in order to stay on the boundary of the particular population.

A specific sampling technique was chosen for each population in order to determine its density. For populations that were very small in relation to their AOO the Nearest Individual Sample Technique (NIST) was used. The NIST entails that the plant nearest to the sample point is located, and the distance between it and the sample point is measured. The density is thus calculated as:

Density = $1/(2D_m)^2$
Where D_m = mean distance for all samples (Hill *et al.*, 2006).

This sampling technique was only used on one (Spits population, Fig. 2.22, p64) of the *Euphorbia groenewaldii* population because its AOO was very small. The population of Tweefontein-Geluk (Chapter 1: Fig. 1.1) was subdivided into subpopulations due to its patchy AOO. The very small subpopulations were also assessed using NIST and the larger subpopulation was assessed using the point-centred quarter method (PCQ).

The PCQ method was employed on all the remaining (large) populations. The PCQ method was used in combination with laying out transects across the population (Mark *et al.*, 1970). The PCQ method involves two perpendicular straight lines crossing each other at a sample point (Mark *et al.*, 1970; Hill *et al.*, 2006). This way four quadrants are created by the straight lines crossing each other forming the centre of all four quadrants (Hill *et al.*, 2006). The distances from the central point to the nearest *E. groenewaldii* plant in each quadrant (e.g. *A*, *B*, *C* and *D*) is then measured (Hill *et al.*, 2006). The size of the quadrants was determined in such a way to fit into a transect (see below). The distances are then averaged and density is calculated. The density is thus calculated as:

Density = $1/D_m^2$
Where D_m = mean of average distances (Hill *et al.*, 2006).

These transects were laid out parallel to one another in an east−west or north−south direction, depending on the layout of the population. Transects ran from one end (on the boundary) of the population in a straight line to the other end (boundary) of the population. All transects covered 25-30% or more of each respective population.

Each transect differed in length (from 200 m to 1000 m) in relation to the AOO of each population. Knots were made in the rope at 5 m intervals, representing the point-centre of each 5 m x 5 m quadrant. Thus, a continuous string of quadrants where placed along the length of a transect. The distance between transects were 10 m to 50 m apart. Each transect was traversed by two people who systematically searched for nearest plants from the centre point within the 5 m zone on either side of the transect line in each quadrant. Due to the large areas occupied by populations, areas of variable densities were encountered. To ensure consistency one plant was measured in terms of its canopy area, in the last quadrant of each set of four quadrants. In the case where there were only plants in, for example, quadrant A and C, a plant in the last quadrant, in this case C, was measured.

The sampling took place over a three month period, from May to July 2007, to coincide with the flowering and fruit-setting periods of the species, which was obtained from Raal (1986).

3.3 Micro-habitat features (Biotic- and abiotic features)

The *Euphorbia groenewaldii* plant measured in each plot was assessed by placing a 1 m x 1 m pseudo-block around each sampled plant and categorized into six classes of micro-habitat features, which three where biotic and three abiotic; i.e; grass, forbs, dead material, stones, fixed rock (ridges and stones that is buried and too large to move) and bare ground. The total percentage (in categories of 5% intervals) of area that one or more of these classes covered around an individual plant was also noted. The percentage ground covered by grass and forbs will give an indication of the extent of inter-specific competition to which *E. groenewaldii* is exposed. During the initial data collection period, observations of the shading conditions showed that a very low percentage of plants per populations were affected by shade. Those that were affected by shade did not seem to suffer any adverse effects; consequently shading as a biotic feature was not considered for this species.

3.4 Abiotic features

3.4.1 Soil analysis

Five soil samples were taken from a 0.4 m x 0.4 m quadrat at each population; four on the perimeter of each population corresponding to the four major compass directions, with a fifth taken from the centre of the population. The depth of the soil samples taken were up to 150 mm. Samples were analyzed at the KwaZulu-Natal Department of Agriculture and Environmental Affairs, Soil Fertility and Analytical Services, for bulk density, pH, organic matter content, total nitrogen, acidity, total cations, available P, K, Ca and Mg. The methodologies used during soil analysis are according to Manson and Roberts (2000).

3.4.2 Fire

The history of fires at each population was obtained by means of interviews with residents and through personal knowledge of the area. Information on whether a fire was part of a management plan in the local area or an accidental fire was recorded. Plants with fire damage (tubercular edges shrivelled and brown to blackish) were documented. Damage was categorised as an estimated percentage of the total canopy area per plant. Any effects that a fire had on *Euphorbia groenewaldii* plants were determined by sightings of new vegetative growth and the initiation of flower production.

3.4.3 Other Abiotic Factors: aspect, slope and altitude

Aspect, slope and altitude were recorded with the field survey using a GPS, compass and topographical maps. An alphanumeric code system was given to each category to help classify different slope angles (>0-5º, >5-10º, >10-20º, and >20-30º). The alphanumeric code system was as follow for slope angles >0-5º = 1, >5-10º = 2, >10-20º = 3, and >20-30º = 4. The alphanumeric code system for Aspect on the filed sheet was north = N, northeast = NE, east = E, southeast = SE, south = S, southwest = SW, west = W, and northwest = NW. The alphanumeric code system for Aspect for statistical analysis was north = 1, northeast = 2, east = 3, southeast = 4, south = 5, southwest = 6, west = 7, and northwest = 8. The alphanumeric code system was as follow for slope position lower slope = 1, middle slope = 2, and upper slope = 3. This coding system helped to speed up field data gathering, and made it compatible with the statistical software used. The different aspects were determined with the aid of a GPS (N, NE, E, SE, S, SW, W and NW).

3.5 Population biology

3.5.1 Developmental stage and canopy size

All measured plants were placed in one of four classes (developmental stages):

- Adult: Plants show evidence of flowering or fruiting. Depending on the stage of a plant in its reproductive cycle, some adult plants may not show any evidence of flowers or fruit, thus plants with four or more branches were considered to be adults.
- Juvenile: Plants are generally small in terms of branch length and canopy area, and consists of 2—3 under- to well-developed branches. It also includes plants showing either primary or secondary growth characteristics (e.g. new branches protruding from the ground or old branches showing new growth at their tips).
- Seedling: Plants consist of a single branch above ground, showing only primary growth characteristics.
- Senescent: Plants that have died either naturally or unnaturally. These plants are characterized by dry brittle branches that range in colour from brown to grey (instead of green or maroon (dormant/undernourished)) with whitish or greyish thorns.

Canopy size was measured by recording the widest diameter of area covered by the plant (L_1) followed by the diameter perpendicular to this (L_2), as described by Pfab (1997). The following equation, taken from Pfab (1997), was then used to calculate the canopy area:

$$\text{Canopy Area} = \pi \times L_1/2 \times L_2/2$$
$$= 0.7854 \times L_1 \times L_2$$

3.5.2 Regenerative capacity

3.5.2.1 Flowering

All plants measured were noted for evidence of flowering activity. Recording of pollinators was done by marking plants with flowers in two stages of development. Stage one of flowering consisted of the development of the outer two cyathia. Stage two consisted of the development of the third (middle) cyathia and the dying off of the outer two cyathia. These recording session involved physically sitting a watching a plant for a 2 hour session per day over a period of 2 weeks. The 2 hour sessions alternated over each day from mid-mornings (8h00-10h00), to mid-afternoons (11h00-13h00), and to late-afternoons (14h00-16h00). Photographs were taken were possible to record physical evidence of any pollinators.

3.5.2.2 Fruit and seed production

All plants measured were investigated for fruit production. *Euphorbia groenewaldii*'s fruiting period is from August to September as fruit takes about two months to mature (Raal, 1986). Any *ad hoc* fruiting events was also looked for to determine if *E. groenewaldii* may produce fruit outside the known recorded data. Each fruiting plant's size was recorded (canopy area) and all the fruit and flowers were counted on each plant so that calculations could be made regarding the flower:fruit ratio. Flowering and fruiting evidence on seedlings, juveniles and adults was also recorded. Possible fruit predators was looked at because a low flower:fruit ratio was noticed during the pilot phase of this study.

3.6 Types of damage and threats to the populations

The type of damage and threats (trampling, herbivory, anthills, or fire) for each measured plant was noted and coded. Trampling was defined as when the plant's branch or branches were broken or flattened but intact. In contrast herbivory was defined as when the branches of the plant were gone and all that remained was a short protrusion from the ground, or a section of the branch was eaten away with the branch still in its original position.

A percentage of the extent of damage according to the canopy area of the plant was then estimated. It was subsequently placed in one of the following categories i) >0-5%, ii) >5-10%, iii) >10-15%, iv) >15-20%, v) >20-25%, and so forth up to 100%.

Indications where large areas were destroyed by previous activities (quarrying) or developments (residential- and business development) were mapped using the aid of a handheld GPS. The sections affected per *E. groenewaldii* populations were mapped by superimposing the GPS data onto Google Earth™ maps to get a clear picture of the impact of human activities and developments have on each population.

3.7 Statistical analyses

For statistical analysis the SPSS Version 14 software was used for population stage structures (section 3.5.1, this chapter) and sizes. Descriptive statistics were used to calculate the percentage damage that trampling, herbivory, anthills and fire, had on the populations. SPSS was further used to perform the median test on canopy sizes as well as to perform a Pearson correlation test on canopy size versus biotic features, and to test the percentage biotic features of all populations. In statistics, Mood's median test is a special case of Pearson's chi-square test (Corder *et al.,* 2009). It is a nonparametric test that tests the null hypothesis that the medians of the populations from which two samples are drawn are identical. The data in each sample are assigned to two groups, one consisting of data whose values are higher than the median value in the two groups combined, and the other consisting of data whose values are at the median or below (Friedlin *et al.,* 2000). A Pearson's chi-square test was then used to determine whether the observed frequencies in each group differed from expected frequencies derived from a distribution combining the two groups (Friedlin *et al.,* 2000; Corder *et al.,* 2009).

In statistics, analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes t-test to more than two groups (Tabachnick *et al.*, 2007). A One-way ANOVA test, in combination with a Homogeneity of Variances Test was performed on the canopy area of plants between all populations in order to ascertain significant differences. A One-way ANOVA test, in combination with a Homogeneity of Variances Test, was also performed for significant differences between canopy and aspect for the species in total. For a detailed explanation of the differences between populations in terms of canopy size, a Bonferroni method was used within a Post Hoc Test. The Tukey HSD test, also within a Post Hoc Test, was used determine if there is any significant differences between aspect and canopy of the populations.

A Phi test for all the populations was run to determine any significant differences in the age classes, in slope degrees, in aspects, between type of damage and in the slope position. Further analyses within each population regarding stage classes, biotic features, type of damage, slope position, slope degrees and aspect were done using Microsoft Excel. Correlations were done for canopy against the biotic cover features such as grass, forbs, dead vegetation, stones, fixed rock and bare ground in order to identify significant differences.

For statistical reasons the different sub-populations of the Tweefontein-Geluk population were combined. This was due to the sub-populations being too small in size and numbers and situated close together.

4. RESULTS

4.1 Biotic features cover

4.1.1 Grass, forb and dead vegetation (dry litter) cover

The amount of grass cover at all six populations was relatively low (Table 2.1), with plants occurring in a grass cover of less than 25% (Table 2.7). The amount of ground cover provided by forbs was also relatively low (Table 2.2), with plants occurring in a forb cover of 1—25% (Pearson Correlation, $r < 0.01$) (Table 2.7). There were no noteworthy differences (Pearson Correlation, $r < 0.004$) between any of the populations with regard to the percentage cover of dead vegetation (Table 2.3). Fifty-six percent (from field sampling) of *Euphorbia groenewaldii* plants occurred where there was no dead vegetation on or around it (Table 2.7).

4.2 Abiotic features cover

4.2.1 Stone cover

Euphorbia groenewaldii growing among rocks and stones (Pearson Correlation, $r < 0.01$) with 73% of the population occurring in a stone cover of 0–25% per plant (Table 2.7). There were very little differences in the percentage of plants found between populations (ranging from 32—46%) that occurred in a stone cover of up to 25% (Table 2.4).

4.2.2 Fixed rock cover

Although the populations of *E. groenewaldii* occurred on rocky and hilly terrains, 57% of the species grew where there are no fixed rocks (Table 2.7). No significant correlation (Pearson Correlation, $r < 0.02$) could be found between *E. groenewaldii* and fixed rock cover. Only Tweefontein-Geluk population's plants (62%) were found in a fixed rock cover of between 26–75% (Table 2.5).

4.2.3 Bare ground cover

Data from all populations showed that 36% of *E. groenewaldii* plants were growing where there was bare ground cover of up to 25% (Pearson Correlation, 2-tailed, $r < 0.05$) (Table 2.7). Only the population of Melkboomfontein (33% of the population) occurred in a bare ground cover between 51–75% (Table 2.6).

4.2.4 Aspect

Results indicate that there was a clear correlation between aspects within populations ($P < 0.0001$) (Table 2.8). *Euphorbia groenewaldii* were more in numbers on the northern aspects (northwest, north and northeast) of slopes, visible in 47% of the *E. groenewaldii* population (Table 2.8). The population density of *E. groenewaldii* was the highest on the northern aspect of slopes (Fig. 2.5).

The Majebeskraal population was mainly found on the eastern aspect of the hill (Table 2.8). The highest percentage of this population (54%) grew on the south-eastern aspect. The north-eastern and eastern aspects had population percentages of 15% and 16%, respectively, of this population (Table 2.8).

The population of Kalkfontein was mainly found on the eastern aspect, containing 54% of its population (Table 2.8).

4.2.5 Slope degrees

There was a clear correlation between the slope degrees within populations ($P < 0.0001$, analyzed through SPSS) (Table 2.9). *Euphorbia groenewaldii* were more in numbers on slopes ranging from less than 5º up to 10º in incline, associated with 73% of the *E. groenewaldii* population (Table 2.9).

The De Put and Tweefontein-Geluk population occurred predominantly on slopes with an incline of between 10–20º, containing over 50% each population, respectively (Table 2.9).

4.2.6 Slope position

The slope position calculations are a more compact and broader outlook of the slope degree feature and are modelled around three categories: (1) lower slope that will range from >0 - 10º, (2) the middle slope that ranges from >10 - 20º and (3) the upper slope that ranges from 20º upwards.

Of all populations, Melkboomfontein had the highest number of plants (65% of the population) on the lower slope (>0 - 10º); Tweefontein-Geluk had the highest number (80%) of plants on the middle slope (>10 - 20º). Kalkfontein has the highest number (24%) of plants on the upper slope (20º+) (Table 2.10). Population densities per slope position support the statistical analysis that the majority of *E. groenewaldii*'s plants occur on the middle slope (Fig. 2.4).

4.2.7 Soil

Soil samples from all the *E. groenewaldii* sites were acidic (Table 2.11), particularly at the Tweefontein-Geluk population which had a pH of 5. Table 2.12 shows that the total nitrogen was also very low (0.11–0.18%) and limited to NH_4^+ form.

The cations in the soil of Kalkfontein were the highest (at least 3 cmol/L higher) of all populations (Table 2.11). Kalkfontein also had particularly high amounts of Magnesium (Mg) (at least 2.5 times higher than that of Melkboomfontein and De Put) (Table 2.11). Melkboomfontein and De Put populations in turn had higher amounts of zinc (Zn) than other populations (Table 2.11). The available phosphorus (P) was extremely high (310.6 ± 73.77 mg/L) at Melkboomfontein (Table 2.11).

The percentage of organic carbon was the same in all the populations on average, except for Kalkfontein which was slightly higher (Table 2.11). The nitrogen content found in all populations was very similar between sites (Table 2.12).

4.2.8 Canopy size per aspect

The mean canopy size occurring on the north-western aspect was at least 2500 cm^2 larger than on any other aspect (Table 2.13 and Fig. 2.3). Canopy size of all populations had significant (Post Hoc Test, $P < 0.05$) differences between the NW aspect and the rest of the aspects (N, NE, E, SE, S, SW) (Table 2.14).

4.3 Population biology

4.3.1 Stage and Size Structure: Canopy area

Adults were the most prominent in all populations; except De Put that had an average 20% less adults than the other populations (Table 2.15b). De Put also had 15% more juveniles on average than the other populations. The number of juveniles and seedlings observed in the other populations were proportionally the same as De Put, except for Majebeskraal where no seedlings were recorded. Melkboomfontein was the population with the most senescent plants; in spite of being the largest population. Other than the living classes (adult, juvenile and seedling), senescent plants constituted a very small portion (0.3%) of the total stage structure throughout all populations.

4.3.2 Size structure: Canopy area

When comparing the maximum canopy areas, a significant difference existed between populations (one-way ANOVA test, $P < 0.0001$). A significant difference (Post Hoc Test, $P < 0.05$) was visible (Fig. 2.6) between the population of Tweefontein-Geluk and the rest of the populations when the mean canopy area of adult plants was compared (Table 2.16 and Table 2.17). Melkboomfontein differs significantly in mean canopy size (Post Hoc Test, $P < 0.05$) with De Put and Tweefontein-Geluk (Table 2.17). Melkboomfontein had more plants with a larger canopy area (Fig. 2.6).

The Median test was used to support the Tukey test (all populations combined) and indicate significant differences in canopy area ($P < 0.0001$) between Tweefontein-Geluk and the rest of the populations' canopy area. The population of Tweefontein-Geluk has significantly larger adult plants, in terms of canopy area (Fig. 2.6), when compared to other populations (Table 2.17). All the populations have an approximate 50% split in canopy size around the median, except for Tweefontein-Geluk and De Put (Table 2.18). De Put population had plants with smaller canopies (Table 2.18) than the rest of the populations. De Put population had more juveniles (Table 2.15a) and therefore generally smaller canopy-sized plants (Fig. 2.6). In contrast, the Tweefontein-Geluk population had plants with larger canopies (Fig. 2.6); most of the plants measured had canopies above the median (281).

4.3.3 Flowering and fruiting

The populations of *E. groenewaldii* differed from each other with respect to the number of plants in each population that carried flowers or fruit or both (Fig. 2.7). De Put and Kalkfontein had the most flowers and fruit, 14% and 7% per population, respectively (Fig. 2.7 and Fig. 2.8). Tweefontein-Geluk had the least number of flowers and fruits (2%).

About 87% of all measured plants were non–reproductive (Fig. 2.8). At the start of the rainfall season (late September) almost all the adult and some juvenile plants started flowering.

Euphorbia groenewaldii plants with a canopy area of less than 500 mm^2 were non reproductive (Fig. 2.9). Only plants with a canopy area of 500 mm^2 and larger started to show some budding and flower production (Fig. 2.9). Only plants with a canopy size of more than 2000 mm^2 produced fruits after flowering (Fig. 2.9).

Flowering and fruit production only occurred in 50% of the *Euphorbia groenewaldii* population on slope portion 2 (middel slope) (Fig. 2.10). Forty five percent of the *Euphorbia groenewaldii* population produced flowers and fruit on slope portion 1 (lower slope) (Fig. 2.10). These results also correlated with the percentage of plants found per slope position throughout all individual *E. groenewaldii* populations (Fig. 2.4).

4.4 Population threats and agents causing damage to *Euphorbia groenewaldii*

All threats and agents of damage that were noted were of a biotic nature. These included trampling, herbivory, and anthills/termites.

Major threats were residential and commercial (office and mining) developments, which had a once–off destructive effect on the small geographical areas in which relative large numbers of *E. groenewaldii* grew.

4.4.1 Trampling

Trampling was one of the bigger threats to this species because four (Melkboomfontein, Majebeskraal, De Put and Spits) of the six populations were affected by livestock, mainly cattle, and to a lesser extent by wildlife.

Thirty-one per cent of the plants in the Melkboomfontein population showed evidence of trampling by livestock (Table 2.19). The population of Majebeskraal is the second highest (8%) impacted by trampling, followed by Spits (6%) and De Put (2%). The population of Kalkfontein showed 0% signs of trampling on *E. groenewaldii* plants (Table 2.19).

4.4.2 Herbivory

Herbivory had a significant effect ($P < 0.0001$) on the *E. groenewaldii* population, showing a 15% (Table 2.19) impact on the population. The population of Majebeskraal was most affected by herbivory (28%), whereas Tweefontein-geluk was least affected (3% of its population) (Table 2.19).

4.4.3 Anthills

Natural occurring anthills had the lowest (1.1%) impact on the *E. groenewaldii* population compared to the other threats ($P < 0.0001$) (Table 2.19). The population of Melkboomfontein was most effected by anthills, with 2.5% of its population affected.

4.4.4 Senescent plants

The effect of senescent plants in the population of *E. groenewaldii* was minimal (4.1%) ($P < 0.0001$). The population of Melkboomfontein had the most (4.5%) senescent plants in its population (Table 2.19). The population of Spits was the only population with 0% senescent plants (Table 2.19).

4.4.5 Fire damage

There had been no official record of fires within the boundaries of the populations, since the species was last monitored by Raal in 1986), and no official fire regime exists. Most populations were located in the old Lebowa homelands where record–keeping was unsatisfactory. Fire data was collected as part of this study during

2007. The populations of De Put, Kalkfontein and a small section of Tweefontein-Geluk had been burnt (by an accidental fire), resulting in fire damage per population of 46%, 69% and 26%, respectively (Table 2.19).

4.4.6 Major (large) impacts

Human activities such as quarrying, agricultural practices and development (residential and business) have an impact on *E. groenewaldii* populations:

1. Tweefontein-Geluk: Brick factory and residential development (Fig. 2.17).
2. Kalkfontein: Quarrying (Fig. 2.18).
3. De Put: Quarrying (Fig. 2.19).
4. Majebeskraal: Quarrying and business development (Fig. 2.20).
5. Melkboomfontein: Quarrying, residential development, and agricultural practices (Fig. 2.21).

5. DISCUSSION

It is difficult to predict the exact rate of decline in *E. groenewaldii* populations from the middle 1980s to the present day, because the available original data was collected in a format that is not compatible to modern day survey techniques. Considering the current threats in and around *E. groenewaldii* populations a decline is expected. The biggest current threat to *E. groenewaldii* populations, except Kalkfontein, is habitat destruction from urban expansion and, in certain sectors, commercial development such as mining in peri-urban areas. This was foreseen by Schemske *et al*. (1994), who observed that development of any kind still remained the biggest threat to any endangered plant species.

5.1 Biotic elements

Euphorbia groenewaldii is found in a habitat of 25% grass and forbs. When there are more grass and forbs, the number of *E. groenewaldii* plants decline. This is evident at the Tweefontein-Geluk and Majebeskraal populations, where more adults than juveniles were recorded and almost no seedlings could be found. This could be due to the large amount of grass and forb biomass in the area. The possible result of this thick grass and forb layers, is that very little recruitment of *E. groenewaldii* seedlings took place for a number of years. It can be concluded that if the percentage of dead vegetation cover is utilized as a form of restriction or competition index, then plants of the Spits and Tweefontein-Geluk populations were subjected to high levels of inter-specific competition with grass and forbs.

There is a notion from Raal (1986) that plants tend to be larger when found in denser grass areas, like the Tweefontein-Geluk population, but it can also be that the properties of the soil may have an influence on the growth and size difference of plants in the different *E. groenewaldii* populations.

Where grass is dominant in a biome, the system requires a number of interacting driving factors (drought, fire and precipitations) to be in place for the recruitment of seedlings and the development of juveniles of succulents (Jeltsch *et al.*, 1996). New growth and flowering was noted after fire affected the populations of Tweefontein-Geluk and De Put, but it also killed *E. groenewaldii* plants. The driving factors for *E. groenewaldii* are probably fire and rainfall, but further studies are needed to determine these factors. It probably would be ideal if rainfall follows an incidence of fire that has cleared the area from competitors and stimulated new growth (Veste *et al.*, 2001).

5.2 Abiotic elements

Where there are almost no biotic cover, *E. groenewaldii* plants feature quite prominently (Table 2.7). This could be because of intraspecific competition from other plant species on space and natural resources (Wang *et al.*, 2005). Where there are a number of low rise schist ridges and loose stones, or even just bare ground, *E. groenewaldii* tend to be more evenly spread and will exist in-between these ridges even if there are no other biotic features in close proximity. If the soil is not deep enough or the space between two ridges is not wide enough, then *E. groenewaldii* will be absent. These ridges form a safety zone (refuge habitat) for these plants against possible trampling and lessen the change of predation by livestock. There is also the possibility of water channelling into these ridges, resulting in a higher moisture and nutrient regime (Table 2.7).

More than 30% of the *E. groenewaldii* population grew in areas that provided 25% bare ground around an individual plant (Table 2.7), which could mean that *E.*

groenewaldii plants prefer space and less intraspecific competition from other plant species (Wang *et al.*, 2005). This can be deduced looking at Table 2.7 where only 15% of the *E. groenewaldii* population was recorded growing in areas that had no bare ground around an individual plant.

With regard to aspect, the angle of the slope and where on a specific slope *E. groenewaldii* occurs, it seems that this species prefers northern-facing aspects (Fig. 2.3), this is also confirmed by Figure 2.5 that shows the highest density of *E. Groenewaldii* population on the northern aspect. According to Raal (1986), a possible reason might be that *E. groenewaldii* need significant amounts of sunlight to grow optimally.

Majebeskraal population had little *E. groenewaldii* plants on the northern aspects. This is because the northern aspect was destroyed by a quartzite quarry. The Spits population's *E. groenewaldii* plants grew mainly on the northern, eastern and southern aspects (Table 2.8) due to the fact that it had basically had no western aspect. This is because the Spits population is situated on a small protrusion, of a larger hill, that protrudes to the east.

According to the results, *E. groenewaldii* plants occur in fewer numbers on the highest part of a slope (Table 2.9). This could be due to the fact that very little soil, to grow in, was found above 20º, and it then consists mostly of schist ridges and small cliffs.

A marked difference is apparent in the number of plants and their canopy sizes on different aspects. At all the populations, the aspect that generally had the largest canopy-sized plants was the north-western one. This again could be because the northern aspect receives the most sunlight of any aspect, which results in a drier environment that is better suited for succulents (Scott & Vogel, 2000). The northern aspects were the second densest, which again could be because of the reason put forward by Scott and Vogel (2000).

5.3 Population biology: The importance of a fire regime

A fire regime is currently not present in any of the surveyed populations. Results from the populations of De Put, Kalkfontein, and the parts of Tweefontein-Geluk, indicate that fire positively affect plants by initiating new growth, flower formation and fruit production from well-established plants. The Tweefontein-Geluk populations have not experienced a fire in the recent past, and the present amount of grass suggests that the area had not been burned for a number of years. In August 2007 an accidental fire swept through sections of the Tweefontein-Geluk population. Although this fire helped stimulate new growth, it did not coincide with the rainfall season.

Raal's (1986) conservation plan showed that the Ga-Mankweng area, did not receive any fire for about 16 years before 1986. It must be kept in mind that poor recordkeeping by the Lebowa administration (under which Ga-Mankweng fell), and limited access by researchers could account for poor record keeping in terms of fire events in the area of the *E. groenewaldii* populations. This area, that includes the populations of Melkboomfontein, Majebeskraal, De Put, Spits and Kalkfontein, are situated on tribal leasehold lands and are subjected to overgrazing and heavy trampling (Fig. 2.12). This removes much of the fuel biomass which could have made it more difficult for fires to start or cover a large area.

In May 2007 there was an accidental fire that affected the Tweefontein-Geluk, Kalkfontein and De Put populations. These populations were subsequently investigated for any effects fire had in terms of new growth, flower and fruit production. The Tweefontein-Geluk, Kalkfontein and De Put populations are also the populations with the most grass fuel load because they are less affected by livestock grazing and human activities (trampling, thatch collecting and development); as a result these populations had a low count of seedlings and consist mostly of adults.

Melkboomfontein has the largest population and is also the most intensely grazed and trampled by livestock. This population is also heavily impacted by a number of human activities, like wood cutting and excavations. This could be the reason for the low probabilities of accidental fire.

Fire has the potential to affect the composition, structure and functioning of an ecosystem. A fire regime, in terms of location, intensity and frequency, may be unfavourable to a species and could lead to that species' decline (Bond, 1984). According to Thomas and Goodson (1992), a hypothesis has been formulated that succulent plants cannot withstand fire and may only survive a fire in the protection of a physical feature such as rocky and sandy areas, which will contain very little biomass to burn. There is a lot of biomass fuel in some the investigated populations (Tweefontein-Geluk, Kalkfontein and De Put), resulting in damage by fire (Table 2.19) even where plants are protected by rocky or sandy areas. However, *E. groenewaldii* plants are tolerant of fire. Most of the *E. groenewaldii* plants of Tweefontein-Geluk, Kalkfontein and De Put populations that were subjected to the May and August 2007 fires were not destroyed, because most of the plants affected by the fire initiated new growth. The new growth was visible on most plants, which means that plants of this species are more tolerant. This was also proven by Pfab and Witkowski (1999a) for *E. clivicola*, where only 3% of the population died after a fire event.

The reasons for *E. groenewaldii'*s fire tolerance include; (1) leaf bases protect the meristems (Thomas & Goodson, 1992), (2) meristems are situated underground (Pfab, 1997), and (3) stems and roots are merged to form an underground tuberous body (Raal, 1986).

According to Thomas and Goodson (1992), plants that have their meristems protected underground can possibly re-grow, but it rarely happens. After the fire that affected De Put, Kalkfontein and a small portion of Tweefontein-Geluk, many plants started to re-grow from sub-terranean tuberous organs. Furthermore, the De Put population had 3.5% more seedlings than other populations, after the fire. This is because the fire covered proportionally more of the De Put population than some of the other populations, which caused new growth and initiated seedling germination.

Although, the populations of De Put, Kalkfontein and Tweefontein-Geluk which were affected by the May 2007 fire, initiated new growth, only a few flowers and fruit was produced. This could be due to a lack of rainfall. Furthermore the Tweefontein-Geluk population generally had larger-sized adult plants than the De Put and

Kalkfontein populations. The reason for this is unclear, but could possibly be ascribed to a number of factors that include; (1) better environmental conditions in the area where it occurs, (2) more regular precipitation, and (3) less natural threats in the area that affect its growth and reproduction capabilities.

If a regular fire regime that coincides with the rainfall season can be formulated for *E. groenewaldii,* it could promote more new growth and possible seed germination (further studying is needed) and help with a constant rate of seedling recruitment at time intervals that is optimal for this species. This was done for *E. clivicola* by implementing a 3 to 5 year fire regime to; (1) help stimulate re-growth and seed setting, (2) to keep the grass biomass at a manageable level for optimal seedling and juvenile establishment, and (3) to increase the recruitment rate to an optimum level (Pfab, 1997; Pfab & Witkowski, 1999a & 2000). Another example of such a study is where Drechsler *et al.* (1999) calculated the optimal stages for a fire regime to promote individual recruitment at a regular time interval for the Australian species *Banksia goodii*. It was calculated that a 15 year interval fire regime helps individual recruitment increase three fold of this species.

5.4 Threats to *E. groenewaldii*

5.4.1 Development

There are many threats that presently impact upon the existence of this species at all its locations. The biggest problem at the moment is urban and commercial development (Fig. 2.17 to 2.21). Other threats include trampling by livestock, herbivory by livestock and wildlife, ants building their nests on and over individual plants, and people collecting *E. groenewaldii*.

The human activities that have the biggest impact at Melkboomfontein are quarrying and residential development (Fig. 2.21). Schist and limestone are harvested for the construction of tar roads in the vicinity. The population is further subjected to heavy digging equipment and large dump trucks moving in and out of the area (Fig. 2.15). Urban development is currently another problem. The village of Mothiba is expanding (Fig. 2.21) and new plots for a small housing development are laid out monthly and are slowly encroaching on the eastern boundary of the population of *E. groenewaldii* at Melkboomfontein. No buffer zone is evident around all populations. It would be ideal if a buffer zone could be established, because *E. groenewaldii* is listed a red data species (SANBI, 2009). This will help keep out human activities and livestock trampling and herbivory and could protect possible pollinator's habitat around *E. groenewaldii* populations.

Majebeskraal (Fig. 2.20), De Put (Fig. 2.19) and Kalkfontein (Fig. 2.18) have similar quarries of various sizes that have already destroyed large segments of each of these populations. The Tweefontein-Geluk populations are the most severely affected by human activity (Fig. 2.17). In the form of a quarry for a brick factory (Fig. 2.17) and sub-urban development that has been there since the 1970s. More than 50% of two of the hills on which the population of Tweefontein-Geluk of this species grow has been destroyed by mining activities, resulting in the acceleration of extinction of this population. The most western section of the Tweefontein-Geluk population is now threatened by an upmarket housing development and by the construction of the N1 eastern bypass (Fig. 2.17) encroaching on its northern and western boundary. This effectively prevents this population of *E. groenewaldii* on any future range expansion. The most eastern section of the Tweefontein-Geluk population is threatened by housing and subsistence farming.

5.4.2 Trampling

At three of the six populations, trampling is a serious threat to large parts of the population. Melkboomfontein is presently the most heavily affected (Table 2.19) by livestock trampling (Fig. 2.12), mostly cattle and free ranging goats. Due to the increase in the local human population (of Ga-Mothiba) at the population of Melkboomfontein, the population is stressed. The villagers move their livestock across the Melkboomfontein population every morning to get to the Diep River valley (Fig. 2.12).

Damage through trampling can also let opportunistic pathogens into the plants system that can destroy the entire plant (Knowles & Witkowski, 2000). The serious impact of trampling is illustrated by the decline of adult *E. clivicola* plants due to either loss of vigour or bacterial infection (Pfab, 1997).

Some populations of *E. groenewaldii* are not as much affected by trampling because they are less accessible to livestock. The property on which the populations of

Kalkfontein and Tweefontein-Geluk occur is fenced off and has no livestock. These populations do have some wildlife (Klipspringers (*Oreotragus oreotragus*) and impalas (*Aepyceros melampus*) (Carruthers, 2008)). Humans also pass through, like local women from the nearby villages that often go into the populations of Kalkfontein and Tweefontein-Geluk and harvest grass for thatching and may accidentally step on *E. groenewaldii* plants. The *Euphorbia groenewaldii* plants in these populations that are situated between rocks or ridges were noted to have little trampling damage.

5.4.3 Herbivory

The grazing and browsing of threatened plant species often causes a decline in population size (Bradshaw, 1981; Witkowski *et al.*, 1997). Most of the damage caused by herbivory are done by livestock, such as goats and donkeys, rodents and birds, all of which consume the branch tips and fruit and in some cases the underground tubers (Pfab, 1997). If this continues this may result in a serious threat to *E. groenewaldii* if no control is implemented.

At first it was thought that all *Euphorbias* are poisonous and will cause serious symptoms, such as inflammation of the skin and mucous membranes, conjunctivitis and even blindness, in humans, livestock and wildlife that come into contact with its milky latex (Rizk, 1987). However, there are quite a few exceptions when it comes to the consumption of *Euphorbias*. Reedbuck (*Redunca arundinum)* and porcupines (*Hystrix cristata*) eat *E. clivicola* (Pfab, 1997), goats and donkeys consume *E. barnardii* (Knowles & Witkowski, 2000); kudu (*Tragelaphus strepsiceros*) consumes *E. restricta*, Black Rhino (*Diceros bicornis*) consumes *E. damarana* (Beytell, 2010) and klipspringer (*Oreotragus oreotragus*) has been observed eating *Euphorbia* species (Stuart & Stuart, 1994).

According to Pfab (1997), if large parts of the photosynthetic tissue of a perennial species is removed by herbivory, the plant's growth tend to be impeded, which leads to smaller-sized plants. The Tweefontein-Geluk's adult plants are larger (Fig. 2.6) than the other five populations of *E. groenewaldii*, and are also under very little herbivore pressure (Table 2.19), which could be due to the above mentioned fact. In contrast, the population of Kalkfontein's plants that are also guarded from livestock herbivory are generally much smaller than the Tweefontein-Geluk's plants. This difference might be due to local environmental conditions or it may have a different genetic basis. This study concur with Raal (1986) in that it might be possible that the Tweefontein-Geluk population is a different species or sub-species from *E. groenewaldii*, but this can only be determined by means of morphological investigations and genetic tests.

Herbivory may have a serious effect on individual *E. groenewaldii* plants, because if the meristems are damaged, then the plants become dormant and will eventually die (Pfab, 1997). Herbivory may have caused some plants of the Melkboomfontein, Majebeskraal and De Put populations to die or become dormant, as observed during field surveys. Many *E. groenewaldii* plants also show signs of herbivory only on the tips of the branches, and this did not cause any mortality.

With an increase in grass biomass there will be an increase in vertebrate and invertebrate species number and richness (Burger & Louda, 1994), which could possibly raise the herbivory impact on a species such as *E. groenewaldii*. The large amount of grass biomass around *E. groenewaldii* plants at the Tweefontein-Geluk population will have higher invertebrate species richness (Grasshoppers (Orthoptera) (Fig. 2.14).

5.4.4 Pollination failure

The only potential pollinators detected were ants. No other pollinators were observed, and no records exist of the pollinators of this species. How successful flowers are pollinated depends on how well the flower is presented in terms of visibility (Pavlik *et al*., 1993), because sufficient numbers of pollinators must be attracted. The possibility of pollination failure of *E. groenewaldii* plants could be due to a number of factors observed during field surveys:

1. Large vegetation biomass found at some populations that could hide *E. groenewaldii* plants and may possibly cause flying pollinators to miss plants and so limit potential pollination incidences.
2. The small size (7 mm in diameter) of the flower (cyathia) may not easily be seen by potential pollinators.

3. Incentives (nectar) offered by the plant may not be viable enough for pollinators to waste their energy on or may attract animals that would eat the whole flower (Yoshihara *et al.*, 2008).

Further research is needed to determine *E. groenewaldii*'s pollination strategies.

5.4.5 Collector pressure

The collection of rare and endangered plants out of their natural environment dates from centuries ago. One of the many examples is the illegal trade of *Aloe peglerae,* from the western Gauteng area. This plant is situated in a Protected Natural Environment of the Magaliesberg and listed under Appendix II of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora). Trade statistics, based on records of export from South Africa, shows that there is very little being done about the international trade in *A. peglerae* (Pfab & Scholes, 2004).

This situation is probably similar for *Euphorbia* species, both endangered and common; collectors could remove these plants from their environment for trade purposes without any permits (Haevermans, 2004). *Euphorbia groenewaldii* is no exception, although it is protected under legislation of the Department of Environmental Affairs and Tourism and NEMA (Republic of South Africa: NEMA, 1998). *Euphorbia groenewaldii* is of commercial importance as it is popular with plant collectors and horticulturists. Despite its conservation status (endangered) and its CITES listing, several internet sites offer the species for sale at an average price of € 5-00 (U4BA, 2010) per seedling and € 2-00 (Euphorbias, 2010) for its seed.

If an endangered plant species has extremely low population numbers, but has just enough numbers to be still sustainable and is still collected out of its environment, it will most likely contribute to population decline and eventual extinction (Pfab & Scholes, 2004).

A good example is *Aloe peglerae*: If this slow growing plant has a population of, for instance, 100 individuals, and if only one of these plants is collected every year, the population will decline rapidly to extinction (Pfab & Scholes, 2004). *Euphorbia groenewaldii*'s populations are larger than that of *A. peglerae*, but could follow the same route if: (1) possible illegal collection activities are not monitored, and (2) harvesting of *Euphorbia* species is granted, and no proper monitoring of the set quota of individuals for harvesting is not in place.

5.5 *Ex situ* conservation if *in situ* conservation fails

Ex situ conservation or off-site conservation of plants is the process of protecting plant species by removing a population or part of a population from its threatened area of occurrence and placing it in a new area (wild or human made). It is also often termed translocation (Given, 1994). This method of conservation may have great value for *E. groenewaldii* due to the current threats that may lead to the plants extinction.

This first priority when conserving a rare and endangered plant is to do it *in situ*, but this method may become very difficult to implement without proper resources, especially if one considers the time, labour and finances that would be saved during *ex situ* conservation. *Ex situ* conservation is not the best alternative when compared to *in situ* conservation for *E. groenewaldii*, and that it should only be enforced for a short period of time until *in situ* conservation can be sustainably implemented (Raal, 1986).

The success of *ex situ* cultivation lies in the understanding of the ecological and biological needs and requirements of a species (Given, 1994). A lack of understanding is so often the down fall of such a project, as was the case of *Aloe polyphylla* that received too much water from gardeners and eventually died due to rot (Pfab, 1997). Therefore, the biological functions of *E. groenewaldii* should be researched in-depth before attempting to conserve it *ex situ*.

According to Raal (1986: Appendix A) *ex situ* conservation includes the following:

a) “The collecting of a representative nucleus of living plants from a population of rare and endangered plants and the maintenance of these plants for the following reasons:
    i. Sufficient material must be obtained from the various propagation techniques so that, by re-introducing the offshoots to the wild, the number of plants in the original populations can be strengthened.

ii. Sufficient material must be obtained from the various propagation techniques so that plants can be re-located within the natural distribution range of the species and new populations establish in analogous habitat types.

iii. Sufficient material for sale to the public or nurseries as a means of reducing collector pressure must be obtained from the various propagation techniques.

iv. If sufficient seed is produced by the plants during *ex situ* conservation this seed can be preserved by storing in a recognized seed bank or distributed to various associations for cultivation.

b) If the need arises, *ex situ* conservation will be used as a means of preserving a species that has become extinct in the wild especially if the natural habitat of the species in question has been destroyed."

If *E. groenewaldii* is to be cultivated it should only be watered in the summer, because it occurs in a summer rainfall region that has an average rainfall of 450-750 mm per annum (Mucina & Rutherford, 2006). *Euphorbia groenewaldii* is a succulent and should thus only be watered moderately when the soil has completely dried out (Raal, 1986). If temperatures of above 30°C persist for a long duration, without any precipitation, then watering once a week will be sufficient. Although plants are frost resistant, it should be grown in temperatures of between 1°C and 30°C (Pfab, 1997).

Despite *E. groenewaldii* preferring open areas with lots of sunshine, some plants (1%) were found growing in shady areas like partly under a torn bush or small rock ledge. It can thus be concluded that they are tolerant to shady conditions, but it's recommended that they are grown in full sun (Pfab, 1997).

5.5.1 Soil

It is very interesting that the pH levels, which dictate plant growth and richness (Medinski, 2007), preferred by the urban population of *E. clivicola* (ph = 4.71) and the Tweefontein-Geluk population of *E. groenewaldii* (ph = 4.85) are very similar. According to Medinski (2007), if the important nutrients, in acidic soils (pH < 6), such as calcium, magnesium, potassium, phosphorus and molybdenum are depleted or unavailable in a form useable to plants, it will lead to nutrient deficiency.

The adults of the population of Tweefontein-Geluk are larger (in canopy area as mentioned in section 4.3.2) than any of the other *E. groenewaldii* populations. Therefore, according to Raal (1986), the population of Tweefontein-Geluk may be *E. tortirama*, but further research into the population's genetic makeup are needed to prove its identity. The plants found at the population of Tweefontein-Geluk are smaller or more stunted than that of the species *E. tortirama* (White *et al.*, 1941) that occurs in the Waterberg. It could possibly be that the soil, in the Tweefontein-Geluk population's area, maybe nutrient deficient (for *Euphorbia* species) as opposed to the soil in the Waterberg area The soil analysis (Table 2.11) did show that the population of Tweefontein-Geluk had the lowest amounts of calcium, magnesium, potassium, and phosphorus than any of the other *E. groenewaldii* populations. Further research is needed to find out if the nutrients in the soil of the population of Tweefontein-Geluk are a determining factor in its growth performance.

According to Raal (1986), the soil found at all the *E. groenewaldii* populations is normally well-drained but there is a high content of clay present that does holds moisture for extended periods and composition of the soil in which the plant grows is made up of quartzitic, granitic and muscovite schist elements.

According to the current soil analysis (Table 2.12), there is a high content of coarse silt and sand. This texture (sandy loam to loamy sand) of soil is preferred by succulents plants, such as *E. groenewaldii* (Valdes-Rodriguez *et al.*, 2011), which could indicate the establishment of the *E. groenewaldii* populations in these areas.

With regard to the organic carbon content (Table 2.11); Kalkfontein had a significantly higher value than the other *E. groenewaldii* populations. This could be due to the large amount of grass biomass that was burnt in the area. The organic carbon nitrogen ratio (10:1) is as expected, because of the clay percentage of between 10% and 20% in all populations (Manson, pers. comm.). The higher the clay content in the soil the more nutrients the soil can hold (Valdes-Rodriguez *et al.*, 2011), therefore it is probably the right amount of clay in the soil for *E. groenewaldii* plant to grow in with enough nutrients available. Further research is needed to determine the soil nutrient – and soil texture class spectrum in which the species *E. groenewaldii* can flourish and this will also lend to better understanding of *ex situ* conservation of this species.

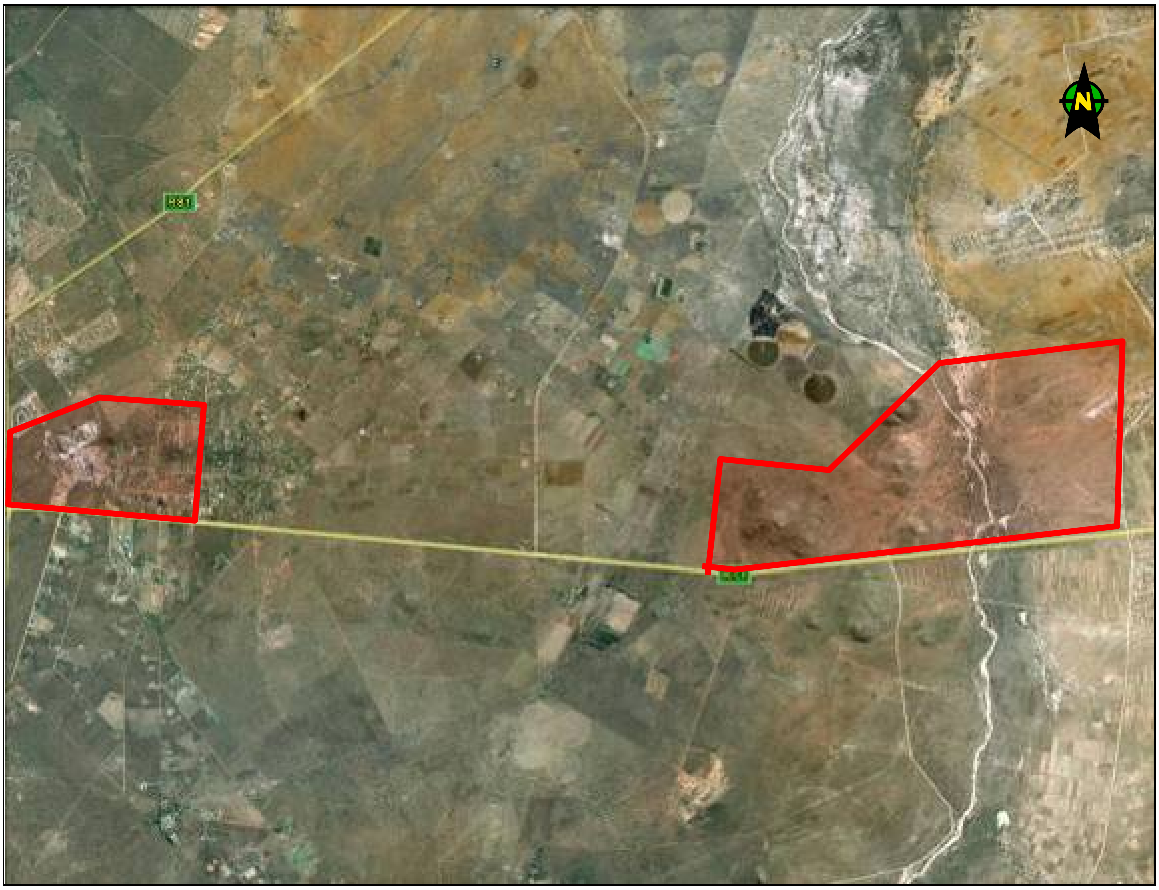

Figure 2.1: Study area of the *E. groenewaldii* populations (Google Earth, 2010).

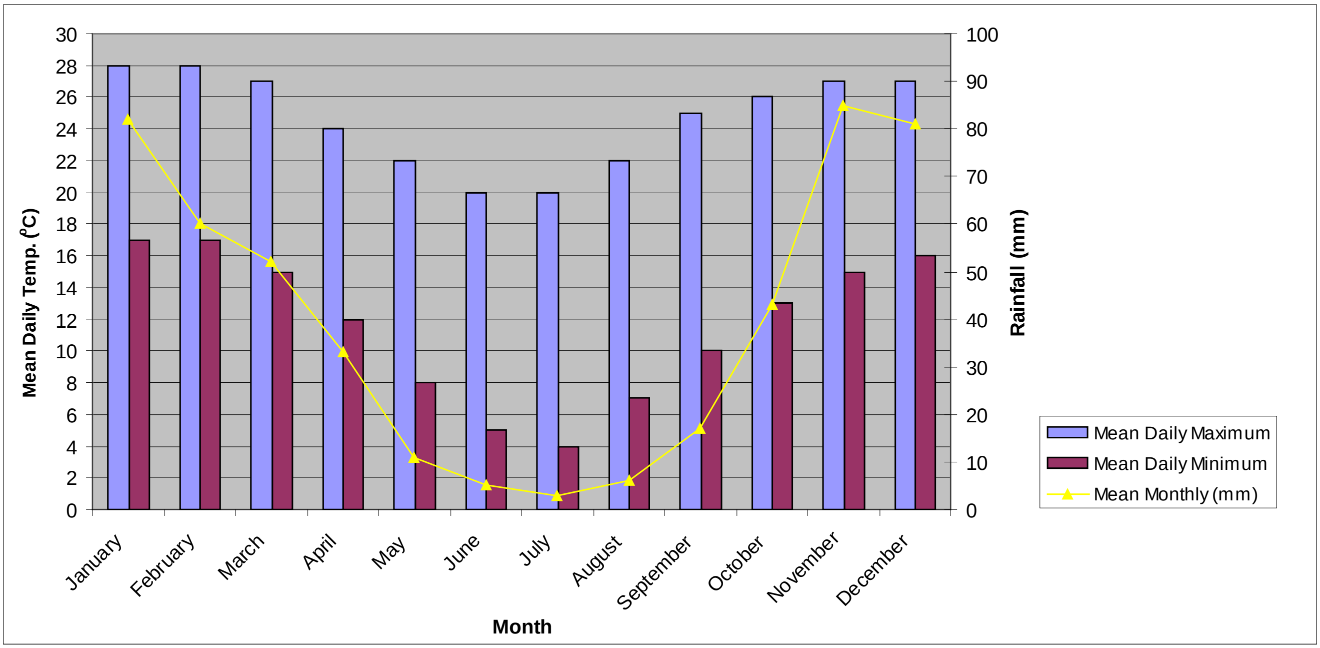

Figure 2.2: Mean monthly rainfall and mean maximum and minimum temperatures through all populations (South African Weather Service, 2003).

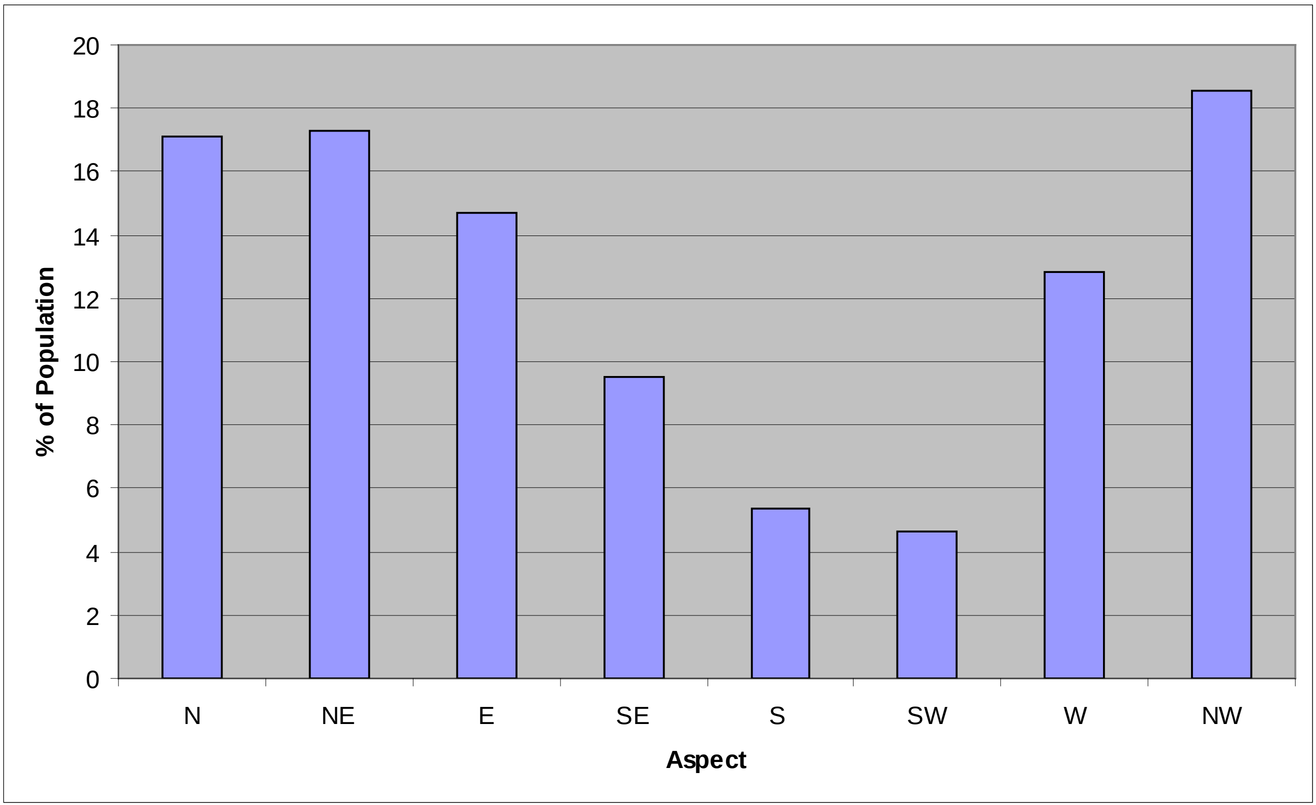

Figure 2.3: Aspect preference of *E. groenewaldii.*

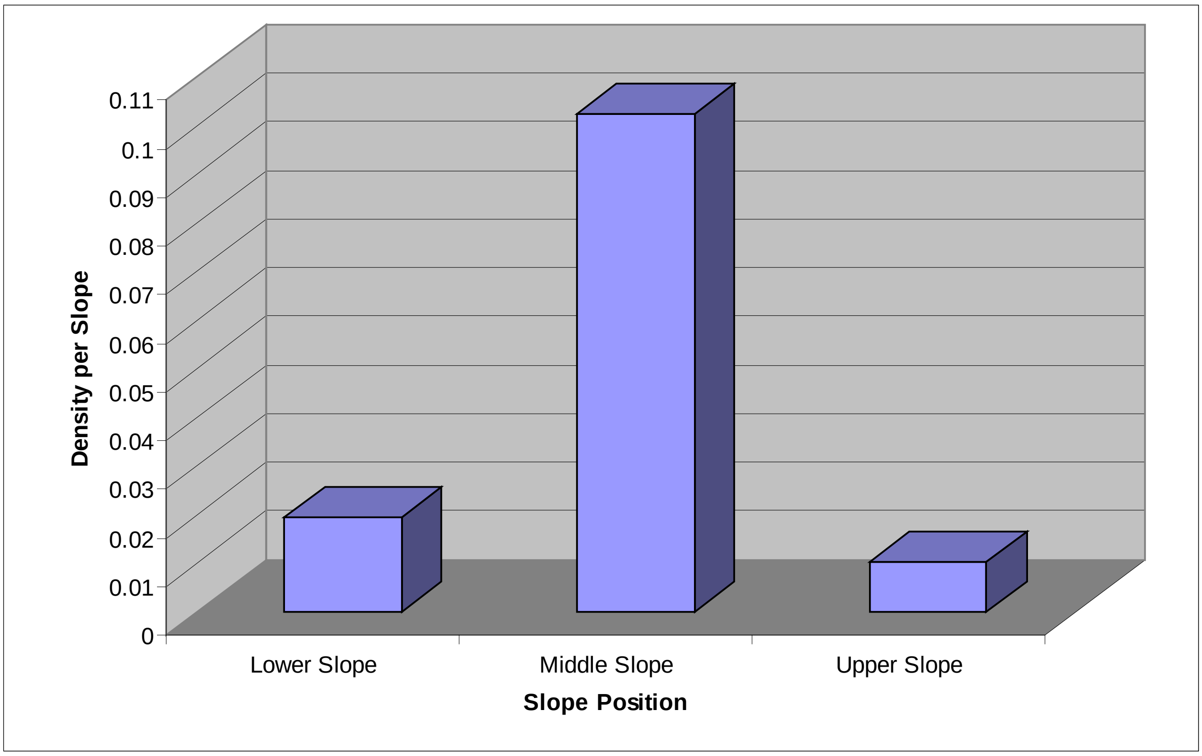

Figure 2.4: The population density per slope position for *E. groenewaldii*.

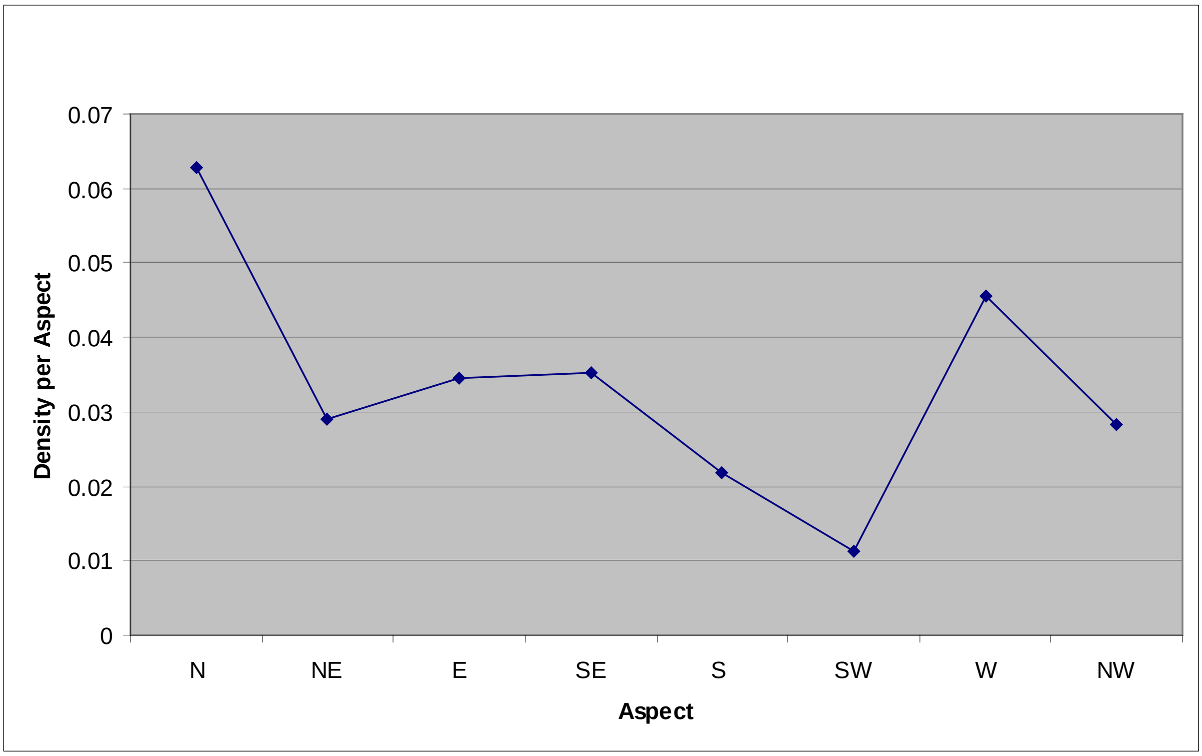

Figure 2.5: The population density per aspect for *E. groenewaldii*.

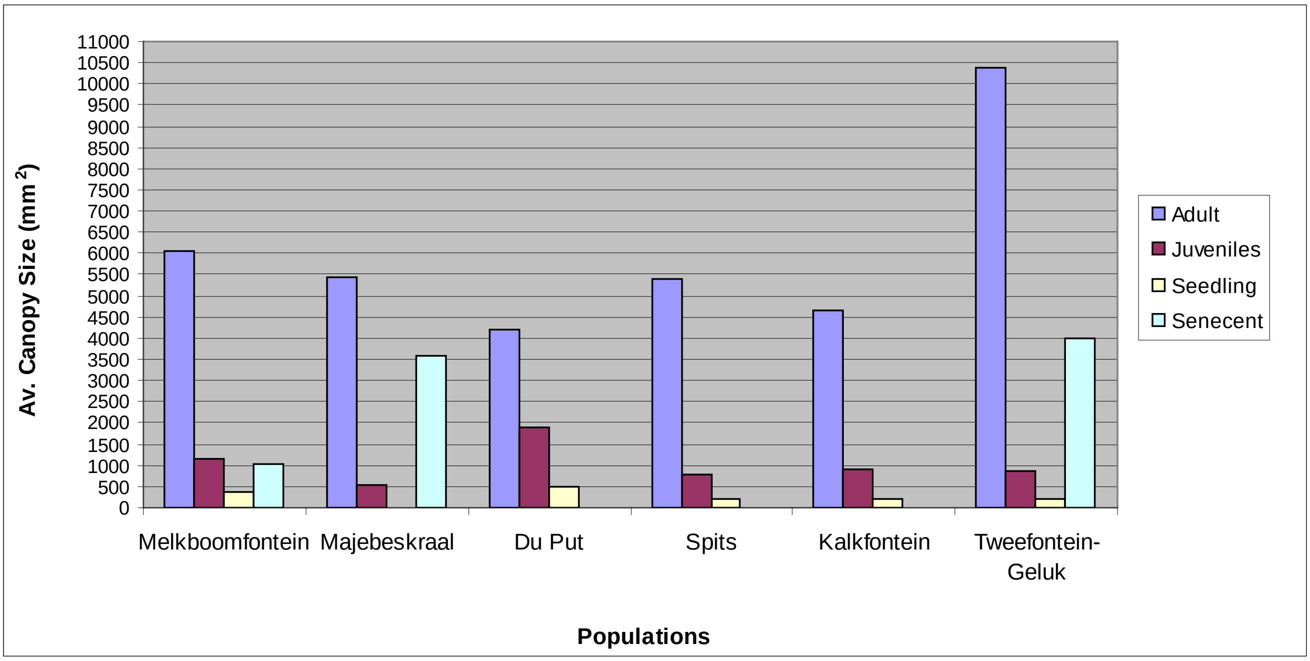

Figure 2.6 The canopy area (size structure) of *E. groenewaldii* populations for each stage class.

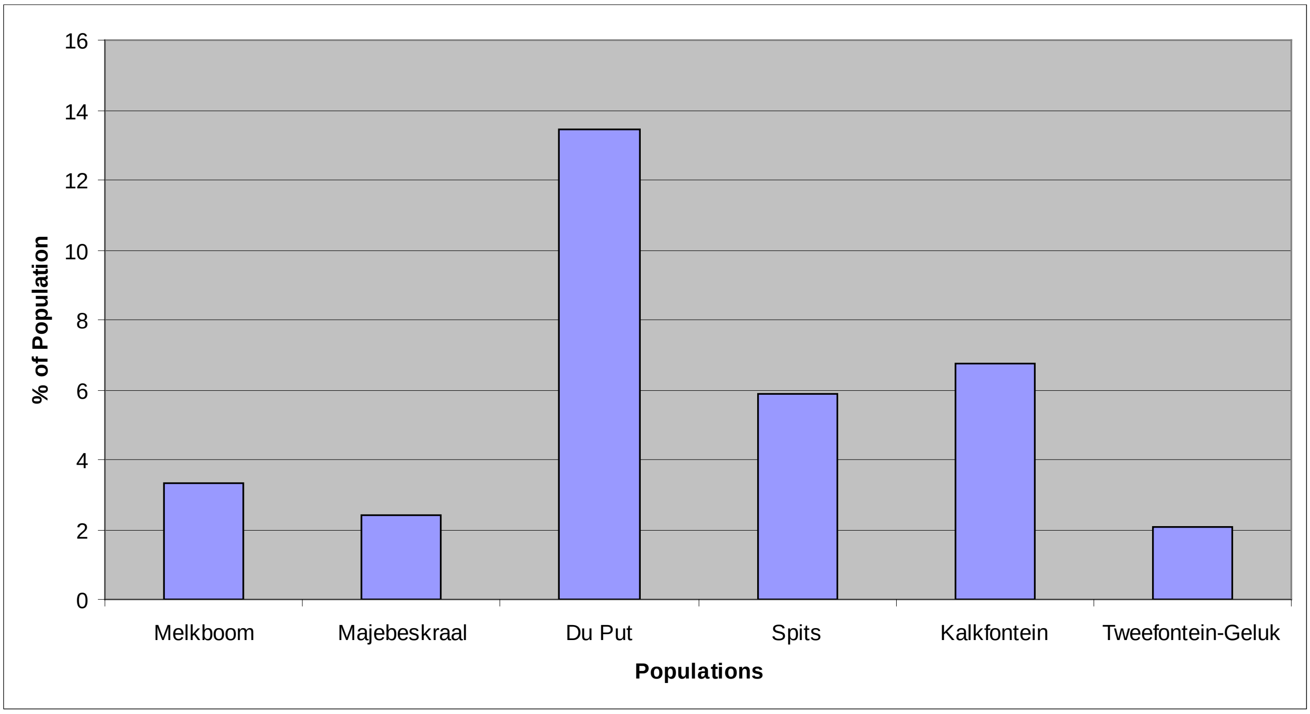

Figure 2.7: Percentage of plants within each population that had flowers and fruits, or just flowers or just fruit.

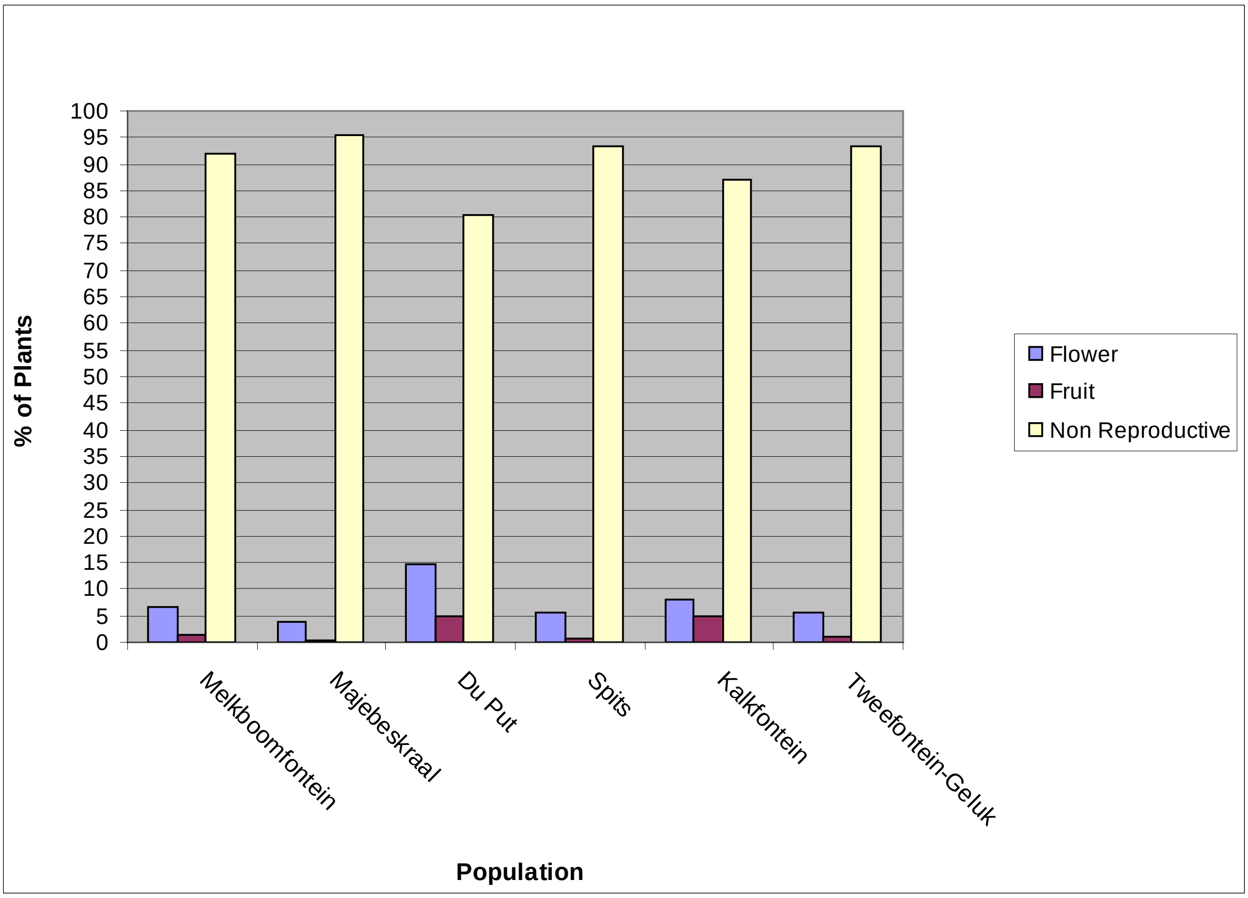

Figure 2.8: Percentage of canopy-measured plants that produced flowers and fruits.

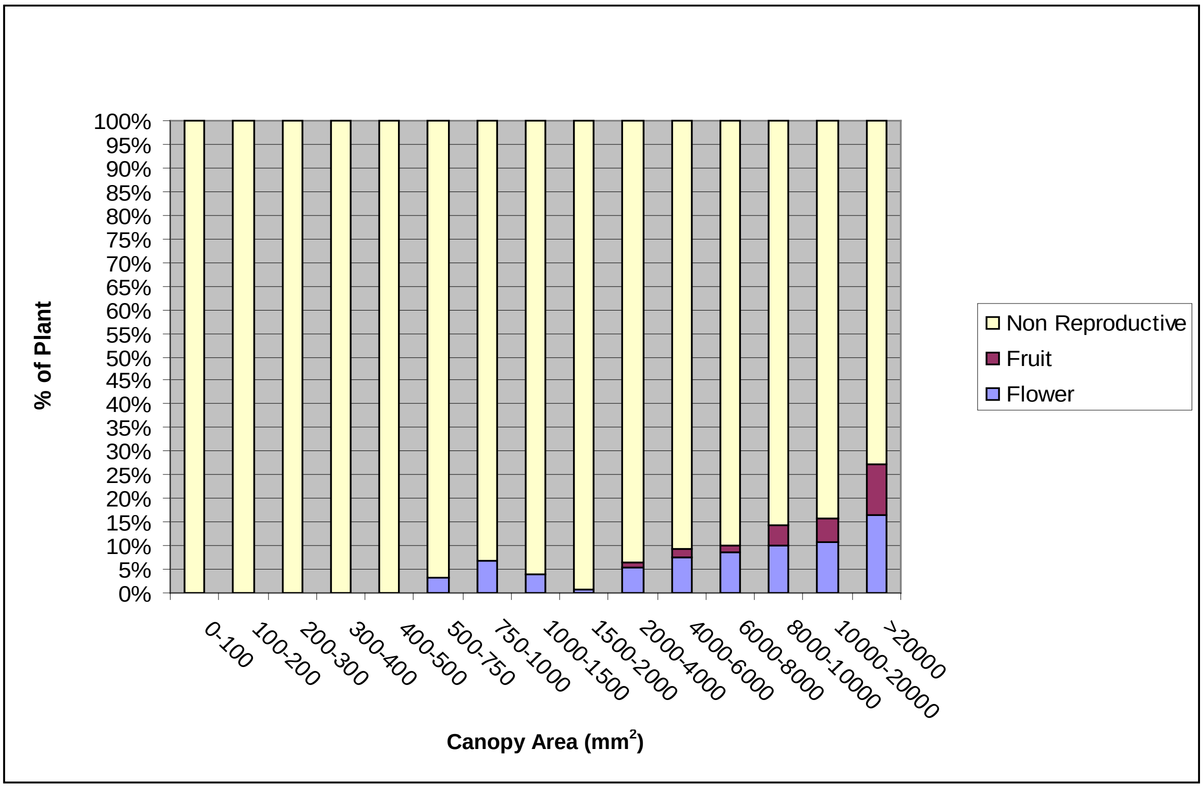

Figure 2.9: Percentage of reproductive and non reproductive plants in each canopy size class, of all populations.

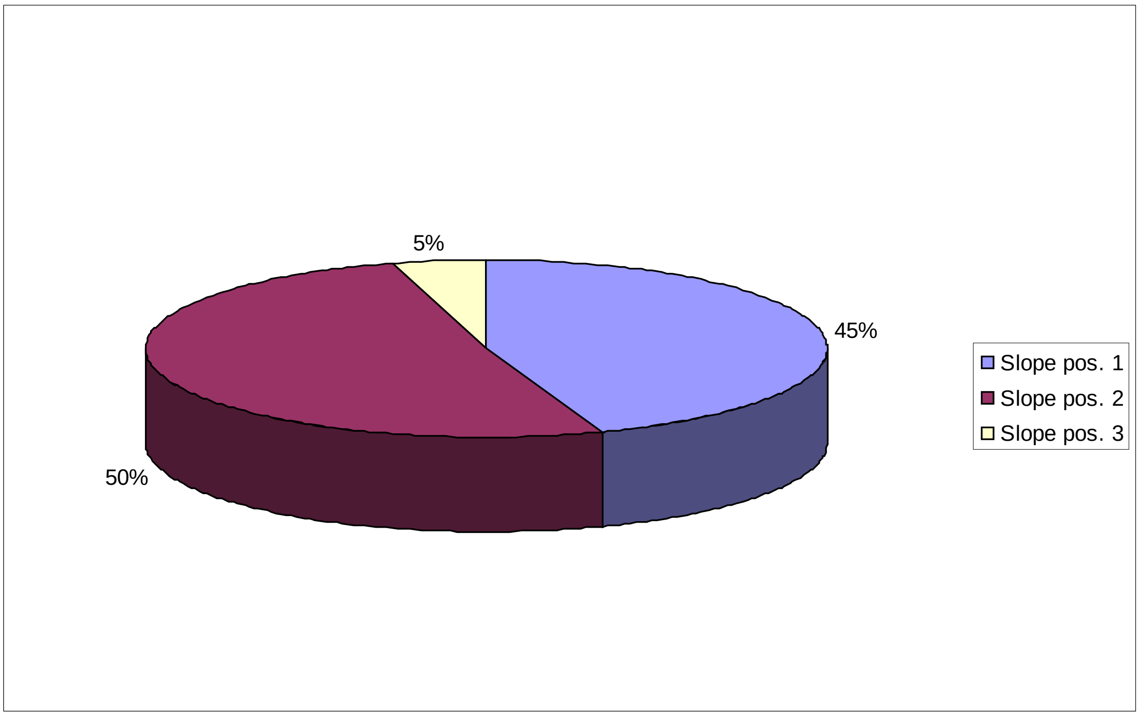

Figure 2.10: Percentage of populations on which slope the most plants produced flowers/fruits.

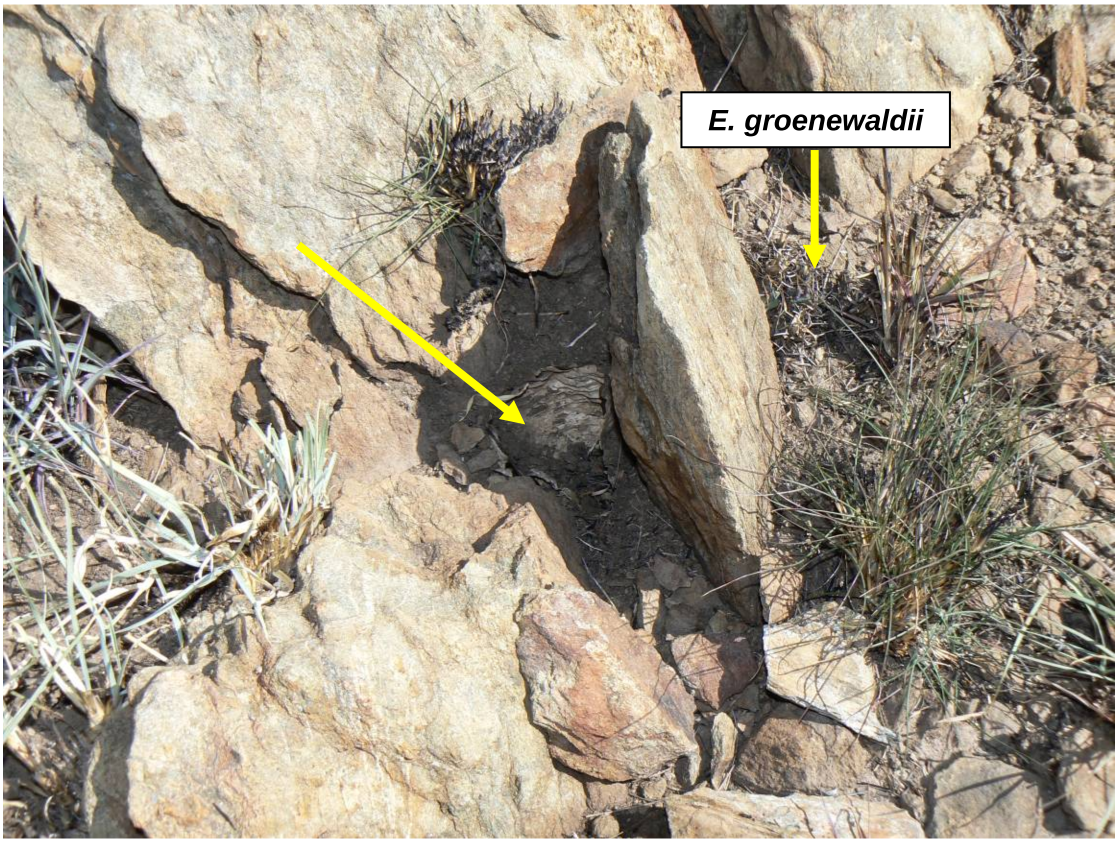

Figure 2.11: An *E. groenewaldii* plant dug out by a porcupine (arrow).

Figure 2.12: Trampling damage by cattle at Melkboomfontein.

Figure 2.13: De Put (Masele) population with littered quartzite.

Figure 2.14: Evidence of invertebrate herbivory at the population of Tweefontein-Geluk.

Figure 2.15: Quarry activity at Melkboomfontein within the populations' boundary.

Figure 2.16: The mined southern aspects at Corobrik brick factory at Tweefontein-Geluk.

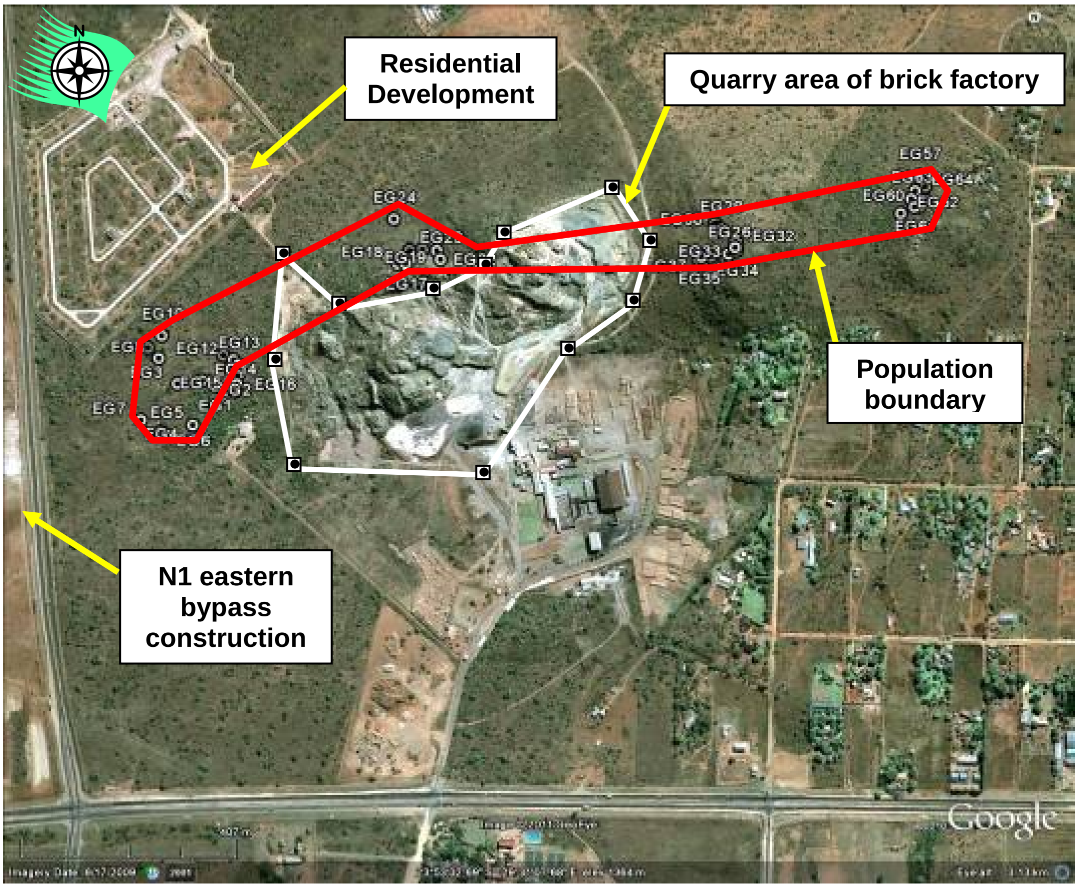

Figure 2.17: Major threats affecting the population of Tweefontein-Geluk (Google Earth, 2010).

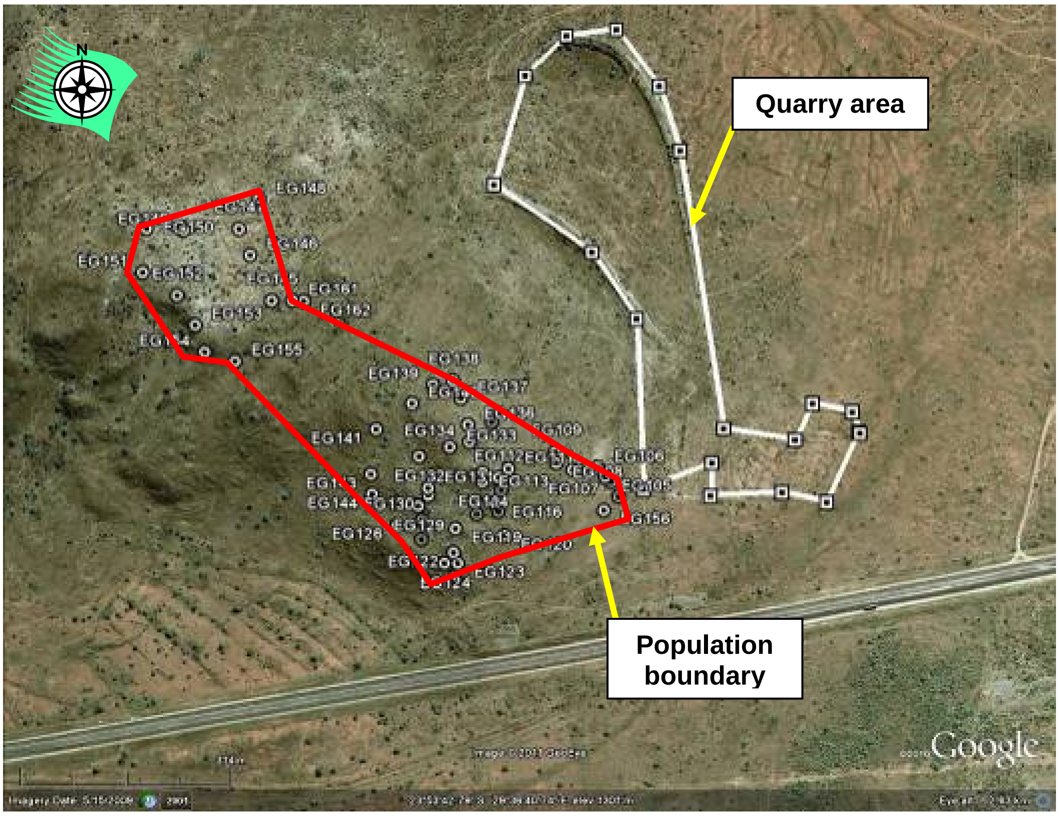

Figure 2.18: Major threats affecting the population of Kalkfontein (Google Earth, 2010).

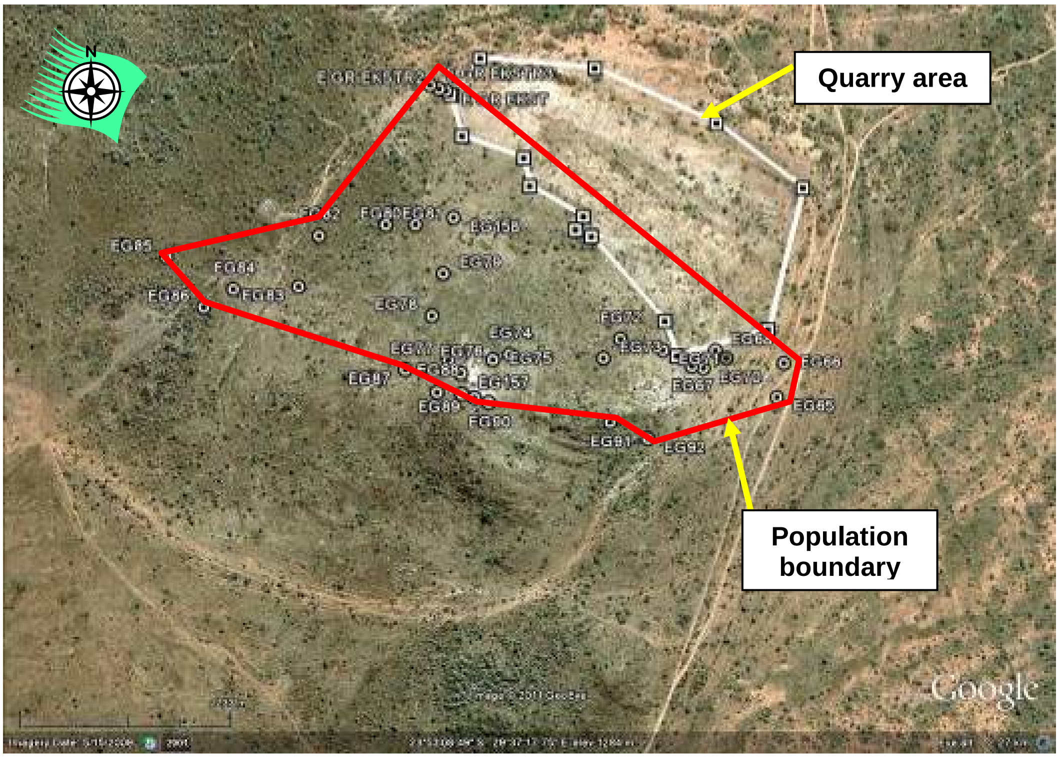

Figure 2.19: Major threats affecting the population of De Put (Google Earth, 2010).

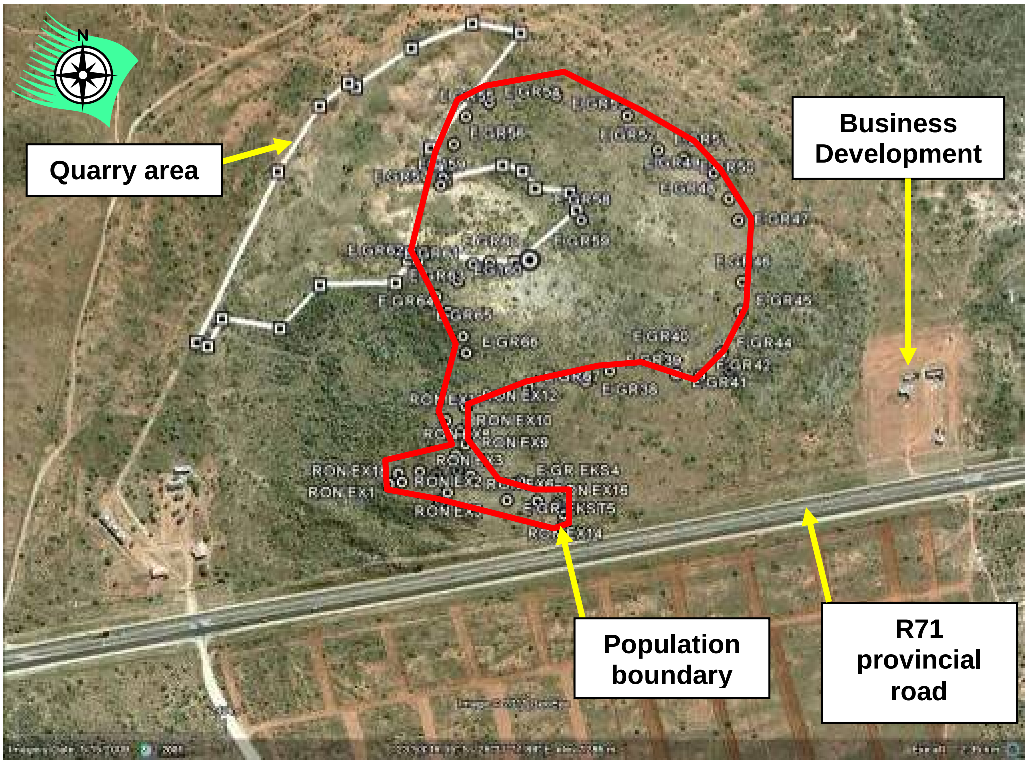

Figure 2.20: Major threats affecting the population of Majebeskraal (Google Earth, 2010).

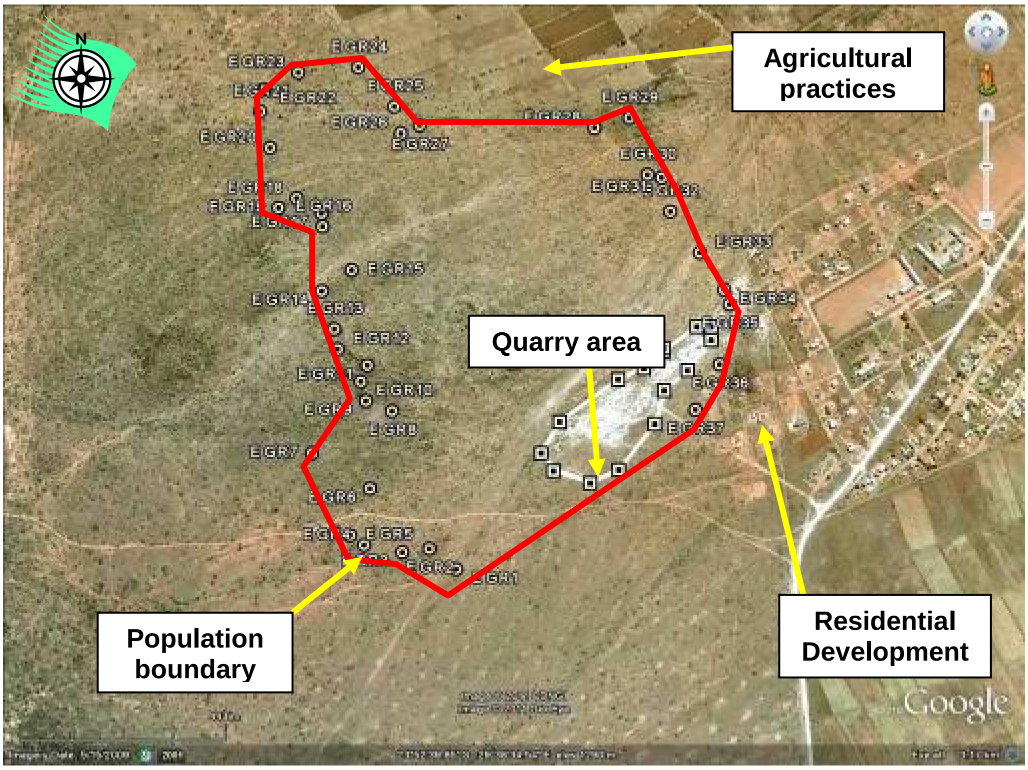

Figure 2.21: Major threats affecting the population of Melkboomfontein (Google Earth, 2010).

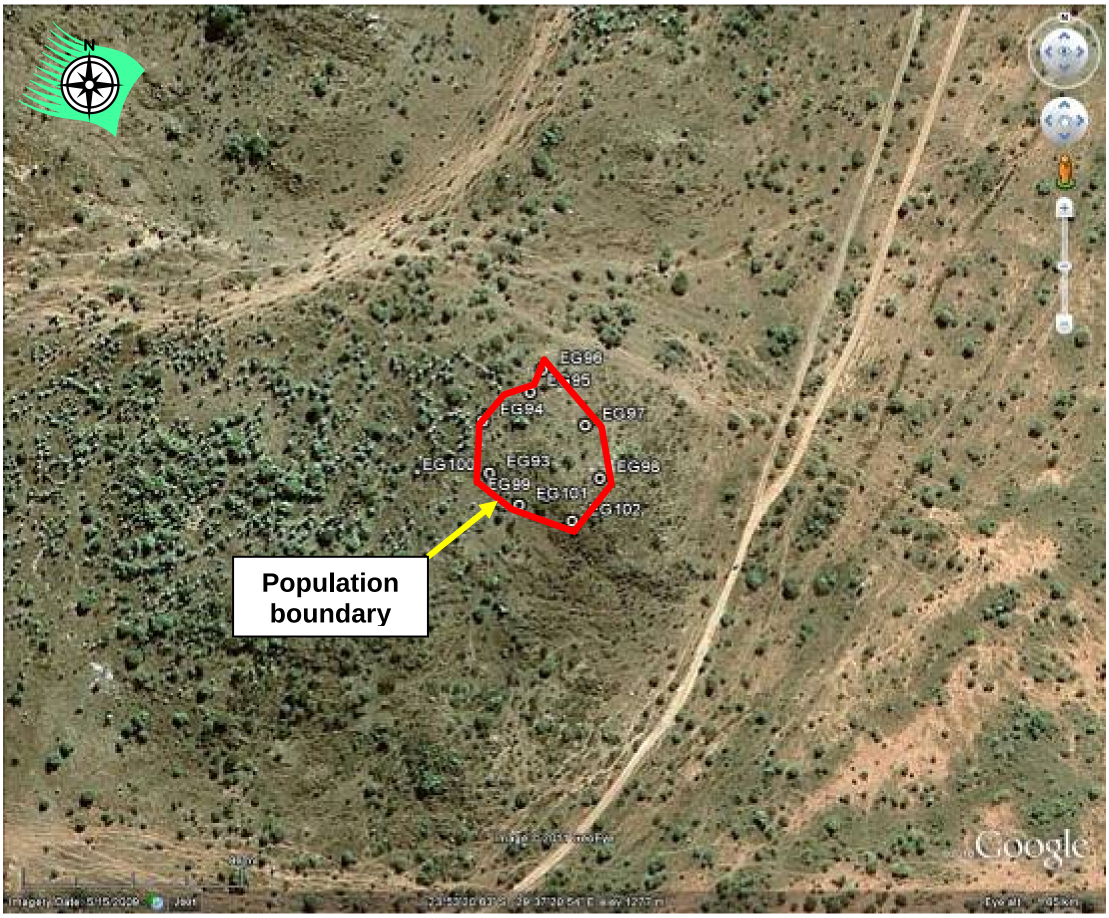

Figure 2.22: Major threats affecting the population of Spits population (Google Earth, 2010).

Table 2.1: Summary of data collected on grass cover per *E. groenewaldii* population.

Biotic Cover	% Cover	Melkboomfontein (n =709)	Majebeskraal (Ronsma) (n =223)	De Put (Masele) (n =157)	Spits (n=103)	Kalkfontein (n=273)	Tweefontein-Geluk (Delmada) (n=157)
Grass	None	7.1	0.0	3.2	0.0	1.5	0.6
	1-25	74.3	58.7	84.1	43.7	93.8	68.2
	26-50	16.2	35.0	12.7	56.3	4.8	30.6
	51-75	2.4	5.8	0.0	0.0	0.0	0.6
	76-100	0.0	0.4	0.0	0.0	0.0	0.0
Total		100	100	100	100	100	100
Source: Fieldwork, 2007							

Table 2.2: Summary of data collected on forbs cover per *E. groenewaldii* population.

		Melkboomfontein (n =709)	Majebeskraal (Ronsma) (n =223)	De Put (Masele) (n =157)	Spits (n=103)	Kalkfontein (n=273)	Tweefontein-Geluk (Delmada) (n=157)
Biotic Cover	**% Cover**						
Forbs	**None**	25.7	56.1	43.3	35.9	62.6	54.1
	1-25	65.3	41.3	56.1	64.1	37.4	45.9
	26-50	7.9	2.7	0.6	0.0	0.0	0.0
	51-75	1.1	0.0	0.0	0.0	0.0	0.0
	76-100	0.0	0.0	0.0	0.0	0.0	0.0
Total		100	100	100	100	100	100
Source: Fieldwork, 2007							

Table 2.3: Summary of data collected on dead vegetation cover per *E. groenewaldii* population.

		Melkboomfontein (n =709)	Majebeskraal (Ronsma) (n =223)	De Put (Masele) (n =157)	Spits (n=103)	Kalkfontein (n=273)	Tweefontein-Geluk (Delmada) (n=157)
Biotic Cover	**% Cover**						
Dead veg.	**None**	58.1	35.9	79.6	85.4	33.3	70.7
	1-25	41.2	62.8	20.4	14.6	66.7	29.3
	26-50	0.7	1.3	0.0	0.0	0.0	0.0
	51-75	0.0	0.0	0.0	0.0	0.0	0.0
	76-100	0.0	0.0	0.0	0.0	0.0	0.0
Total		100.0	100.0	100.0	100.0	100.0	100.0
Source: Fieldwork, 2007							

Table 2.4: Summary of data collected on stone cover per *E. groenewaldii* population.

Abiotic Cover	% Cover	Melkboomfontein (n =709)	Majebeskraal (Ronsma) (n =223)	De Put (Masele) (n =157)	Spits (n=103)	Kalkfontein (n=273)	Tweefontein-Geluk (Delmada) (n=157)
Stones	**None**	41.6	11.7	14.0	29.1	19.0	56.7
	1-25	46.3	31.8	31.8	34.0	45.4	36.9
	26-50	9.9	35.0	26.1	34.0	20.9	5.1
	51-75	2.0	19.7	22.9	2.9	12.5	1.3
	76-100	0.3	1.8	5.1	0.0	2.2	0.0
Total		100.0	100.0	100.0	100.0	100.0	100.0

Source: Fieldwork, 2007

Table 2.5: Summary of data collected on fixed rock cover per *E. groenewaldii* population.

		Melkboomfontein (n =709)	**Majebeskraal (Ronsma) (n =223)**	**De Put (Masele) (n =157)**	**Spits (n=103)**	**Kalkfontein (n=273)**	**Tweefontein-Geluk (Delmada) (n=157)**
Abiotic Cover	**% Cover**						
Fixed rock	**None**	71.9	61.9	66.2	28.2	42.5	17.2
	1-25	9.0	7.2	5.7	14.6	7.0	6.4
	26-50	9.4	11.7	8.3	28.2	13.9	41.4
	51-75	6.5	12.1	9.6	23.3	22.0	21.7
	76-100	3.1	7.2	10.2	5.8	14.7	13.4
Total		99.9	100.0	100.0	100.0	100.0	100.0
Source: Fieldwork, 2007							

Table 2.6: Summary of data collected on bare ground cover per *E. groenewaldii* population.

		Melkboomfontein (n =709)	Majebeskraal (Ronsma) (n =223)	De Put (Masele) (n =157)	Spits (n=103)	Kalkfontein (n=273)	Tweefontein-Geluk (Delmada) (n=157)
Abiotic Cover	**% Cover**						
Bare ground	**None**	3.2	32.7	8.3	17.5	31.1	23.6
	1-25	19.9	55.6	52.9	68.0	34.8	40.1
	26-50	31.0	9.0	25.5	14.6	20.9	26.1
	51-75	32.9	2.7	10.8	0.0	10.6	8.9
	76-100	13.0	0.0	2.5	0.0	2.6	1.3
Total		100.0	100.0	100.0	100.0	100.0	100.0
Source: Fieldwork, 2007							

Table 2.7: Summary of data collected on all the micro-habitat features cover (biotic and abiotic) for the population of *E. groenewaldii.*

E. groenewaldii		**% Micro-habitat features overall**					
Cover		**Biotic**			**Abiotic**		
	% Cover All Pop.	**Grass cover**	**Forb cover**	**Dead vegetation**	**Stones**	**Fixed rock**	**Bare ground**
	None	3.7	41.2	55.9	31.7	57.0	15.4
	1-25	73.9	54.4	43.6	41.1	8.2	35.5
	26-50	20.5	3.9	0.5	17.8	14.7	24.2
	51-75	1.9	0.5	0.0	8.2	12.7	18.4
	76-100	0.1	0.00	0.0	1.2	7.5	6.5
Source: Fieldwork, 2007							

Table 2.8: Summary of the percentage/counted plants of *E. groenewaldii* per aspect per population.

			Population						
			Melkboomfontein (n=709)	Majebeskraal (Ronsma) (n=223)	De Put (Masele) (n=157)	Spits (n=522)	Kalkfontein (n=273)	Tweefontein-Geluk (Delmada) (n=436)	All Population
Aspect	N	within Population	30.2%	3.6%	26.1%	23.0%	0.7%	22.7%	20.9%
	NE	within Population	18.5%	14.8%	35.7%	5.7%	1.1%	26.8%	15.9%
	E	within Population	4.5%	15.7%	7.6%	28.5%	3.5%	7.6%	17.5%
	SE	within Population	8.3%	53.4%	3.2%	3.8%	5.1%	2.3%	9.8%
	S	within Population	17.9%	4.0%	0.0%	16.5%	9.9%	0.0%	10.7%
	SW	within Population	13.0%	4.9%	0.0%	6.7%	17.2%	0.0%	8.0%
	W	within Population	0.4%	0.9%	0.0%	7.5%	9.9%	17.7%	6.4%
	NW	within Population	7.2%	2.7%	27.4%	8.2%	2.6%	22.9	10.8%
Total		% within Population	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 2.9: Summary of the percentage/counted plants of *E. groenewaldii* per slope degree per population.

			Population						All Populations
			Melkboomfontein (n=709)	Majebeskraal (Ronsma) (n=223)	De Put (Masele) (n=157)	Spits (n=522)	Kalkfontein (n=273)	Tweefontein-Geluk (Delmada) (n=436)	
Slope Deg.	< 5	Count within Population	69.8%	39.5%	11.5%	39.1%	21.2%	19.7%	40.9%
	5 - 10	Count within Population	23.7%	30.9%	31.2%	58.0%	21.2%	21.6%	32.0%
	10 - 20	Count within Population	5.6%	26.9%	50.3%	2.9%	42.9%	58.7%	24.5%
	20 30	Count within Population	0.9%	2.7%	7.0%	0.0%	14.7%	0.0%	2.7%
Total		Count within Population	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 2.10: Summary of the percentage/counted plants of *E. groenewaldii* per slope position per population.

			Population						Total
			Melkboomfontein (n=709)	Majebeskraal (Ronsma) (n=223)	De Put (Masele) (n=157)	Spits (n=522)	Kalkfontein (n=273)	Tweefontein-Geluk (Delmada) (n=436)	
Slope Pos.	Lower	within Population	65.6%	39.0%	27.4%	0.0%	4.8%	19.7%	29.9%
	Middle	within Population	27.1%	47.5%	51.6%	100%	71.8%	79.1%	62.2%
	Upper	within Population	7.3%	13.5%	21.0%	0.0%	23.4%	1.1%	7.9%
Total		within Population	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 2.11: Soil characteristics (mean ± standard deviation) of the sites from the six populations of *Euphorbia groenewaldii*.

Soil Characteristic	Populations					
	Spits	Majebeskraal (Ronsma)	Kalkfontein	Tweefontein-Geluk (Delmada)	Melkboomfontein	De Put (Masele)
pH (KCl)	5.35 ± 0.41	5.24 ± 1	5.282 ± 0.30	4.846 ± 0.30	5.568 ± 0.54	5.416 ± 0.79
Bulk density (g/ml)	1.246 ± 0.10	1.218 ± 0.09	1.082 ± 0.09	1.188 ± 0.03	1.322 ± 0.08	1.282 ± 0.11
Acidity (cmol/L)	0.074 ± 0.02	0.098 ± 0.03	0.056 ± 0.02	0.086 ± 0.05	0.06 ± 0.04	0.09 ± 0.03
Tot. Cations (cmol/L)	7.744 ± 1.51	8.376 ± 3.47	11.432 ± 3.66	7.98 ± 2.40	7.53 ± 1.37	7.402 ± 2.78
Acid saturation %	1 ± 0	1.6 ± 0.55	0.4 ± 0.55	1.2 ± 0.84	0.6 ± 0.55	1.4 ± 0.55
Organic Carbon %	1.01 ± 0.37	1.104 ± 0.41	1.994 ± 0.67	1.174 ± 0.13	0.97 ± 0.35	1.146 ± 0.47
Available P (mg/L)	4.8 ± 1.48	3 ± 2	8 ± 4.85	3 ± 1	48.2 ± 42.98	7.6 ± 2.97
Available K (mg/L)	115.4 ± 19.45	194.2 ± 89.60	177.4 ± 73.63	84.6 ± 13.52	242 ± 117.18	252.6 ± 183.28
Available Ca (mg/L)	738.4 ± 170.93	692.8 ± 288.31	820.2 ± 176.70	543.4 ± 172.71	861.2 ± 209.52	870.4 ± 461.05
Available Mg (mg/L)	448.2 ± 232.04	525.6 ± 445.36	830 ± 386.02	603.6 ± 232.53	310.6 ± 73.77	282.2 ± 86.70
Total Zn (mg/L)	0.8 ± 0.29	0.74 ± 0.43	1.66 ± 0.50	0.72 ± 0.38	2.4 ± 2	3.08 ± 4.56
Total Mn (mg/L)	11.8 ± 6.10	27.2 ± 30.03	20.8 ± 9.42	20.4 ± 5.86	12 ± 4.69	18.6 ± 6.77
Total Cu (mg/L)	2.98 ± 0.57	4.16 ± 3.45	3.14 ± 0.44	2.04 ± 0.41	3.56 ± 0.86	3.88 ± 1.23

Table 2.12: Soil characteristic of Nitrogen (mean ± standard deviation) and the particle size analysis (mean ± standard deviation) with the texture class of the sites from the six populations of *Euphorbia groenewaldii*.

Populations	Total % Nitrogen	Clay % (<0.002mm)	Fine Silt % (0.02-0.002 mm)	Coarse Silt & Sand% (0.02-2 mm)	Texture Class
Spits	0.116 ± 0.03	12.8 ± 4.15	7 ± 3.61	79.8 ± 6.83	Sandy Loam to Loamy Sand
Majebeskraal (Ronsma)	0.124 ± 0.04	15 ± 10.07	7.2 ± 3.27	77.8 ± 12.93	Sandy Loam to Loamy Sand to Sandy Clay Loam
Kalkfontein	0.184 ± 0.05	17.4 ± 4.34	12.6 ± 4.22	70.2 ± 7.5	Sandy Loam to Sandy Clay Loam
Tweefontein-Geluk (Delmada)	0.12 ± 0.01	15 ± 3.08	9.8 ± 1.1	74.6 ± 3.21	Sandy Loam
Melkboomfontein	0.11 ± 0.03	11 ± 1.87	5.6 ± 1.82	83.4 ± 3.21	Sandy Loam to Loamy Sand
De Put (Masele)	0.126 ± 0.04	12 ± 2	6 ± 2.24	82 ± 4.18	Sandy Loam to Loamy Sand

Table 2.13: A summary of mean canopy sizes between aspects of all *E. groenewaldii* populations.

Canopy Aspect	N	Mean	Std. Deviation	Minimum	Maximum
N	484	5671.8	6340.2	66.8	62180.1
NE	370	6426.1	7650.2	66.0	81367.4
E	407	5160.1	5213.5	44.0	49668.7
SE	227	5333.8	5144.7	78.5	36599.6
S	249	4882.1	4347.9	23.6	27143.4
SW	185	4928.4	4009.3	296.9	21794.9
W	148	6465.4	7014.8	176.7	39563.7
NW	250	8077.6	9107.8	84.8	62236.7
Total	2320	5835.1	6422.1	23.6	81367.4

Table 2.14: A Post Hoc Test, using the Tukey HSD method. The * indicates a significant difference in canopy size between aspects.

Post Hoc Test	(I) Aspect	(J) Aspect	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Tukey HSD	N	NW	*				
	NE	NW	*				
	E	NW	*				
	SE	NW	*				
	S	NW	*				
	SW	NW	*				
	NW	N	2405.78425*	495.46552	0.000	902.7053	3908.8632
		NE	1651.46398*	520.81451	0.033	71.4845	3231.4434
		E	2917.52125*	511.17967	0.000	1366.7707	4468.2718
		SE	2743.83939*	583.22261	0.000	974.5344	4513.1444
		S	3195.46242*	569.55896	0.000	1467.6084	4923.3164
		SW	3149.22390*	616.94557	0.000	1277.6145	5020.8333
		NW	1612.21733	659.77942	0.221	-389.3358	3613.7705

Table 2.15a: Summary of the percentage of *E. groenewaldii* plants of per stage class per population. This table represents the canopy-measured plants.

	Measured plants		Population						
			Melkboomfontein (n=709)	Majebeskraal (n=223)	De Put (n=157)	Spits (n=522)	Kalkfontein (n=273)	Tweefontein-Geluk (n=436)	All Pop.
stage Class	Adult	within Population	93.7%	94.6%	72.6%	90.0%	95.2%	91.3%	91.3%
	Juvenile	Count within Population	5.2%	4.5%	21.0%	7.7%	4.0%	7.6%	7.1%
	Seedling	within Population	1.0%	0.0%	6.4%	2.3%	0.7%	0.9%	1.5%
	Senescent	within Population	0.1%	0.9%	0.0%	0.0%	0.0%	0.2%	0.2%
Total		within Population	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 2.15b: Summary of the percentage of *E. groenewaldii* plants of per stage class per population. This table represents the total number of plants counted.

Total count			Populations						All Pop.
			Melkboomfontein (n=2303)	Majebeskraal (n=720)	De Put (n=393)	Spits (n=586)	Kalkfontein (n=833)	Tweefontein-Geluk (n=522)	
stage Class	Adult	% within Pop.	95.1%	98.2%	77.6%	92.7%	96.3%	92.5%	93.9%
	Juvenile	% within Pop.	3.7%	1.5%	18.6%	5.6%	3.1%	6.5%	4.9%
	Seedling	% within Pop.	0.7%	0.0%	3.8%	1.7%	0.2%	0.8%	0.9%
	Senescent	% within Pop.	0.5%	0.3%	0.0%	0.0%	0.4%	0.2%	0.3%
Total		% within Pop.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 2.16: Summary of all the canopy sizes (mm^2) between populations is given. The mean and standard deviation are indicated.

Canopy Populations	N	Mean	Std. Deviation	Minimum	Maximum
Melkboomfontein	709	5479.4	5701.5	103.7	81367.4
Majebeskraal (Ronsma)	223	5208.5	4342.0	132.0	33019.8
De Put (Masele)	157	3480.1	2891.2	66.0	15701.7
Spits	522	4912.8	4939.5	23.6	54051.2
Kalkfontein	273	4474.4	3409.2	197.9	24033.2
Tweefontein-Geluk	436	9538.2	9975.6	66.8	62180.1
(Delmada)	2320	5835.1	6422.1	23.6	81367.4
Total					

Table 2.17: A Post Hoc Test, using the Bonferroni method. The * indicates a significant difference in canopy area between populations.

Post Hoc Test	(I) Population	(J) Population	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Bonferroni	Melkboomfontein	Majebeskraal	270.86040	472.56900	1.000	-1117.6662	1659.3870
		(Ronsma)	199.27778*	542.89873	0.004	404.1047	3594.4508
		De Put (Masele)	566.61689	354.97967	1.000	-476.4027	1609.6365
		Spits	1004.99227	438.41371	0.330	-283.1775	2293.1620
		Kalkfontein	-	374.60123	0.000	-5159.4683	-2958.1230
		Tweefontein-	4058.79564*				
		Geluk (Delmada)					
	Majebeskraal	Melkboomfontein	-270.86040	472.56900	1.000	-1659.3870	1117.6662
	(Ronsma)	De Put (Masele)	1728.41738	641.24260	0.106	-155.7147	3612.5494
		Spits	295.75649	492.40593	1.000	-1151.0560	1742.5690
		Kalkfontein	734.13188	555.57143	1.000	-898.2768	2366.5404
		Tweefontein-	-	506.73378	0.000	-5818.5673	-2840.7447
		Geluk (Delmada)	4329.65604*				
	De Put (Masele)	Melkboomfontein	-	542.89873	0.004	-3594.4508	-404.1047

	Majebeskraal	1999.27778*	641.24260	0.106	-3612.5494	155.7147
	(Ronsma)	-	560.25099	0.159	-3078.8192	213.4975
	Spits	1728.41738	616.50400	1.000	-2805.7294	817.1583
	Kalkfontein	-	572.88454	0.000	-7741.3523	-4374.7945
	Tweefontein-	1432.66089				
	Geluk (Delmada)	-994.28551				
		-				
		6058.07342*				
Spits	Melkboomfontein	-566.61689	354.97967	1.000	-1609.6365	476.4027
	Majebeskraal	-295.75649	492.40593	1.000	-1742.5690	1151.0560
	(Ronsma)	1432.66089	560.25099	0.159	-213.4975	3078.8192
	De Put (Masele)	438.37539	459.72679	1.000	-912.4176	1789.1683
	Kalkfontein	-	399.33473	0.000	-5798.7584	-3452.0666
	Tweefontein-	4625.41253*				
	Geluk (Delmada)					
Kalkfontein	Melkboomfontein	-	438.41371	0.330	-2293.1620	283.1775
	Majebeskraal	1004.99227	555.57143	1.000	-2366.5405	898.2768
	(Ronsma)	-734.13188	616.50400	1.000	-817.1583	2805.7294
	De Put (Masele)	994.28551	459.72679	1.000	-1789.1683	912.4176
	Spits	-438.37539	475.04130	0.000	-6459.5788	-3667.9971
	Tweefontein-	-				

	Geluk (Delmada)	5063.78791*				
Tweefontein-	Melkboomfontein	4058.79564*	374.60123	0.000	2958.1230	5159.4683
Geluk (Delmada)	Majebeskraal	4329.65604*	506.73378	0.000	2840.7447	5818.5673
	(Ronsma)	6058.07342*	572.88454	0.000	4374.7945	7741.3523
	De Put (Masele)	4625.41253*	399.33473	0.000	3452.0666	5798.7584
	Spits	5063.78791*	475.04130	0.000	3667.9971	6459.5788
	Kalkfontein					

Table 2.18: The Median Test indicates the number of plants per populations falling above or below the middle canopy size of all populations combined.

		Population					
		Melkboomfontein	Majebeskraal (Ronsma)	De Put (Masele)	Spits	Kalkfontein	Tweefontein-Geluk (Delmada)
Canopy	> Median	356	115	49	239	120	281
	<= Median	353	108	108	283	153	155

Table 2.19: Summary of noticeable threats and damage for different populations of *E. groenewaldii* expressed as a percentage.

		Population						Total
		Melkboomfontein	Majebeskraal (Ronsma)	De Put (Masele)	Spits	Kalkfontein	Tweefontein-Geluk (Delmada)	
Type of Damage								
	None	36.4%	58.3%	40.1%	82.6%	20.9%	60.3%	51.8%
	Trampling	31.2%	7.6%	1.9%	5.9%	0.0%	0.7%	11.9%
	Herbivory	24.8%	28.3%	11.5%	11.5%	6.6%	3.2%	15.0%
	Ant hills	2.5%	1.3%	0.0%	0.0%	1.1%	0.5%	1.1%
	Fire	0.1%	0.0%	45.9%	0.0%	68.9%	25.9%	16.1%
	Senescent	4.9%	4.5%	0.6%	0.0%	2.6%	9.4%	4.1%
Total		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Source: Fieldwork, 2007								

CHAPTER 3
THE IUCN RED LIST CRITERIA, POPULATION SIZE AND CONSERVATION REASSESSMENT OF *EUPHORBIA GROENEWALDII*

1. INTRODUCTION

None of the *Euphorbia groenewaldii* populations are physically protected in any of the current locations. It is endemic to the Polokwane Plateau Bushveld; a veld type closely associated with the Mamabolo Mountain Bushveld type (Mucina & Rutherford, 2006). As the species is not formally protected, opportunities can arise for external factors (human activity and development) to influence it in a negative way, mostly because of its close proximity to human settlements. This may have caused a few smaller populations, for instance the Rietpol population, to dwindle to extinction.

The first real effort made to conserve *E. groenewaldii* was done by Raal (1986) in the 1980s through the Transvaal Provincial Administration. The conservation plan developed by Raal (1986) focused on all possible aspects relevant to *E. groenewaldii* at the time, which are the following:

- Nomenclature and classification
- Legal status for protection
- Description of field characteristics, diagnostic description, related species and taxonomic problems as well as a diagram representation
- Geographical distribution
- Habitat description
- List of associated plants
- Population biology
- Threats to survival
- Reproduction biology
- Possible pollinators
- Seed dispersal mechanisms
- Flowering and fruiting periods
- Vigour, trends, and status of known populations

- Recommended essential habitats
- Land ownership and status
- Management to promote the survival of the taxon
- Cultivation and seed storage
- Significance of taxon
- Monitoring of the species and
- Conservation urgency and strategy.

According to field data and dossiers found in Raal's (1986) conservation plan, the Division of Nature Conservation of the Transvaal Provincial Administration (TPA) monitored *E. groenewaldii* from 1986 to 1993. Since then it seems that few conservation efforts were conducted. A few environmentalists from the University of Limpopo alerted the authorities of the illegal activities (quarrying or human development) going on in and near to these few *E. groenewaldii* populations. Some of these illegal activities are due to ignorance or blatant carelessness.

The bulk of the *E. groenewaldii* populations occur within a 3 km^2 area, including an estimated million or more plants (Raal, 1986). The Tweefontein-Geluk population is separated from the other five populations by about 10 km. Currently there is a lot of speculation concerning whether the Tweefontein-Geluk population is *Euphorbia groenewaldii* or *E. tortirama*. The question of whether the Tweefontein-Geluk population's plants are *E. groenewaldii* or *E. tortirama* was also posed in the conservation plan of Raal (1986). A brief morphological investigation was done to determine if differences between the Tweefontein-Geluk population's plants and the other *E. groenewaldii* populations exists.

The type location (farm Rietpol 858-LS), presumably extinct, was 12 km to the northeast of the Melkboomfontein population (Raal, 1986). All this evidence suggests that very small populations of this species exist in pockets of the same environmental make-up (soil type, geology, micro climate, and micro habitat features) in the vicinity. Although a thorough search was done before the 1990s, Geographical Information Systems (GIS) has developed in the mean time and can now, with sufficient data, help identify suitable areas (habitats) for many plants species with a specific biotic and abiotic make-up (Given, 1994).

Not one of the six populations are free from extrinsic interferences, such as biological, ecological or human activities. Conservation of *E. groenewaldii* is therefore urgently needed. Some populations such as the Tweefontein-Geluk are on the brink of extinction. This alarm was raised by Raal in 1986. However, it is strange that the conservation status of *E. groenewaldii* was rated as endangered by the IUCN guidelines before 1986, then downgraded to vulnerable after the first conservation plan for *E. groenewaldii* was compiled by Raal (1986).

For a taxon to be moved between categories it must adhere to the following rules created by the IUCN Red List Guidelines (World Conservation Union, 2006):

"A. A taxon may be moved from a category of higher threat to a category of lower threat if none of the criteria of the higher category has been met for five years or more. However, if the taxon is being moved from Extinct in the Wild as a result of the establishment of a re-introduced population, this period must be 5 years or until viable offspring are produced, whichever is longer.

B. If the original classification is found to have been erroneous, the taxon may be transferred to the appropriate category or removed from the threatened categories altogether, without delay. However, in this case, the taxon should be re-evaluated against all the criteria to clarify its status.

C. Transfer from categories of lower to higher risk should be made without delay.

D. The reason for a transfer between categories must be documented as one of the following:

- Genuine change in the status of the taxon.
- Criteria revision (due to differences between the 1994 and 2001 versions of the criteria).
- New information about the status of the taxon.
- Errors in previous assessment.
- Taxonomic changes (taxon is newly split, lumped, or recognized)".

Many threats and pressures (see chapter 2) bear down on almost all the populations today. Considering this, a suitable *ex situ* habitat for *E. groenewaldii* must be found, should *in situ* conservation fail in the near future. The remaining plants can, mean while, be relocated to sites where there is very little disturbance, and where a breeding population can be established once again.

A comprehensive approach must be followed to acquire data of the targeted species' geographical distribution, habitat and abundance, before searching for new sites, in order to conserve its diversity. The biocenoses of a region are recorded using grid squares to list taxa in the process of acquiring data. This is only useful at a regional scale. Distribution patterns are rarely analyzed in the context of major environmental and landscape features (Vanderpoorten *et al.*, 2005). GIS is used to overcome this problem. It can integrate complex information from different datasets at different geographical scales (Draper *et al.*, 2003). GIS has been used to investigate certain impacts associated with ecological conditions and land-use types related to species diversity, as well as species rarity at regional scale (Vanderpoorten *et al.*, 2005). The relationship between all these features must be investigated and analyzed in order to meet the conservation objectives most advantageous to the species (Draper *et al.*, 2003).

Ecological factors should be considered to ensure the successful introduction of an endangered plant into its new environment. These ecological factors include the macro-climate, slope, soil, exposure, associated community, habitat size and degree of disturbance (Pfab, 1997). When selecting a site, it must be studied on a large scale, using topographical maps, soil- and geology maps, aerial photographs and field surveys (Pavlik *et al.*, 1993). When these studies are completed in laboratories and in the field, then suitable micro-sites can be selected (Pfab, 1997).

Geographic Information Systems (GIS) are seldom used to find additional sites for rare and endangered plants to be relocated to (Pfab, 1997). However, studies are starting to use GIS to determine additional sites for rare and endangered species (Powell *et al.*, 2005). Geographical Information Systems are more used when planning to minimize habitat destruction and maximize the effectiveness of mitigation efforts during a development planning and design phase (Wu & Smeins, 2000). According to Wu and Smeins (2000), remote sensing, GIS technologies, spatial analysis and modelling approaches enable local-system information to be scaled to landscape- and regional systems, based on field investigations. This is done to develop habitat models when planning conservation and development.

1.1 Objectives

The project aims to study *E. groenewaldii* ecology, conservation, management, and monitoring, and improve the *E. groenewaldii* conservation management plan through the following:

1. Establish the dynamics of the population; that is whether numbers are increasing or decreasing.
2. Briefly investigate possible morphological differences between the Tweefontein-Geluk population and the other *E. groenewaldii* populations.
3. Identify potential sites to relocate *E. groenewaldii* to if necessary and search for additional unknown populations.
4. Determine the true conservation status of *E. groenewaldii* on the threatened species Red Data List (2011) using all the information that is currently available.

2. MATERIALS AND METHODS

2.1 Population dynamics

The dynamics of the *E. groenewaldii* populations are compared over a period of about 24 years (1986-2010), to ascertain if any changes occurred in the number of plants per population. This was done using data from Raal's (1986) Conservation Plan for *E. groenewaldii*, and current field survey data of existing *E. groenewaldii* populations.

Differences in results obtained between the 1986 study (population dynamics) (Raal, 1986) and the current (2007) field investigations will be discussed. Only data collected during the 1980s by Raal (1986) will be compared with similar data collected in this study. These include slope aspects, stage structure of each *E. groenewaldii* population, estimated population size, and density (plants/Ha).

Monitoring *E. groenewaldii* by the Transvaal Provincial Administration (TPA) in the 1980s consisted of permanent monitoring plots placed within each of the, then seven, populations. Only one population didn't need plots; this was for the now presumably extinct Rietpol population that had covered an area of just 100 m^2 (Raal, 1986). Monitoring was done by the TPA during May and June of each year (1982 to 1986). The monitoring plot sizes were different for each population (Raal, 1986). The difference in plot size seem to be correlated with the area of occupancy for each *E. groenewaldii* population covered, but no explanation was given in Raal's (1986) conservation plan for *E. groenewaldii.* Local landmarks were used to delineate the exact location of the plots in order to be located the following year. In some instances rock piles were used to corner-off each plot (Raal, 1986).

All the plants had been counted from 1982 to 1986 and if there were new plants, they would be added to the previous year's recount (Raal, 1986). All the characteristics of the populations (density, age class numbers, area of occupancy and estimated populations size) were noted and the data calculated to ascertain if any changes occurred from previous years. Data collected included: the stage of a plant (adult, juvenile, or senescent), its reproductive status (if it was flowering or fruiting), whether it was damaged (by herbivory and trampling) and whether there were any threats and illegal collecting taking place. New growth, the number of branches, senescent branches and any other visible changes in *E. groenewaldii* plants were also noted.

2.2 Population census, sampling strategies and techniques

See chapter 2, section 3.2

The Tweefontein-Geluk population is fragmented, by human activities, forming sub-populations. These sub-populations were surveyed using sampling techniques (PCQ and NIST) that best suited each sub-population. At the largest sub-population (most western part of population), nine transects of 200 m x 10 m were used to cover this population. The PCQ sampling technique was used to determine the density of the population per square metre; then multiplied with the calculated AOO to obtain the estimated population size. The other sub-populations were sampled using the NIST to determine the density of the population per square metre and then multiplied with the calculated AOO to obtain the estimated population size. All the sub-population size estimates were added together.

Comparing population size estimate data between Raal's (1986) work and the current study (2007) is very difficult. The difference in sampling techniques used and area sampled for each population of *E. groenewaldii* will be compared.

Raal (1986) used Poisson distribution to estimate the population size of *E. groenewaldii*. Poisson distribution can be explained as follows (Ahrens *et al.*, 1974):
In probability theory and statistics, the Poisson distribution (or Poisson law of small numbers) is a discrete probability distribution that expresses the probability of a given number of events occurring in a fixed interval of time and/or space if these events occur with a known average rate and independently of the time since the last event. The Poisson distribution can also be used for the number of events in other specified intervals such as distance, area or volume.

3. RESULTS

3.1 Differences in population dynamic methods compared

3.1.1 1986 (Raal, 1986) vs. 2007 (Current study)

In 1986 when the last data sampling was done by the TPA from the Division of Nature conservation, the following methods were used to monitor *E. groenewaldii* populations: locality, number of individuals per population and stage-class structure (Raal, 1986). The stage-classes were structured by calculating the percentage of adults, juveniles and senescent plants out of the total number of plants counted on each plot or transect (Table 3.2). The total estimated population size was then broken up according to the percentage of each stage-class (Table 2.15b). The differences in area covered and results of the estimated population size are compared below.

1. Rietpol (1986): This population was discovered last and monitored in April 1980, but after 1980 the population could not be found again. At the time of this original survey (Raal, 1986), the population covered 100 m^2 (Table 3.1). All the plants had been counted (50 individual plants) and no population estimates were needed.

Rietpol (2007): in the current during 2007 no population could be found after rigorous searching, and therefore the population was considered extinct (Table 3.1).

2. Melkboomfontein (1986): The Area of Occupancy (AOO) estimated was 800 m x 1000 m and twenty (15 m x 15 m) plots were laid out (Raal, 1986). Data from these plots were extrapolated to obtain the population size. Raal (1986) reiterated that this method served only as a guideline and may, to some degree, be statistically inaccurate. The estimated total *E. groenewaldii* plants were between 404 622 and 1 014 755.

   Melkboomfontein (2007): The AOO calculated for the population was determined using a handheld GPS. The GPS data (of the population boundary) was superimposed onto a Google Earth image (Google Earth, 2010) (see chapter 2, Fig. 2.21) amounting to an AOO of 700 000 m^2. Sixteen transects of 1000 m long and 10 m wide were walked across the entire population covering 23% of the population (Table 3.1). The Point-Centred Quarter (PCQ) sampling technique was used (see chapter 2, section 3.2) to determine the density of the population per square metre and then multiplied with the calculated AOO to obtain estimated population size. The estimated population size of *E. groenewaldii* plants was 20 146. The difference between Raal's (1986) result, taking the minimum number of plants' calculated value, and the result of this study was 384 476 plants.

3. Majebeskraal (1986): According to Raal (1986) the Spits (now Ronsma) population covered an area of approximately 40 m x 50 m (Table 3.1). A plot of 20 m x 20 m was placed in the densest area of the population. Only 96 plants were counted and data were then extrapolated using Poisson distribution to estimate the population size Raal, (1986). The estimated total of *E. groenewaldii* plants were 480.

   Majebeskraal (2007): The area of occupancy calculated for this population was very different from Raal's (1986) 400 m^2. The GPS data (of the population boundary) was superimposed onto a Google Earth image (Google Earth, 2010) (see chapter 2, Fig. 2.20) amounting to an AOO of 100 000 m^2. Eleven transects, 300 m long and 10 m wide, were laid out covering 33% of the population (Table 3.1). The PCQ sample technique was used see chapter 2, section 3.2) to determine the density of the population per square metre and then multiplied with the calculated area of occupancy to obtain the estimated population size. The estimated population size of *E. groenewaldii* plants was 1 219. The difference between Raal's (1986) population size estimation (480) and the current result population size estimation is 739 plants. Raals' (1986) value is less than half the number of plants found in 2007 (Table 3.2).

4. De Put (1986): This population was not covered to its full extent in 1986 as only 2500 m^2 (Raal, 1986) of the 73 278 m^2 available were surveyed (Table 3.1). Only 81 plants were counted in a 20 m x 10 m plot (Raal, 1986). This was then extrapolated, using Poisson distribution, to obtain an indication of the number of plants in the area amounting to an estimated total of 1 012 plants.

   De Put (2007): During the recent survey the population AOO was greater (73 278 m^2) than originally calculated by Raal (1986). The area was covered by seven transects, 500 m long and 10 m wide, covering 48% of the population (Table 3.1). The PCQ sampling technique was used to determine the density of the population per square metre and then multiplied with the calculated area of occupancy to obtain the estimated population size. The estimated population size of *E. groenewaldii* plants was 2 282. The difference between the number of estimated (385) plants' originally calculated by Raal (1986), and the new result was 1 270 plants. Raals' (1986) value is less than half the number of plants found in 2007 (Table 3.2).

5. Spits (1986): The following are possible explanations for the lack of data for this population. The Spits population may never have been located. It may have been included in the De Put population calculations, or may even be the De Put population.

   Spits (2007): The Spits population covers a smaller area than the other populations (1 630 m^2), therefore the Nearest Individual Sampling Technique

(NIST) (see chapter 2, section 3.2) was followed to determine the density of the population and estimated population size. Every plant found was recorded covering approximately 90% of the population (Table 3.1). The population of Spits was considered a distinct sub-population of the De Put population in the current population dynamics of this study.

6. Kalkfontein (1986): The AOO measured for Kalkfontein was 500 m x 150 m (Table 3.1). Only one plot of 200 m^2 was placed in this large population (Raal, 1986). Just 22 plants were counted and extrapolated, using Poisson distribution, to determine the estimated population size. The estimated total plants in the population were 8 250.

   Kalkfontein (2007): This population has the second largest AOO (103 419 m^2) in the extent of occurrence (EOO) of *E. groenewaldii*. Fifteen transects, 300 m long and 10 m wide, covering 44% of the population (Table 3.1) was layout. The PCQ Sample Technique was used to determine the density of the population per square metre and then multiplied with the calculated area of occupancy to obtain the estimated population size. The estimated population size was 824 (Table 3.3).

7. Tweefontein-Geluk (1986): This population was divided into sub-populations that covered an area of 2 325 m^2 (Raal, 1986). The Poisson distribution was used for each sub-population to predict an estimated sub-population size. After all sub-population numbers were estimated these were added together to provide a total estimated plants for the whole population. The total estimated number of plants was 15 084 (Table 3.2).

   Tweefontein-Geluk (2007): The AOO calculated for this population was much larger than Raal's (1986) AOO. The GPS data (of the population boundary) was superimposed onto a Google Earth image (Google Earth, 2010) (see chapter 2, Fig. 2.17) amounting to an AOO of 33 137 m^2.

   The estimated population size of *E. groenewaldii* plants was 1 116 (Table 3.3). Although the AOO calculated in 2007 is 26 times smaller than what was calculated in 1986, there are approximately 14 times less plants (1 116) estimated in this population in 2007. This reduction in plants over time may be caused by the impact of the Brick factory and mining activities in this population's boundaries. It could also be because, there are large differences (Table 3.1) in the calculations of 1986 and 2007, for instance the AOO calculated (Table 3.1) for each population of *E. Groenewaldii*, sampling techniques used to determine population densities, and the technology (GPS, computers and internet) available to determine a populations AOO. Raal's (1986) methods could have caused his calculations to be statistically incorrect.

3.2 Population sizes

The reason for differences in population sizes and areas of the two studies may be due to a larger percentage (46%) of the *E. groenewaldii* population have been surveyed in 2007 than in 1986 (15%) in 1986 (Table 3.1).

Additional discrepancies in Raal's (1986) method are that most populations had one plot, compared to multiple transects in 2007, in the densest part of the population and that not as much of the population was surveyed as in 2007. Seedlings and senescent plants could have been missed in the earlier study. Therefore Raal (1986) did not count any seedlings or dead plants at any of the populations, except at Tweefontein-Geluk (Table 3.2). More comprehensive sampling techniques could have been followed by Raal (1986) during his annual monitoring of the *E. groenewaldii* populations. For example, the two sampling techniques described in chapter 2, section 3.2, plotless sampling recommended as a quick method to estimate densities and canopy area of plants (Hill *et al.*, 2006). The temporary plots method provides an overview of community structure and species distribution or abundance (Hill *et al.*, 2006). However, for monitoring purposes many plots are needed per population. When compared to permanent plots (as used by Raal, 1986), less data can be compared between survey dates, because progress of individual plants cannot be tracked (Hill *et al.*, 2006).

The following three stage-structures were described for *E. groenewaldii* by Raal (1986):

1.) Sexually mature plant: Plants showing true flower formation or definite positive signs of flower formation. These plants are characterized by having a massive subterranean, tuberous root system and three to seven short, spirally-twisted branches.
2.) Juvenile plants: Plants showing either primary or secondary growth characteristics, but showing absolutely no flower formation or signs of flower formation. These plants are characterized by having an under-developed subterranean, tuberous root system and one to three under-developed to well develop branches.
3.) Senescent plants: Plant that have died either naturally or unnaturally.

Raal (1986) only found senescent plants (93) at the population of Tweefontein-Geluk (Table 3.2). The area monitored by Raal (1986) covered 6% (Table 3.1) of the Tweefontein-Geluk population. This was the highest covered population of *E. groenewaldii*, apart from the total count of the population of Rietpol. Adult plants were the highest represented (Table 3.2) stage-structure in all the *E. groenewaldii* populations during 1986.

In the current study (2007) senescent plants were noted in most of the *E. groenewaldii* populations, with the most senescent plant found in the Melkboomfontein population (Table 3.2). Adult plants were the highest represented (Table 3.2) stage-structure in all the *E. groenewaldii* populations during the current study (2007).

No further monitoring of the investigated populations took place since 1986; this makes monitoring and comparing across years in terms of population dynamics very difficult.

Table 3.1: Comparison in area covered during the field survey between 1986 (Raal, 1986) and 2007 (this study).

		1986			**2007**		
		Area sampled			**Area sampled**		
Populations	**Area of Occupancy (m^2)**	**m^2**	**%**		**m^2**	**%**	
Rietpol	100	100		100	No Data		No Data
Melkboomfontein	700 000	4 500		0.6	160 000		23
Majebeskraal	100 000	400		0.4	33 000		33
De Put	73 278	200		0.3	35 000		48
Spits	1 630	No Data*		No Data*	1 467		90
Kalkfontein	103 419	200		0.2	45 000		44
Tweefontein-Geluk	38 089	2 325		6	33 137		87
Total	1 016 516	156 543	**Mean**	15.4	471 663	**Mean**	46.4

* Raal (1986) had no data to compare with.

Table 3.2: Estimated numbers of adults, seedlings and senescent plants for 1986 (Raal, 1986) and 2007 (based on densities for each population (chapter 2)).

	1986				**2007**			
Populations	**Adult (av.)**	**Juv. (av.)**	**Senesc. (av.)**	**Total (av.)**	**Adult**	**Juv.**	**Senesce**	**Total**
Rietpol	45	5	0	50	No Data	No Data	No Data	No Data
Melkboomfontein	694 916	14 742	0	709 689	19 159	886	101	20 146
Majebeskraal	470	10	0	480	1 197	18	4	1 219
De Put	987	25	0	1 012	1 771	511	0	2 282
Spits	No Data*	No Data*	No Data*	No Data*	800	62	0	862
Kalkfontein	7 876	375	0	8 250	785	39	3	824
Tweefontein-Geluk	14 099	892	93	15 084	1019	95	2	1 116
Total	732 491	16 941	93	749 618	24 731	1 611	110	26 450

* Raal (1986) had no data to compare with.

3.3 Population density

The population densities were calculated using the nearest individual equation and multiplied by the estimated area of occupancy of each population (Table 3.3). The largest population (in this study) of an estimated 20 146 plants was in the Melkboomfontein population that also has the largest area of occupancy, estimated at 700 000 m^2 (Table 3.3). The *E. groenewaldii* population of Spits has the highest density of 0.53 plants/m^2 (Fig. 3.1) in a very small area of occupancy of approximately 1630 m^2 of all the populations (Table 3.3). The *E. groenewaldii* population at Spits was the only population where the NIST was used covering about 90% of the population. This resulted in a more accurate estimate of the population density (Fig. 3.1). Kalkfontein has the lowest density of all the investigated populations, with 0.01 plants/m^2. Despite having the second largest area of occupancy (an estimated 103 419 m^2), it has the smallest estimated number of plants (estimated at 824 plants) (Table 3.3).

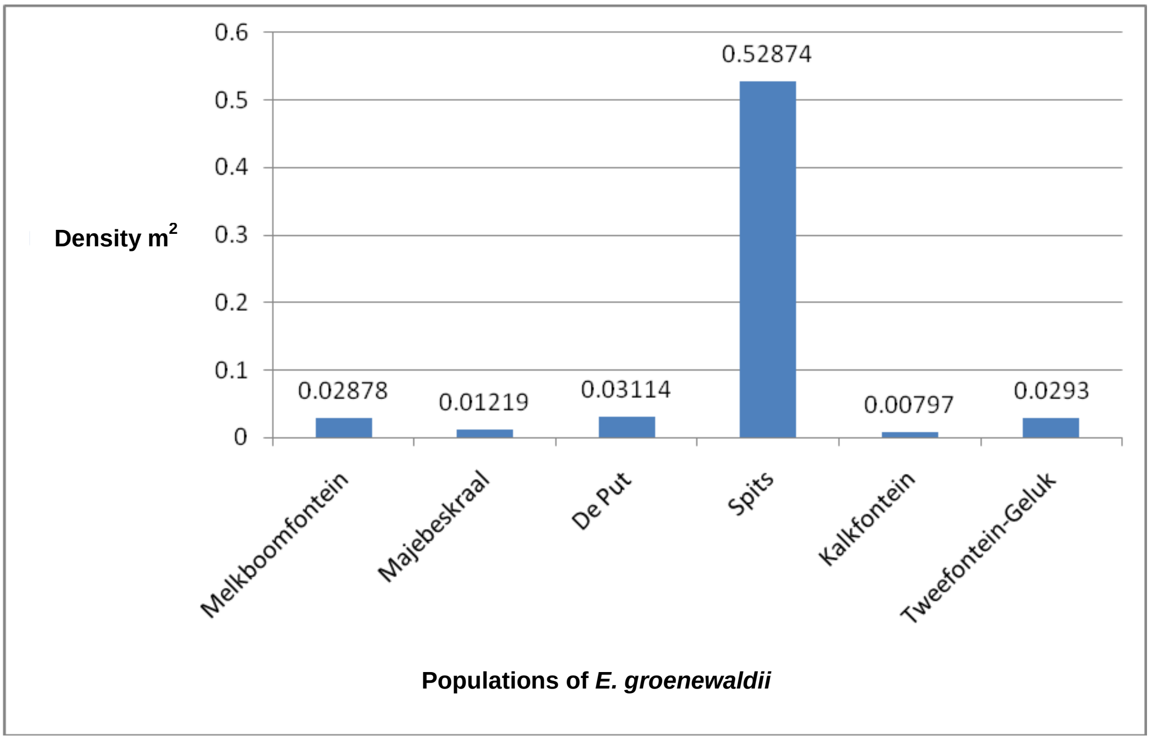

Figure 3.1: The total density (plants per m^2) of each population within their area of occupancy.

Table 3.3: Plant density (plants per m^2) calculated using the areas covered during data sampling.

Populations	Tot. Density (m^2)	Est. Pop. Size	Est. Area of Occupancy per Population (m^2)
Melkboomfontein	0.02878	20 146	700 000
Majebeskraal	0.01219	1 219	100 000
De Put	0.03114	2 282	73 278
Spits	0.52874	862	1 630
Kalkfontein	0.00797	824	103 419
Tweefontein-Geluk	0.02930	1 116	38 089

* The number of individuals measured was inserted into an equation to obtain the estimated population size.

4. DISCUSSION

4.1 Population size

All six populations in this study were much smaller in estimated population size (Table 3.2) than predicted by Raal's (1986) Conservation Plan. This could be because only a very small area (Table 3.1) of each population were being surveyed in 1986. Alternatively calculations used by Raal (1986), in order to estimate the population size for all the populations may have been flawed. This could be due to the small percentage of area covered by Raal (1986) (Table 3.1) for each population of *E. groenewaldii*.

The population size of *E. groenewaldii* estimated during this study was approximately 26 450 plants (Table 3.2). This is in stark contrast to the estimated population size of 749 618 plants (Table 3.2) calculated by Raal (1986). It is difficult to draw comparisons between these estimates being very different in sampling methods used (Poisson distribution), calculations made and technology (GPS, internet and computer programs) used. Assuming that Raal's (1986) calculations are correct and compared to this study's calculations then the total species population has declined dramatically.

In the populations of Melkboomfontein, Kalkfontein, and Tweefontein-Geluk the differences in stage structure numbers and total estimated population size, between the studies (Raal, 1986) of 1986 and 2007, are large (Table 3.2).This means there was either a big decline in estimated plant numbers over 24 years in spite of inaccurate information used by Raal (1986) due to the level of population ecology 24 years ago. Assuming calculations from Raal's (1986) study is accurate, after the standards of his day, compared to this study's calculations then the possible cause of the decline in population could be due to human activities (quarrying). This would eliminate large sections of these populations in a very short period of time (1 year).

In the populations of Majebeskraal and De Put, the differences in stage structure numbers (larger in this study) and total estimated population size (larger in this study) are noticeably different (Table 3.2). A possible reason might be because a more comprehensive survey was conducted or different sampling techniques were used.

In all the populations the adult stage structure dominated (93.9%, Table 2.15b) with an estimated 24 731 plants (Table 3.2). The possible reasons for this could be due to a lack of a fire regime (see chapter 2, section 5.3) (Pfab & Witkowski, 1999a) to stimulate new growth or an impact on populations' reproductive performance like herbivory (see chapter 2, section 5.4.3) (Pfab & Witkowski, 1999b) eating branches, inflorescences or fruit, preventing plants to reproduce. It could also be due to the lack of pollinators, because of habitat fragmentation (splitting up populations) (Andrieu *et al.*, 2009) by human activities (quarrying and development), which could lead to pollination failure (see chapter 2, section 5.4.4).

In Raal's (1986) conservation plan he noted that *E. groenewaldii* plants preferred the northern, eastern and western aspect. This was also proven in this study where very similar aspects (northern, south-eastern and western) were found to be the densest populated (see chapter 2, Fig. 2.5).

4.2 What legislation protects *E. groenewaldii*?

4.2.1 Past

During the 1980s a number of steps were taken to promote the survival of *E. groenewaldii*. Firstly, the taxon had been declared a protected plant under the Nature Conservation Ordinance of the Transvaal (Nature Conservation Ordinance Number 12 of 1983). Secondly, the taxon was listed under Schedule II of the Conservation for International Trade of Rare and Endangered Species of Fauna and Flora in 1985 (UNEP-WCMC, 2009), and finally, some plants were cultivated at the Flora Subsection at Lydenburg (Raal, 1986).

4.2.2 Present

The National Environmental Management Act (NEMA) of 1998 created Act 107 to give ordinance and power to environmental officers to enforce an environmental impact assessment on any activity impacting negatively on the immediate natural surroundings. This could only be enforced if local and governmental agencies are willing to undertake the endeavour. The following are a general set of objectives for an integrated environmental management activity according to the Republic of South Africa's Government Gazette (1998):

"The general objective of integrated environmental management is to-

(a) Promote the integration of the principles of environmental management set out in section 2 into the making of all decisions which may have a significant effect on the environment.
(b) Identify, predict and evaluate the actual and potential impact on the environment, socio-economic conditions and cultural heritage, the risks and consequences and alternatives and options for mitigation of activities, with a view to minimizing negative impacts, maximizing benefits, and promoting compliance with the principles of environmental management.
(c) Ensure that the effects of activities on the environment receive adequate consideration before actions are taken in connection with them;
(d) Ensure adequate and appropriate opportunity for public participation in decisions that may affect the environment.
(e) Ensure the consideration of environmental attributes in management and decision-making which may have a significant effect on the environment.
(f) Identify and employ the modes of environmental management best suited to ensuring that a particular activity is pursued in accordance with the principles of environmental management."

Following this, administrators must be proactive and more aware of what is happening in and around their provinces. In the Limpopo Province an environmental legislation framework was drawn up, under the Limpopo Environmental Management Act (LEMA), to protect the environment locally and to cover issues such as land reform and planning, natural and cultural resource use, conservation, biodiversity, genetically modified organisms, environmental assessment, pollution and waste management (Rampedi, 2006).

The objectives of LEMA are (Rampedi, 2006):

"The objectives of the Limpopo Environmental Management Act are to: manage and protect the environment in the Province, to secure ecologically sustainable development and responsible use of natural resources in the Province, to contribute to the progressive realization of the fundamental rights contained in Section 24 of the Constitution of the Republic of South Africa, 1996 (Act No. 108 of 1996), and to give effect to international agreements affecting environmental management which are binding on the Province."

According to Rampedi (2006), LEMA provides enforcement measures upon suspicion and illegal activities. Section 96 of the Environmental Management Act assigns these powers to Environmental Compliance Officers. If the officer has reasonable suspicion a provision of the Act has been breached, the officer will: Enter any land, premises, building tent, camping place, vessel or container; direct the person in charge of a vessel to stop, or use such force as may be reasonable to stop the vessel, seize anything, question a person, demand from any person who performs an act, or suspected of performing acts that require permits, written permission, exemption to produce such a document, and seize stock or other animal trespassing in a protected or reserved areas (Rampedi, 2006).

According to Leroy (pers. comm.), nothing is currently being done to protect *E. groenewaldii*, even though the Department of Environmental Affairs and Tourism know exactly where this plant occurs and what its conservation status is. *Euphorbia groenewaldii* is currently protected only by LEMA, under Act 7 of 2003. The Act states that no person, whether the plant is protected or not, may without a permit (Act No. 7 of 2003):

a) "Pick, be in possession of, sell, purchase, donate, receive as a gift, import into, export or remove from the Province, or convey a specially protected plant; or
c) Pick any indigenous plant –
   i. On a public road;
   ii. On land next to a public road with a distance of a 100 metres measured from the centre of the road;
   iii. Within an area bordering any natural water course, whether wet or dry, up to and within a distance of 50 metres from the high water mark on either side of the natural water course; or

iv. In a Provincial Nature Reserve, a Site of Ecological Importance, a Protected Environment or a Private Nature Reserve; or

d) Collect firewood."

Although the Act makes provision for the protection of *E. groenewaldii,* also listed within this Act under Schedule 12 Protected Plants, there is still collector pressure on the taxon. This is one of the threats to the future existence of this species and other *Euphorbias* of the region, and it goes strongly against the Act. It is thus recommended that the status for *E. groenewaldii* should be changed or revised to a higher conservation level in the Province, and that is should be completely protected from any disturbance in order to fully enforce the LEMA legislation on illegal activities on and around this species.

According to Mark Leroy (pers. comm.), the LEMA may disappear in a few years' time and be incorporated into NEMA. This will negatively impact plants in the Limpopo Province with a status of vulnerable to endangered, because NEMA only concentrates on bigger endangered vegetation types and critically endangered plants. It is recommended that Limpopo Province's environmental affair department set their own task force to monitor and report on rare and endangered plant species, like *E. groenewaldii*, in the province's boundaries.

4.3 Is it *Euphorbia groenewaldii* or *Euphorbia tortirama*?

Since the preliminary investigations there has been doubt about the Tweefontein-Geluk (Delmada) population species identification. The morphological differences from other populations question the clarification as *E. groenewaldii*.

Euphorbia groenewaldii is closely related to *E. tortirama*. This is due to the presence of well elevated tubercular projections on spirally-twisted branches, which are positioned in many angles, as well as the rather noticeable short stem near its apex. *Euphorbia tortirama* appears at first glance to be a more robust species than *E. groenewaldii* (White *et al.*, 1941).

The two species can be distinguished from one another by branches that are more tubercled on *Euphorbia groenewaldii* and irregularly tuberculated in *E. tortirama*.

Euphorbia groenewaldii does not have any spine shields that are united along a continuous margin along the angles, but are always separate. Whereas in *E. tortirama* the spine shield unite into a continuous horny margin. Another difference is that the central cyathium of the cyme, which develops first in the spine-paired species, is exclusively a male flower in *E. tortirama*, but in the case of *E. groenewaldii* it develops an ovary and the cyathium tends to be bisexual (White *et al.*, 1941).

Individuals from the most westerly *E. groenewaldii* population (Tweefontein-Geluk) are very robust and resemble *E. tortirama*. Raal (1986) suggested that the robust morph of *E. groenewaldii* individuals from this population are actually *E. tortirama* or *E. groenewaldii* x *E. tortirama* hybrids. If there is the possibility that hybridization can occur between *E. groenewaldii* and *E. tortirama*, it must still be tested and scientifically proven. Raal (1986) surmised that *E. groenewaldii* does not hybridize with any other *Euphorbia* species.

After the analysis of the Rietpol, Melkboomfontein, Majebeskraal, De Put, and Kalkfontein populations, Raal (1986, p.20) stated:

"The above described populations are comprised of what are believed to be the true *E. groenewaldii* plants. Specimens of these plants fit the original, formal description of the species as published in Flowering Plants of Africa Volume 30 (1938) (plate 714) and are believed to be the true species."

He also offers reasons why the Tweefontein-Geluk population differs from the rest of the *E. groenewaldii* populations. According to Raal (1986), this population consists of plants identified by Dyer as *E. groenewaldii* but which, on closer inspection, resemble specimens of *E. tortirama*. The plants in the population are more robust, have markedly contracted main stems and have branches that are more twisted than plants of other populations.

Raal (1986) also stated that the Tweefontein-Geluk population will be included in the Conservation Plan until differences can be clarified with better chemotaxonomy and other taxonomic methods. It is also the recommendation of this study that advanced genetic tests should be done to clarify the true identity of *Euphorbia* species of the this population.

4.3.1 A comparison between *Euphorbia groenewaldii* and *Euphorbia tortirama*

Differences in morphology noticed during field data collection in 2007 and was compared with plants from the Tweefontein-Geluk population and descriptions from White *et al.* (1941):

- *Euphorbia groenewaldii*:

1. Tuberous body up to 22 cm long and 10 cm thick.
2. Stem distinguished from the root by horizontal impressions known as branch scars.
3. Branches 3 cm to 12 cm long.
4. Spine shield separate above base or extent to the flowering eye (Fig. 3.4).
5. Flowers peduncles are 6 mm to 15 mm long and stout (Fig. 3.2).
6. Bracts are colourless and inconspicuous (Fig. 3.2).

- *Euphorbia tortirama*:

1. Tuberous body up to 30 cm long and 15 cm thick.
2. Stem distinguished from the root by a slightly warty appearance.
3. Branches 6 cm to over 25 cm long in rock crevices, but mostly contracted.
4. Spine shield unite into a continuous horny margin and extend around the base of the flowering eye, but do not encircle it (Fig. 3.5).
5. Flower peduncles are 4 mm to 8 mm long and stout (Fig. 3.3).
6. Bracts oblong, ciliate, hooded and enclosing the young cyathia. Bracts pinkish to red in colour and conspicuous (Fig. 3.3).

The observations made during this study, as well as the data of White *et al.* (1941), show that there are morphological differences between plants from Tweefontein-Geluk and the other populations. These differences may also be the result of environmental conditions, soil make-up and anthropogenic stresses (White *et al.*, 1941; Archer, pers. comm.). Robert Archer (Dr.) is a control scientist at the South African National Botanical Institute (SANBI) and works on the systematics of

Euphorbiaceae and Celastraceae, petaloid monocots and trees. He specialise in *Euphorbias*. Currently plant specialists are still uncertain about the true identity of the Tweefontein-Geluk population (Archer, pers. comm.).

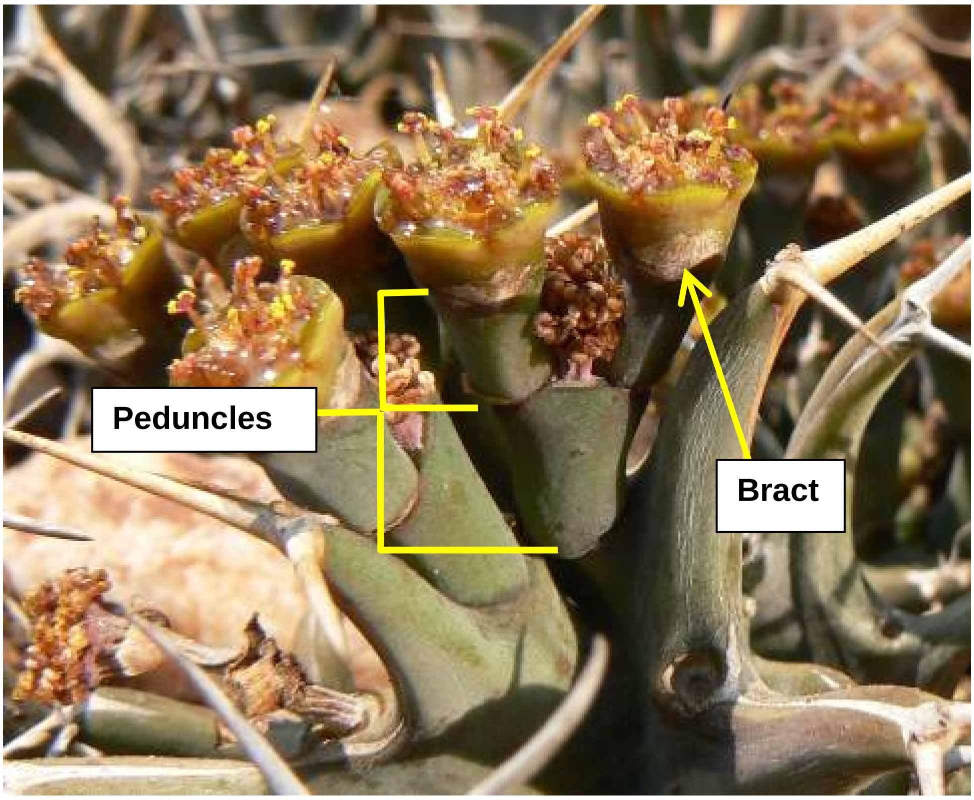

Figure 3.2: The long peduncles of the *E. groenewaldii* plant. A cream-coloured bract is visible.

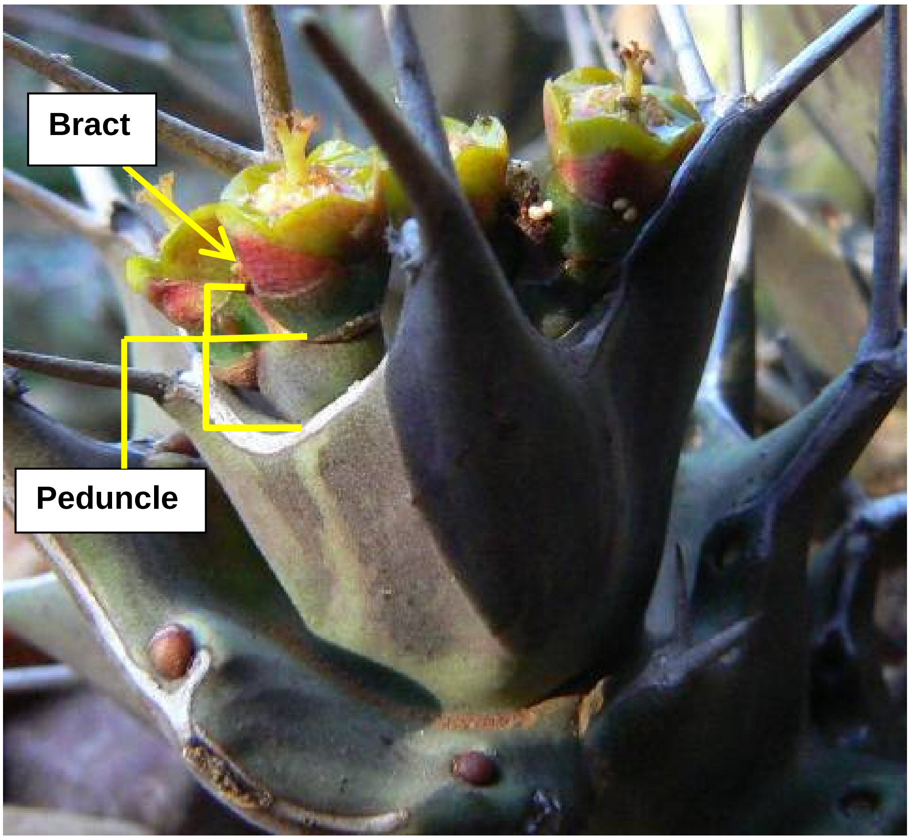

Figure 3.3: The short peduncle of *E. tortirama* (bracket). The colourful bract enclosing the flower as the cyathia appears (arrow).

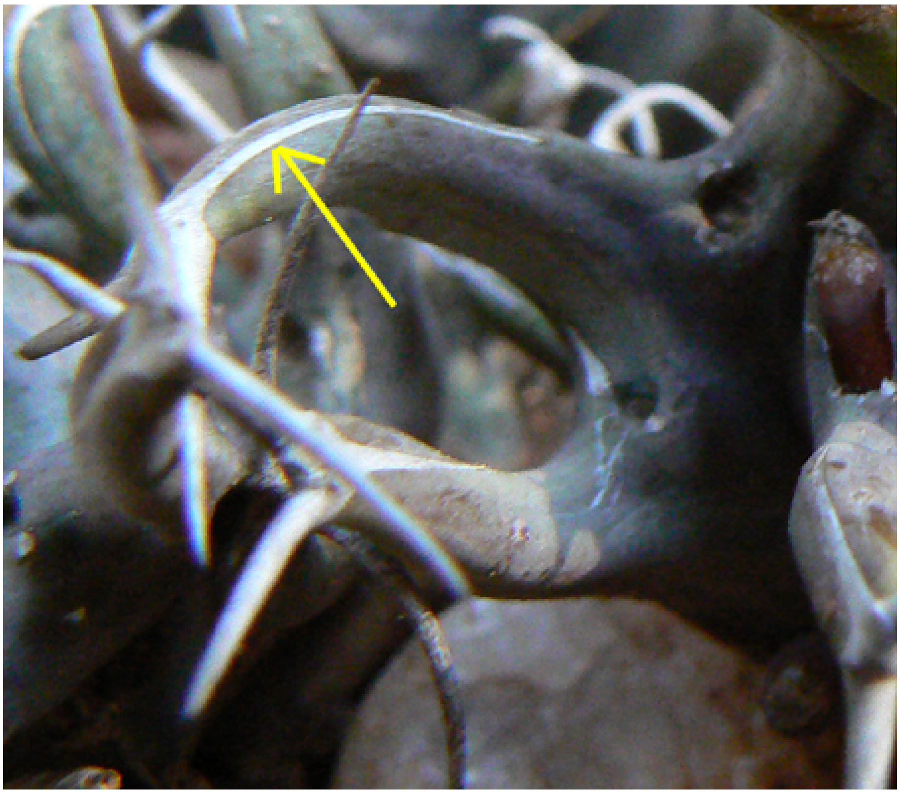

Figure 3.4: The spine shield of an *E. groenewaldii* plant (arrow).

Figure 3.5: The spine shield of an *E. tortirama* plant (arrow).

4.4 IUCN Status of *Euphorbia groenewaldii*

The conservation status of *E. groenewaldii* was considered endangered in the provincial borders of Transvaal (now comprising the provinces of Northwest, Gauteng, Limpopo and Mpumalanga) before 1986. When Raal's Conservation Plan on *E. groenewaldii* was first compiled its status was downgraded to Vulnerable. Raal considered just one of the three Transvaal populations to be critically threatened, potentially extinct due to very low number of individuals being found. Raal (1986) stated that there were no immediate threats to the three populations in the Transvaal, although these populations had relatively few plants within their area of occupancy. The status of *E. groenewaldii* was downgraded to Vulnerable on account of the large populations found in the old Lebowa National State (now incorporated into the Limpopo Province), even though it was threatened to a certain degree by herbivory and trampling (Raal, 1986).

The publication of the Red Data List of Southern African Plants by Hilton-Taylor (1996) in the mid 1990s, based on the IUCN guidelines, the status of *E. groenewaldii* reverted back to Endangered in South Africa. Even today after the assessment of the Threatened Plants Program, *E. groenewaldii* remain at the status of endangered (SANBI, 2009).

4.4.1 Nature of criteria for threatened species

See chapter one, section 3.2.2.

A threatened species only need to meet one of the five criteria (A, B, C, D and E) to be listed under one of the threatened categories (Critically Endangered, Endangered or Vulnerable), but it is important to asses a taxon against as many criteria as possible if available data permits (World Conservation Union, 2006). Listing a threatened taxon should be studied as fully as possible. Enough data must be available or have been collected accurately to assess or reassess a particular species. For example, under Criterion A one needs to know the following according to the World Conservation Union (2006):

> Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible AND understood AND ceased, based on and specifying any of the following:
> (a) Direct observation
> (b) An index of abundance appropriate to the taxon
> (c) A decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality
> (d) Actual or potential levels of exploitation

To see the definitions that are important to understand the terminology used in the five criteria listed above as provided by the World Conservation Union (2006), see Addendum B.

During the course of this study (2007) the conservation status of *E. groenewaldii* was: Endangered (SANBI, 2007). The data collected in this project and analyzed by using the IUCN's Red Data List Criteria, makes it was evident that the status of *E. groenewaldii* must be upgraded to Critically Endangered (CR). This is primarily due to its small area of occupancy and its extent of occurrence. *Euphorbia* *groenewaldii*'s IUCN status is: Critically Endangered: B1+2ab(ii). The IUCN status of *E. groenewaldii* with additional in formation is: Critically Endangered: A2bc; B1+2ab(ii); C2a(i, ii).

The Critically Endangered: B1+2ab(ii) status of *E. groenewaldii* means that the geographic range in terms of its extent of occurrence (B1) is less than 100 km^2 and in terms of its area of occupancy (B2) is less than 10 km^2. The (a) indicates that *E. groenewaldii* is found at ≤ 10 locations and the (b(ii)) that the population of *E. groenewaldii* is continuing to decline in terms of its area of occupancy. The conservation status of *E. groenewaldii* was upgraded to CR during February of 2009 due to the information provided from this study (SANBI, 2009).

Urgent action is needed to save this species from possible extinction in the near future. This can only be done through appropriate legislation and proactive actions that include the continued monitoring of the existing populations and grass-root implementation of Legislation.

CHAPTER 4

CONSERVATION MANAGEMENT RECOMMENDATIONS FOR *EUPHORBIA GROENEWALDII* AND CONCLUSION

1. PROPOSED CONSERVATION AND MANAGEMENT PLAN

Euphorbia groenewaldii is certainly in urgent need of conservation due to its rare and endangered conservation status (Critically Endangered (CR)) (SANBI, 2009), with the focus on its small extent of occurrence (EOO) (World Conservation Union, 2006). To conserve a rare and endangered species, unique growth requirements (such as micro-habitat features, # 2, section 3.3) for the species should be identified to properly manage the possible risks involved (Parsons & Hermanutz, 2006).

Two steps are necessary to ensure a successfully implemented conservation management plan (Caughley, 1994). Firstly, the reasons for the decline in species numbers must be identified by means of scientific methods. Secondly, sound groundwork must be done to conclusively identify the agents threatening the species. When the threatening agents are identified, methods to remove or neutralize these must be investigated (Caughley, 1994).

It is a daunting task to conserve rare and endangered plants, because the fragile state of such plants leaves very little room for error when formulating conservation measures (Holsinger and Gotlieb, 1991). Realistic and efficient management guidelines are necessary to enable conservation biologists and landowners to conserve endangered plants such as *E. groenewaldii*. Escalating threats (see, section 2.1) to the survival of these plants, as well as the relentless political constraints (job creation, available land for occupation and food production) imposed makes these management guidelines more important than ever (Schemske *et al.*, 1994).

2. PLANNING AND DESIGN PHASE

2.1 Management guidelines for identified threats

Conservation of *E. groenewaldii* can be achieved by first eliminating the smaller threats, such as, trampling and over-grazing by livestock by the fencing off individual populations. The populations of Kalkfontein and Tweefontein-Geluk are the least affected by trampling and herbivory of livestock (Table 2.19). The plants of these two populations occur on schist ridges and rocky areas that do not support high grazing capacities (Raal, 1987; Knowles & Witkowski, 2000).

The populations of *E. groenewaldii* facing threats such as trampling and herbivory by livestock are at Melkboomfontein and Majebeskraal (Table 2.19). Tribal villages close by on the eastern side use the land on which these *E. groenewaldii* populations occur to graze livestock (Fig. 2.12).

Conservation management of these populations affected by trampling and herbivory of livestock is needed immediately. Integrating endangered plant conservation and sustaining local cultural activities was conceptualised by the Regional Wildlife Service of Valencia County (New Mexico, USA) through the use of Plant Micro-Reserve (PMR) plots (Laguna *et al.*, 2004). Plant Micro-Reserves are small land plots (up to 20 ha) of peak value in terms of plant species richness and endemism or rarity. Local (Capricorn district municipal environmental section) or provincial (like the Limpopo department of economic development, environment and tourism) authorities then monitor and conserve plant species and vegetation types over a long term. This new statutory protection feature was created by the Regional Wildlife Service (USA) by means of a decree. The legal system confers a permanent status to PMRs providing protection to plants and land while allowing traditional activities compatible with plant conservation. Plant Micro-Reserves would fall into IUCN categories Ib (Wilderness area) and IV (Habitat/species management area), designations where the administrations and/or the landowners play a major role in conservation by means of active management (Laguna *et al.,* 2004).

If up to 20 ha of suitable habitat could be established for each of the *E. groenewaldii* populations, then almost all the populations will be protected. All the *E. groenewaldii* populations' area of occupancy is less than 20 ha. However, only about a third of the Melkboomfontein population would be protected in a 20 ha reserve, because this particular population covers 70 ha. Some conservation biologists argue that more species should be included in small protected areas rather than in one large block of equivalent size. Then, there is also the other side of the spectrum that argues that small reserves are of little value because long term support of populations are not viable (Laguna *et al.*, 2004). In *E. groenewaldii*'s case small reserves (PMRs) would probably be the better option due to constraints found at each population. These constraints are quarries, human settlements, agriculture, and expanding infrastructure.

Major threats (see chapter 2, section 5.4.1) currently affecting most of the *E. groenewaldii* populations are residential development, road construction and repair (see chapter 2, Figs. 2.17 to 2.21). The result of these human activities is the need for building material, which leads to quarries being created near these developments. A brick factory, gravel and sand quarries are currently affecting this species populations of Melkboomfontein, Majebeskraal, De Put and Tweefontein-Geluk. These activities, especially the quarries, should have been prevented (and still need to) by environmental government authorities due to the conservation status of *E. groenewaldii* (CR) (World Conservation Union, 2006; Act No. 7 of 2003 (LEMA)).

Any one that wants to quarry for any purpose on government or private land must apply for a mining permit (quarry area must not exceed 1.5 ha) or mining rights (if the quarry area exceed 1.5 ha) (Act No. 28 of 2002 (MPRDA)). This application includes an environmental impact assessment (EIA) that investigates all possible impacts on the immediate environment of the quarry location (Act No. 28 of 2002 (MPRDA)). The EIA determine all possible mitigation measures for all possible impacts on the environment (from a proposed activity), including socio-economic impacts (Act No. 107 of 1998 (NEMA)). The EIA also contain an Environmental Management Programme (EMPr) that guides contractor and site engineers in order to avoid and prevent irreversible environmental damage (Act No. 107 of 1998 (NEMA)). The EMPr contains information on environmental rehabilitation concurrent to the construction and operation phases (Act No. 107 of 1998 (NEMA)). Specialist studies are included in the EIA that focus on specific fields (fauna, flora, avifauna, herpetofauna and cultural-historical elements) (Act No. 107 of 1998 (NEMA)). This legal process was not followed by the people or companies that created the quarries which now affect the *E. groenewaldii* populations. They would otherwise have avoided quarrying near the *E. groenewaldii* populations.

Establishing a plant micro reserve (PMRs) are a plausible solution. Restricted access should be enforced on all the PMRs. Only authorized personnel, including the owners of the land and scientists/researchers, should be allowed access. If endangered plant species occur in privately-owned land, the owner must be informed about the species in order to know where they are located. Regular assessments of their status must be undertaken by a competent authority (scientists/researchers, government officials). Landowners should also be educated in protecting and preserving these endangered plants. The collection of any plant material should be strongly discouraged within these fenced-off areas. If the owner is willing, an effort must be made to buy the area of land on which the endangered population occurs.

2.2 Buffer zones

Reserves protecting an endangered plant should also protect the surrounding vegetation, plays an important role in the endangered plant's ecosystem (Lombard *et al.,* 2001). If the size of the reserve cannot be enlarged then a buffer zone around the endangered population can be established. Buffer zones still allow local traditional activities to take place in a controlled and sustainable manner, but filter out the effects these practises may have on the endangered plant population. Sometimes conservationists have to compromise because these measures are the only way some cultures can sustainably survive (Kala, 2000).

Buffer zones extend an ecological network. In the broader sense these zones, according to Meier *et al.* (2005), provide the following: "Buffer zones preserve main ecological functions in landscapes, such as: (1) accumulating material and dispersing human-induced energy, (2) receiving and transforming wastes from populated areas, (3) recycling and regenerating resources, (4) providing wildlife refuges and conserving genetic resources, (5) serving as migration-tracts for biota,

(6) serving as barriers, filters and/or buffers for fluxes of material, energy and organisms in landscapes, (7) serving as a support-framework for regional settlements, (8) providing recreation areas for people, and, consequently, (9) compensating and balancing all inevitable outputs of human society."

2.2.1 Urban Edges

Urban development has an "edge effect" (Holway, 2004) on the environment. In other words urban develpoment fragments, isolates and degrades natural habitats; simplifies and homogenizes the biodiversity; and disrupts hydrological systems and nutrient cycling (Alberti & Marzluff, 2004). The concept of a buffer zone is frequently advocated by environmental managers who are conserving threatened species. Apart from reducing the "edge effect" associated with anthropogenic impacts, a buffer zone of adequate size has an immensely positive effect on the ecological health of rural and urban landscapes. The buffer zone reduces reducing erosion, improves water quality, increases biodiversity, and expands wildlife habitats. However, the concept of buffer zones is rarely implemented in practice despite these benefits (Lovell & Sullivan, 2006).

The effect of buffer zones on the immediate environment and the quality it provides to a reserve is immeasurable. Edge effects are neutralised like urban waste and agricultural byproducts such as poisons (Thorell & Götmark, 2005). This is the case at the *E. groenewaldii* populations of Delmada and Melkboomfontein close to human development and settlements.

A good understanding of pollutants and possible anthropogenic threats to *E. groenewaldii* must be established in order to determine the size of the buffer zone (Schou *et al.*, 2006) around each population. The size and shape of the buffer zone may differ for each population depending on how severe the external influences are on *E. groenewaldii*. Buffer zones can range from 50 m to 600 m (Schou *et al.*, 2006). In order for *E. groenewaldii* plant seeds to disperse easily, a relatively wide buffer zone may be needed according to the plant's seed dispersal capabilities and needs. If the buffer zone is too narrow, then seeds for example may be washed down a slope and out of the buffer zone, outside the protection of the buffer zone (Ma *et al.*, 2002).

2.2.2 Buffer zones for each *E. groenewaldii* population

Tweefontein-Geluk (see chapter 2, Fig. 2.17):

This population is fragmented by the brick factory and residential development. A 35 m buffer zone around each sub-population is advisable. Larger areas (habitat) north of some of the sub-populations should also be included in the buffer zone. This would include more of possible pollinator's habitat (Pengelly *et al.*, 2010). This may ensure future pollination success (Pengelly *et al.*, 2010) for the remaining plants. It could also enable the dispersal of seeds (Ma *et al.*, 2002).

Kalkfontein (see chapter 2, Fig. 2.18):

This population is currently the least disturbed or impacted by livestock and human activities (see chapter 2, Table 2.19). There is extensive natural environment left around this population. A buffer zone of at least a 100 m is recommended. This excludes the R71 road south of the population. This may help include most of the possible pollinator habitat (Pengelly *et al.*, 2010). This may enable pollination success (Pengelly *et al.*, 2010) in the future for the remaining plants. It may enable the dispersal of seeds (Ma *et al.*, 2002).

De Put (see chapter 2, Fig. 2.19):

The main impact on this population is a sand quarry along the northern to eastern boundary. A fair amount of natural environment remains around this population. At least a 100m buffer zone is recommended. This includes the sand quarry affecting this population. This may help include most of the possible pollinator habitat. This may ensure pollination success (Pengelly *et al.*, 2010) in the future for the remaining plants and enable the dispersal (Ma *et al.*, 2002) of seeds.

Majebeskraal (see chapter 2, Fig. 2.20):

The impacts on this population are a gravel quarry on the north-western boundary; a brick making factory on the south-eastern; a motel on the south-western boundary; the R71 road along the southern boundary and the livestock trampling and herbivory along boundaries unaffected by human activities with some the natural environment left. A 50 m buffer zone is necessary as this may include most of the possible pollinator habitat, according to Pengelly *et al.* (2010), ensuring future pollination success (Pengelly *et al.*, 2010) and enabling the dispersal (Ma *et al.*, 2002) of the remaining plants.

Melkboomfontein (see chapter 2, Fig. 2.21):
This population is impacted by a gravel quarry within its boundaries; residential development along the eastern boundary and agricultural practices on the northern boundary. Trampling and herbivory by livestock is also an impact on this population. The quarry should be closed and further activity in the quarry should be prohibited. A buffer zone of 35 m is necessary near al human activities. Larger buffer zones should be implemented to include more natural environment where there are no human activities impacting on this population's boundary (Ma *et al.*, 2002). This may include most of the possible pollinator habitat (Pengelly *et al.*, 2010); ensure future pollination success (Pengelly *et al.*, 2010) and assist the dispersal (Ma *et al.*, 2002) of the remaining plants.

Spits (see chapter 2, Fig. 2.21):
This population is least impacted upon by human activities (Table 2.19). As much natural environment as possible should be included around this population to include all possible factors (pollinators and dispersal areas) affecting its future survival. A 100m buffer is recommended. This may include most possible pollinator habitat (Pengelly *et al.*, 2010); ensure future pollination success, according to Pengelly *et al.* (2010), and assist the dispersal (Ma *et al.*, 2002) of the remaining plants.

In order to establish buffer zones and enable the PMR system to work the cooperation of local municipalities, tribal chiefs and local communities is required (Trisurat, 2006). Establishing a successful and sustainable management system for this species, could produce benefits, such as tourism and a healthier and more productive ecosystem for these plants.

3. OPERATIONAL PHASE

3.1 Fire regime

With a reserve system in place a possible fire regime should be considered. Fire plays a crucial role in the survival, ecology and evolution of many plant species including the different *Euphorbia* species. Fire enables plant regeneration (new growth) and recruitment (seed germination) by activating dormant seed. Therefore it is very important to study the complete effect of fire (Regan *et al.*, 2003) on this species. A fire regime with a set cycle must be implemented to determine if *E. groenewaldii* is truly tolerant to fire and to what degree; i.e., to what intensity and frequency (Pfab, 1997).

Before humans moved into a specific area, modified it and over-grazed it, a larger area subjected to fire was possible due to of a higher grass biomass. Today there could be more frequent fire due to human settlements in the area of the *E. groenewaldii*, but these would not necessarily cover large areas due to overgrazing.

Fires maintained the biodiversity of the ecosystem. Fire frequency within small reserves must be scrutinised due to the effect of fire on plant community composition and function (Lunt, 1997). *Euphorbia clivicola* is a good example of a rare *Euphorbia* that needs a good fire management plan. According to Pfab (1997), the vegetation of the protected site must be burnt more often than the occasional natural occurring events. This also depends on the current biomass fuel, as well as the rainfall of the area. The size of the area to be burned: Another important factor if only the areas where the plants occur are burned, herbivores will congregate in these areas because of the new growth of grass and causing rigorous trampling and damage to *Euphorbia* species.

3.2 Management of reserves

Management of these PMRs are crucial:

1. Detecting illegal activity in and near these PMRs.
2. Ensuing that the selected fire regime is implemented correctly.
3. Maintaining existing infrastructure (fences and roads).
4. Educating and communicating with the surrounding tribal communities conserve the environment and *E. groenewaldii*.

3.3 Catastrophic events

Even if proclamation of the *E. groenewaldii* population reserves (such as PMRs) can be established, there is still the problem of dealing with a population such as *E. groenewaldii* occurring in such a small area (extent of occurrence). This situation carries with it the effect of possible localised catastrophic events, such as, urban and/or commercial developments, extreme fires, prolonged draughts and disease that could decimate an entire population in a very short time (Jusaitis *et al.*, 2004).

3.3.1 *Ex situ* conservation as last resort

It is preferable to conserve *E. groenewaldii* in its natural environment. If this is no longer a viable option, suitable areas that fit *E. groenewaldii*'s environmental requirements as closely as possible can be located for *ex situ* conservation. This is helpful particularly in the event of a catastrophe that may decimate one or more of the original populations (Jusaitis *et al.*, 2004). Seeds should be harvested from all the populations, to keep a genetic pool representing *E. groenewaldii* as diversely as possible. These seeds must be germinated under greenhouse conditions close to the natural conditions of the species (Heywood & Iriondo, 2003), and seed obtained can be stored in a seed bank for future propagation (Lee *et al.*, 2006). Should population numbers start to drop quickly for one or another reason, these new cultivated seedlings of this species can be used to restock the depleted populations (Pfab & Witkowski, 2000). When the original site is completely lost to collectors, trampling, and so forth, these seedlings can be used to start a new population at a suitably acquired site and the remaining plants can be translocated. According to Jusaitis *et al.* (2004), several small translocations to different sites may be preferable to a single large one. The effective long-term storage of seed in an *ex situ* seed bank should also assist in appeasing this primary threat.

3.3.2 Geographical information system

The use of a geographical information system (GIS), with enough resource variables (altitude, soil type and climate) factored (overlaid) into such a process (*ex situ* conservation), can help to predict where a species will occur. It may also identify additional sites, that would suite the specific requirements of a species, should *ex situ* translocation be considered (Chuanyan *et al.*, 2006). GIS is also a valuable tool in conservation management. It can be used as an ecological model of biodiversity to predict possible threats to a population, such as encroaching urban development (Hall *et al.*, 1984) and land-use changes (Gontier *et al.*, 2006). The results of this study will be valuable when developing a conservation action plan, for *E. groenewaldii* and as a template to conserve of other species of concern.

4. MONITORING

In order to manage a plant population it is, foremost, vital to understand its biology and ecology. Once that is known, an intensive monitoring program has to be set in motion to keep assessing the status of the population. Strategies to monitor plant populations can be classified into three groups, that is: inventory studies, demographic surveys and fixed-point landscape photography.

4.1 Inventory studies

Inventory studies involve the counting individuals in a population at predetermined intervals within a set time period. Through this method one can roughly determine the population's status. Certain life stages (seedlings or dormant plants), depending on the time of year and conditions, of the species may be absent or inconspicuous (Palmer, 1987).

4.2 Demographic surveys

Additional information can be obtained by conducting demographic surveys. This can provide information on the estimates of demographic parameters or even on the number of reproductive individuals. This will involve repeatable sampling methods, such as quadrates and transects (Palmer, 1987).

Demographic monitoring studies can give the maximum amount of information when assessing the status of endangered plants (Schemske *et al*., 1994). These strategies are the basis for the most successful studies (Williams, 1981). For example, a demographic study of *E. perangusta,* an endemic to the northern regions of South Africa, confirmed its endangered status. This study revealed an intense increase in the plants' mortality rate and a decline in flower formation and seedling recruitment (Raal, 1988).

Other methods used in demographic studies are the use of permanent quadrates, a repeatable sampling method. In this case there is a specific time period involved where individual plants are marked and growth, survival and reproduction are documented (Palmer, 1987). Many other factors can be determined; for example, dispersal strategies, seedling establishment, clonal growth, and mortality (Davy & Jeffries, 1981).

4.3 Fixed-point landscape photography

Fixed-point landscape photography is a technique used to monitor plant populations. This technique only helps with large-scale observation of a population because the resolution tends to be ineffective in identifying seedlings and sometimes juveniles. Thus, a great amount of ground truthing and guessing is required for this method (Williams, 1981).

From a management point of view, aerial photography can be used to detect changes in land use over time. For example, a decline in the threatened plant population can be linked to these changes. *Euphorbia barnardii* is a good example; aerial photography showed that human habitation caused changes in the landscape directly affecting *E. barnardii* populations (Witkowski *et al*., 1997).

5. CONCLUSION

If this conservation management plan is followed then a step in the right direction of conserving this species is made. Further research is required on the species' biological and ecological requirements. Conserving *E. groenewaldii* should be enabled utilising this conservation management plan. The threats studied, such as, trampling (Table 2.19), herbivory (Table 2.19), anthills (Table 2.19), fire (Table 2.19) and large scale destruction (Fig. 2.17 to 2.21) are already impacting on and endangering the survival of *E. groenewaldii* populations.

The future of this unique succulent depends on local communities, environmentalists, conservationists as well as the local and provincial authorities. They have the resources to save this unique species from possible extinction from developers, mines, engineers and contractors.

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ADDENDUM A

Associated vegetation to *Euphorbia groenewaldii*

Plants associated with *E. groenewaldii*, ranging from trees, shrubs, to herbs and graminiods. The information was obtained from the TPA Conservation Plan for E. groenewaldii (Raal, 1986).

Trees	*Acacia caffra* (Thunb.) Willd.
	Acacia karroo Hayne
	Acacia tortilis (Forsk.) Hayne subsp. *heterocantha* (Burch.) Brenan
	Berchemia zeyheri (Sond.) Grubov.
	Cassine transvaalensis (Burtt Davy) Codd
	Combretum molle R. Br. ex G. Don
	Croton gratissimus Burch. subsp. *gratissimus*
	Diospyros lyciodes Desf. subsp. *Sericea* (Bernh.) De Wint.
	Diospyros lycioides Desf. subsp. *lyciodes*
	Euclea undulata Thunb. var. *undulata*
	Grewia flava DC.
	Gymnosporia heterophylla (Eckl. & Zeyh.) N.K.B. Robson
	Gymnosporia senegalensis (Lam.) Exell
	Mundulea sericea (Willd.) A. Chev.
	Ormocarpum trichocarpum (Taub.) Harms ex Burtt Davy
	Pappea capensis Eckl. & Zeyh.
	Peltophorum africanum Sond.
	Rhus pyroides Burch.
	Vangueria infausta Burch.
	Zanthoxylum capense (Thunb.) Willd.
	Ziziphus mucronata Willd. subsp. *mucronata*
Shrubs	*Crotalaria burkeana* Benth.
	Crotalaria sphaerocarpa Perr. ex DC.
	Euclea undulata Thunb. var. *myrtina* (Burch.) Hiern.
	Grewia vernicosa Schinz.
	Vernonia fastigiata Oliv. & Hiern
Herbs and Graminoids	*Aerva leucura* Moq.
	Alectra pumila Benth.

	Antizoma angustifolia (Burch.) Miers ex Harv. cf. *Brachiaria serrata* (Spreng.) Stapf
	Aristida canescens Henr. subsp. *canescens*
	Aristida congesta Roem. & Schult.
	Aristida diffusa Trin.
	Aristida meridionalis Henr.
	Asclepias burchellii Schltr.
	Asparagus suaveolens Burch.
	Barleria pretoriensis C.B.CL.
	Barleria saxatilis Oberm.
	Blepharis integriflora (L.F.) E. Mey var. *setosa* (Nees) Oberm.
	Bonatea porrecta (Bol.) Summerh.
	Cassia biensis Steyaert
	Cassia italica (Mill.) Lam. ex F.W. Andr. subsp. *arachnoides* (Burch.) Brennan
	Chaetacanthus setiger (Pers.) Lindl.
	Chascanum hederaceum (Sond.) Moldenke var. *hederaceum*
	Chascanum pinnatifidum (L.f.) E.Mey.
	Crassula capitella Thunb. subsp. *nodulosa* (Schonl.) Toelken
	Crotolaria lotoides Benth.
	Cymbopogon scoparius Stapf
	Cyphocarpha angustifolia Lopr.
	Dicerocaryum zanguebarica (Lour.) Merr.
	Dicoma anomala Sond. subsp. *anomala*
	Dicoma macrocephala DC.
	Drimiopsis barkei Bak.
	Dyschorista transvaalensis C.B.Cl.
	Enneapogon scoparius Stapf
	Epaltes gariepina (DC.) Steetz.
	Eragrostis rigidior Pilg.
	Euphorbia inaequilatera Sond.
	Felicia mossamedensis (Hiern.) Mendonca.
	Felicia muricata (Thunb.) Nees.
	Fockea angustifolia F. Schum.
	Geigeria burkei Harv. subsp. *Burkei* var. *elata* Merxm.

	Gomphrena celosioides Mart.
	Helichrysum caespititium (DC.) Harv.
	Heliotropum sp.
	Hermannia boraginiflora Hook.
	Heteropogon contortus (L.) P.Beauv. ex Roem. & Schult.
	Hibiscus calyphyllus Cav.
	Hirpicium bechuanense (S. Moore) Roessl.
	Hyparrhenia anamesa Clayton
	Indigofera heterotrichia DC.
	Indigofera rhytidocarpa Benth
	Indigophera circinnata Benth.
	Ipomoea obscura (L.) Ker Gawl var. *fragilis* (Choisy) A. Meeuse
	Ipomoea papilio Hallier f.
	Lantana rugosa Thunb.
	Lasiocorys capensis Benth.
	Leonotis leonitis (L.) R.Br. var. *leonitis*
	Leucas martinicensis (Jacq.) R.Br.
	Lippia javanica (Burm.f.) Spreng. / C. Pretorius.
	Lycium cinereum Thunb. agg.
	Merremia tridentata (L.) Hallier f. subsp. *angustifolia* (Jacq.) Ooststr.
	Monsonia angustifolia E. Mey.
	Ocimum canum Sims
	Pegolettia senegalensis Cass.
	Pelargonium dolomiticum Knuth
	Pentzia calcarea Kies
	Philyrophyllum schinzii O. Hoffm.
	Pogonarthria squarrosa (Licht.) Pilg.
	Pollichia campestris Aiton
	Polygala hottentotta Presl
	Protasparagus africanus (Lam.) Oberm.
	Rhaphionacme procumbens Schltr.
	Rhynchelytrum repens (Willd.) C.E. Hubb.
	Rhynchosia cf. *confuse* Burtt Davy
	Rhynchosia totta (Thunb.) DC.
	Ruellia cf. *cordata* Thunb.

	Scabiosa columbaria L.
	Senecio harveianus MacOwen
	Senecio transvaalensis H. Bol.
	Senecio venosus Harv.
	Sida chrysantha Ulbr.
	Sida cordifolia L.
	Solanum catombelense Peyr.
	Striga elegans Benth.
	Stylosanthes fruticosa (Retz.) Alston
	Sutera atropurpurea (Benth.) Hiern
	Sutera burkeana (Benth.) Hiern
	Tephrosia cf. *T. sparsiflora* H.M. Forbes
	Tephrosia longipes Meisn. var. *lurida* (Sond.) J.B. Gillett
	Tephrosia plicata Oliv.
	Themeda triandra Forsk.
	Trachyandra reflexipilosa (Kuntze) Oberm.
	Tribulus terrestris L.
	Tricholaena monachne (Trin.) Stapf & C.E. Hubb.
	Vernonia poskeana Vatke & Hildebr. var. *poskeana*
	Waltheria indica L.

ADDENDUM B

Definitions that are important to understand the terminology used in the five criteria listed in the World Conservation Union's IUCN Red List Categories and Criteria (2006):

Population
The total number of mature individuals of the taxon.

Sub-population
Geographically or otherwise distinct groups in the population between which there is little demographic or genetic exchange (typically one successful migrant individual or gamete per year or less).

Mature individual
Individuals known, estimated or inferred to be capable of reproduction.

Continuing decline
Recent, current or projected future decline (which may be smooth, irregular or sporadic) which is liable to continue unless remedial measures are taken.

Severely fragmented
The situation in which increased extinction risks to the taxon result from the fact that most of its individuals are found in small and relatively isolated sub-populations (in certain circumstances this may be inferred from habitat information).

Extend of occurrence (EOO)
The area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon, excluding cases of vagrancy.

Area of occupancy (AOO)

The area within its 'extent of occurrence' that is occupied by a taxon, excluding cases of vagrancy. The measure reflects the fact that a taxon will not usually occur throughout the area of its extent of occurrence, which may contain unsuitable or unoccupied habitats.

According to the World Conservation Union (2006), in this case Critically Endangered can be: A2cd; B1+2de; C2a(i). Only the criteria for the highest category of threat that the taxon qualifies for should be listed. For example, if a taxon qualifies for criteria A, B, and C in the Vulnerable and Endangered category and only criterion A in the Critically Endangered category, then only the criterion A met in the Critically Endangered category should be listed (the highest category of threat). Additional criteria that the taxon qualifies for at lower threat categories may be included in the documentation.