ENVIRONMENTAL FACTORS ASSOCIATED WITH *Juttadinteria albata* (L. BOLUS) L. BOLUS, POPULATION STRUCTURE AND ASSESSMENT OF ITS PERFORMANCE IN TRIAL PLANTING AT SENDELINGSDRIF MINE

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ABSTRACT

Juttadinteria albata is a leaf succulent plant species endemic to the southern Namib in the Succulent Karoo in Sendelingsdrif near the Orange River. The proposed strip mining for diamonds at NAMDEB's new Sendelingsdrif mine may contribute to the loss of up to 39% of *J. albata* population. This may increase the risks of extinction for *J. albata* and species which may be interacting with it. The aim of the study was to investigate the biology of *J. albata* for ecological restoration post mining. The specific objectives of this study were to determine the relationship between infiltration rate, rockiness cover, slope angle, Aspect (the direction in which the slope faces), soil texture and soil elements that may be associated with *J. albata* in the study area; to determine the population structure of *J. albata* in the study area, and to determine, as part of a trial planting, the most suitable post mining slopes and Aspects for the growth of *J. albata* that would be applied during its ecological restoration. The study was carried out through a field survey and a heap experiment. For the field survey, infiltration rate, slope angle, rockiness cover, soil texture and concentrations of soil elements in paired 4 m x 4 m quadrats were recorded. Canopy diameters, height and counts of live *J. albata* and Aspect were recorded in 4 m x 4 m quadrats where *J. albata* was found. *Juttadinteria albata* present in a total of 1,500, 2 m x 2 m quadrats were recorded to determine its spatial distribution pattern. *Juttadinteria albata* was grown on 12 experimental heaps in different Aspects and slopes. The results of the study revealed that quadrats where *J. albata* was found had significantly higher rockiness cover (t=6.40, df=40, P<0.001, paired t-test), slope angle (t=6.30, df=40, P<0.001) and organic carbon (t=3.84, df=23, P<0.01) than where it was not found. *Juttadinteria albata* was found in the western, southwestern, southern, southeastern, eastern, northeastern and level Aspects (*F*=1.38, df=6, P=0.26, One-way ANOVA test) in the study area because these Aspects are cool due to less intense sunlight exposure. Rocks capture primary sources of organic matter and steep slopes are effective at intercepting cool moist wind (moisture mainly from Orange River) resulting in favorable sites for *J. albata* on rocky steep slopes. Furthermore, *J. albata* followed a clumped spatial distribution pattern (variance=0.32>mean=0.07) in the study area. *Juttadinteria albata* plants could be capturing organic matter under their canopies or their dead parts resulted in higher concentrations of organic carbon in the soil which could possibly have also resulted in clumped distribution pattern. Finally, results showed that mean number of leaves of cuttings of *J. albata* in the level Aspect on the experimental heaps was significantly higher (*F*=6.07, df=8, P<0.001, ANOCOVA test) than those in the eastern, northeastern and northern Aspects at the end of heap experiment because these three Aspects are warm (e.g. northern Aspect receives more intense sunlight). Also, the mean canopy volume of cuttings of *J. albata* on steep slope was significantly higher (*F*=12.05, df=1, P<0.001, ANOCOVA test) than that on gentle slope experimental heaps at the end of heap experiment due to moisture on steep slopes. It is recommended that *J. albata* should be transplanted in clumped layouts on rocky steep slopes facing cool Aspects (as recorded in the present study) in mined areas with addition of organic mulch to post mining soils for organic carbon.

Key words: *Juttadinteria albata***,** Sendelingsdrif diamond mine, strip mining, environmental factors, population structure and heap experiment.

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ACRONYMS

ANOCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
ArcGIS	Geographic Information System for working with maps
CAM	Crassulacean Acid Metabolism
CEC	Cation Exchange Capacity
CR	Critically endangered
df	Degrees of freedom
GPS	Global Positioning System
IUCN	International Union for Conservation of Nature
MANOVA	Multivariate Analysis of Variance
N/A	Not applicable
NAMDEB	Namdeb Diamond Corporation (Pty) Ltd
NBRI	National Botanical Research Institute of Namibia
NGSTP	Namibia Government Scholarship and Training Programme
SE	Standard Error
UNAM	University of Namibia

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DEDICATION

This thesis is dedicated to my little sister Julia Ndilokelwa Nauyoma. This is to show that I love you so much my little queen sister, you are such a blessing to me. I decided to dedicate this thesis to you because at nine years old you sent me a text message encouraging me to work hard; I am sure you will not remember it but I do.

DECLARATION

I, Lineekelaomwene Tuhafeni Nauyoma, hereby declare that this thesis is a true reflection of my own research, and that this work, or part thereof has not been submitted for a degree in any other institution of higher education.

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Lineekelaomwene Tuhafeni Nauyoma

CHAPTER 1: INTRODUCTION

1.1 General introduction

Mining activities such as removal of topsoil or plants, contribute to ecosystem disturbances, which may result in the disturbance or even extinction of plant species and associated animal species (Zietsman, 2011; Bradshaw, 1997; Mather & Chapman, 1995). The Namdeb Diamond Corporation (Pty) Ltd (NAMDEB) strip mining for diamonds in the Sperrgebiet National Park, in the Succulent Karoo contributes significantly to Namibia's Gross Domestic Product (6.8% for all diamond mining activities in Namibia) (Namibia Statistics Agency, 2013). However, this strip mining involves destruction of succulents with small geographic ranges; many such species in the Family Mesembryanthemaceae occur in the area (Fortuin, 2011; Mannheimer, 2010). Majority of the members of the Mesembryanthemaceae (93 % of its genera) such as *Cephalophyllum*, *Brownanthus*, *Eberlanzia* and *Hartmanthus* occur in the Succulent Karoo biome which is the only arid land to qualify as one of the top 25 global biodiversity hotspots (Burke, 2006; Burke, 2004a; Driver, Desmet, Rouget, Cowling & Maze, 2003; Brooks et al., 2002; Myers, Mittermeler, Mittermeler, da Fonseca & Kent, 2000; Cowling, 1999; Smith et al., 1998; Cowling, Richardson & Pierce, 1997).

One of the Critically endangered (CR) International Union for Conservation of Nature (IUCN) Red Data list of plants from the Mesembryanthemaceae, *Juttadinteria albata* (L. Bolus) L. Bolus, has a highly restricted range centred in the area of the proposed Sendelingsdrif diamond mine at NAMDEB (Mannheimer, 2006;

Loots, 2005; Burke, 2004b). Sendelingsdrif diamond mine is situated on the Namibian bank of the lower Orange River in the southern Namib Desert within the Sperrgebiet National Park. It has been estimated that all strip mining activities could contribute to the loss of up to 39% of *J. albata* population, with the Sendelingsdrif diamond mine contributing a large proportion of this (Burke, 2004b). Although ecological restoration of the population in the mined areas was identified as a viable strategy to mitigate this impact, little is known regarding the biology of this restricted range plant species (Burke, 2004b).

In order to document and understand the ecological implications of the destruction and loss of the *J. albata* and its habitat and to prevent the species from becoming extinct, a study of the biology of *J. albata* was necessary (Fortuin, 2011; Wassenaar, 2010). In addition, ecological data including habitat requirements for plants such as *J. albata* will be important at the time of restoration of the area both during and after mining (Fortuin, 2011; Burke, 2004b).

1.2 Statement of the problem

Mining activities at the proposed Sendelingsdrif diamond mine may cause plant habitat destruction resulting in the loss of a part of or entire population of *J. albata* from the habitat (Fortuin, 2011; Burke, 2004b). Diamonds will be extracted through a strip mining process in which the topsoil where the endemic *J. albata* grows will be removed, or buried by mining waste (Fortuin, 2011). This may increase the risks of extinction for this endemic species because a high percentage of its global population may be lost due to this mining process (Burke, 2004b).

Endemics plants play important ecological roles such as harboring other species in habitats (Padilla & Pugnaire, 2006; Cowling et al., 1997). They are a source of pride and provide researchers with valuable scientific information which help maintain the health, productivity and beauty of their unique environments (Robison & Allen, 1995). A loss of a part of or entire population of *J. albata* from the habitat may also increase the risks of local extinctions for other species which may be interacting with *J. albata* for survival in the habitat (Fortuin, 2011; Burke, 2004b).

1.3 Aims and objectives of the study

The research was carried out in order to characterize selected environmental factors associated with *J. albata* and to study the population structure of *J. albata*.

The specific objectives of the present study were:

a) To determine the relationship between density of *J. albata* and infiltration rate, rockiness cover, slope angle, Aspect (the direction in which the slope faces), soil texture and soil elements in the study area.
b) To determine population structure of *J. albata* in the study area.
c) To determine, as part of a trial planting, the most suitable post mining slopes and Aspects for the growth of *J. albata* that would be applied during its ecological restoration.

1.4 Research hypotheses

a) Significantly higher infiltration rate, rockiness cover, slope angle and concentrations of total nitrogen, iron, magnesium, organic carbon, calcium and extractable phosphorus in topsoil (0-10 cm depth) will be associated with significantly higher density of *J. albata* because *J. albata* seem to occur at specific sites in the study area. Furthermore, significantly higher density of *J. albata* will be associated with sandy, loamy sand and sandy loam soils and southern Aspect (the direction in which the slope faces; Aspect will not be defined anymore in the rest of the thesis). This is because the study area is characterized by these soil textures and southern Aspect faces the Orange River which supplies moisture to support plant life and it also faces away from direct sunlight which can result in high plant cover.

b) The population structure of *J. albata* among different habitats (namely: Sheltered gully, Broad sandy wash, Rocky hills, Shallow soil on ridges, Proto terrace, Meso terrace and Lower terrace) in the study area significantly differ because *J. albata* may be responding differently to germination and growth conditions in these different habitats. Also, *J. albata* follow a clumped distribution pattern in the study area because *J. albata* seem to prefer patches which could have specific favorable germination and growth conditions.

c) Cuttings and whole *J. albata* plants in the southern Aspect and on steep slopes on twelve experimental heaps of a mixture ratio between three different post mining waste materials will have significantly higher number of leaves and canopy volumes. This is because this Aspect faces the Orange River and may be receiving extra moisture and it also faces away from direct sunlight which can result in significantly higher number of leaves and canopy volumes of cuttings and whole *J. albata* plants. Steep slope experimental heaps are much higher and could be effective at intercepting cool moist wind (moisture mainly from the adjacent Orange River) than gentle slope experimental heaps which can as well result in significantly higher number of leaves and canopy volumes of cuttings and whole *J. albata* plants. Also, southern Aspect and steep slope on twelve experimental heaps will have significantly higher germination, survival and growth rates of *J. albata* due to the same reasons provided.

1.5 Significance of the study

This study was carried out to provide scientific information about selected environmental factors which may be associated with *J. albata* and its population structure in the study area. This information was required in the ecological restoration of *J. albata* population and its habitat both during and after strip mining activities at Sendelingsdrif diamond mine. Furthermore, this study attempted to reveal the most suitable post mining slopes and Aspects for *J. albata* which is also imperative in its ecological restoration. At the time when the present study was started, there was no documented specific study on the population structure and habitat requirements of *J. albata* hence data obtained in the present study will contribute to proper restoration plans after mining ceases (Fortuin, 2011; Wassenaar, 2010).

1.6 Limitations of the study

The duration of the study could not allow an investigation of the population dynamics of *J. albata* in the study area. Many years are required to study population dynamics in plants (Barbour, Burk, Pitts, Gillian & Schwarts, 1999).

CHAPTER 2: LITERATURE REVIEW

2.1 *Juttadinteria albata* and its characteristics

Juttadinteria albata is a dwarf perennial erect leaf succulent shrub (Figure 1) in the Family Mesembryanthemaceae which on average can reach maximum height of 30 to 40 cm (Mannheimer, 2006; Loots, 2005; Burke, 2004b). *Juttadinteria albata* is endemic to the southern Namib in the Succulent Karoo in a small area near the Orange River, both on the Namibian and South African side of the river. It is protected in Namibia by Nature Conservation Act No.4 of 1975 and has also been accorded CR status by the IUCN (Mannheimer, 2006; Loots, 2005; Burke, 2004b). The distribution range of *J. albata* overlaps in an area where there is a large diamond deposit which is currently being mined on both sides of the Orange River (Fortuin, 2011; Burke, 2004b).

Juttadinteria albata is characterized by an upright growth form (Figure 1) but this may vary between individuals with some that grow very low to the ground (Burke, 2004b). The leaves are elongated, flat above, blue - green in color, about 50 - 80 mm long, up to 20 mm thick and triangular in cross section (Mannheimer, 2006; Burke, 2004b). The leaves have epicuticular wax with additional, scattered wax platelets and very smooth epidermis. The flowers are mostly white and are very large, up to 50 mm in diameter and are enveloped by four fleshy leaves in two pairs of equal lengths (Mannheimer, 2006; Burke, 2004b). The plant has thin seeds enclosed in capsules which open only upon wetting (Burke, 2004b). All species of *Juttadinteria* have, in addition to fine roots, one or two roots that spread from the base of the plant but they have no distinct tap root (Mannheimer, 2006).

Figure 1. *Juttadinteria albata* plants growing in their habitat at Sendelingsdrif.

2.2 The Family Mesembryanthemaceae

Family Mesembryanthemaceae (Greek name for ‘mid-day flower’) is composed mainly of succulent plants (van Jaarsveld & Pienaar, 2000; Smith et al., 1998; Ihlenfeldt, 1994). Succulent plants have fleshy leaves, stems or roots which are adapted to store water and enable the plants to survive prolonged dry periods (Eggli, 2003; van Jaarsveld & Pienaar, 2000). Members of the Mesembryanthemaceae are also known as “vygies”, “Fig-marigolds”, “flowering stones”, “ice plants”, “midday flowers” or “mesembs” and include a diversity of many fascinating and even bizarre plant forms (van Jaarsveld & Pienaar, 2000; Smith et al., 1998; Scwantes & Shurly, 1954). Mesemb plants occur mainly in the Southwestern parts of the African continent, from Angola into Namib Desert to the Cape, extending well into the east over the central plateau of South Africa and reaching into Zimbabwe and Botswana (Leister, 2000; Cowling, 1999; Smith et al., 1998). Outside this core area, this family is also found from northern Tanzania to Yemen, in Arabia and Madagascar. In addition, a few species in this family occur around the Mediterranean Sea, in Australia and New Zealand and the adjacent islands (Hartmann, 2001; van Jaarsveld & Pienaar, 2000; Smith et al., 1998). The Mesembryanthemaceae presently consists of 116 genera and about 2000 species and account for a greater percentage of Southern Africa succulent flora (Pierce, Esler & Cowling, 1995; Ihlenfeldt, 1994).

Mesembs are annual to perennial succulents where growth rate varies a great deal (Leister, 2000; Herre, 1971). For instance genera such as *Glottiphyllum*, *Aridaria* and *Mesembryanthemum* are short-lived or annuals completing their life cycle within one rainy season (van Jaarsveld & Pienaar, 2000). Species such as *Ruschia spp.* and *Stoberia arborea* are long-lived or perennials or slow growers and their growth rates depend on availability of water (van Jaarsveld & Pienaar, 2000). The range of this family is dominantly characterized by winter rain and species react by forming leaves and flowers mostly during that period (Hartmann, 2003; Smith et al., 1998). Fruits develop towards or in the dry summer period and seeds are ready for dispersal at the beginning of the next rainy season although this may differ from species to species (Smith et al., 1998; Ihlenfeldt, 1994). The species in this family have hygrochastic fruit capsules with rain dispersed seeds as a strategy for adaptation in arid and semi-arid lands in which this family is distributed (Burke, 2012; Leister, 2000; Smith et al., 1998; Ihlenfeldt, 1994).

Mesembs are generally found in sandy gravel and well-drained soils but this can also vary from species to species (Smith et al., 1998). Temperatures in the distribution areas of mesembs are low during winter and this is normally when the growing season takes place. However, growth ceases during summer when temperatures are hot (van Jaarsveld & Pienaar, 2000; Smith et al., 1998; Schwantes & Shurly, 1954). Insects pollinate mesembs because they are attracted to the mostly brightly colored petals; the flowers open during the day, in the afternoon or at night (van Jaarsveld & Pienaar, 2000; Smith et al., 1998; Ihlenfeldt, 1994). Many species in this family utilize CAM photosynthesis or are able to switch to the CAM from C_4 photosynthetic pathways (Burke, 2012; Whitford, 2002; Larcher, 1973).

This plant family is threatened by illegal collectors due to its attractiveness, agriculture practices such as overgrazing, mining and urban expansion (van Jaarsveld & Pienaar, 2000; Smith et al., 1998). Most of the mesembs have had their conservation status investigated and have been assigned IUCN Red Data conservation status (Smith et al., 1998). Mesembs are used as garden plants and landscaping and grown as curiosity plants. Other uses of these Mesembs include: food for both humans and animals, used in medication to treat various diseases such as sore throats and for fungal infections, important ingredients of traditional beer, traditional soap making, making cooking shelter around the fire, building shelter for animals and humans, used in removing hairs from animals and used as a source of moisture in an emergency for humans (van Jaarsveld & Pienaar, 2000; Smith et al., 1998).

2.2.1 Cultivation of Mesembs

Mesembs are easy to cultivate if given porous rich soil, deep pots and ample watering to facilitate germination (van Jaarsveld & Pienaar, 2000; Smith et al., 1998). General watering should be reduced to often light watering after germination since mesembs are adapted to semi-arid and arid conditions (Hammer, 1995). Cultivation of mesembs can be done both indoor and outdoor with propagation by seed and vegetative means (van Jaarsveld & Pienaar, 2000). Growing mesembs is often a process of trial and error and one must always start with easy growing species to more difficult ones (van Jaarsveld & Pienaar, 2000). For outdoor cultivation it is always best to plant cuttings at the beginning of the growing season in order to save water but they can also be planted any time of the year as long as sufficient moisture is provided for successful rooting (van Jaarsveld & Pienaar, 2000; Smith et al., 1998; Schwantes & Shurly, 1954).

Cuttings 100 to 150 mm in length are suitable and they can either be planted directly in a well-drained sandy medium or may be rooted *in situ* for later planting (van Jaarsveld & Pienaar, 2000; Smith et al., 1998). Rooting of cuttings takes place within a month depending on temperature and weather but because mesembs are rapid, opportunistic, relatively short-lived growers, some tend to die back after two or three years and need repropagation (van Jaarsveld & Pienaar, 2000; Smith et al., 1998).

When mesembs are grown indoors, it is important to note that they need ample light and sufficient air movement when in active growth (Smith et al., 1998).

Mesemb seeds can be harvested as soon as fruit capsules have hardened and dried and are ready for sowing (Leister, 2000; Smith et al., 1998). Mesemb seeds are best sown in shallow trays in sandy, well-drained soil. The first step is to place the medium in a tray and water it thoroughly before sowing the seeds evenly on the medium and covering the seeds with a thin layer of sand of about 1 mm deep. Germination is rapid and so is the subsequent growth (Smith et al., 1998; Schwantes & Shurly, 1954).

2.3 Strip mining for diamonds at NAMDEB

Strip mining for diamonds involves mining from the surface down to the bedrock and this type of mining is employed by NAMDEB with current operations (Fortuin, 2011; Pallett, 1995). NAMDEB currently holds seven diamond mining licenses covering both land and sea areas on and along the southwest coast of Namibia with the main land based operations in Oranjemund and satellite mines near Lüderitz and along the Orange River (Fortuin, 2011; Pallet, 1995). The company operates in the Sperrgebiet National Park located within the only arid land to qualify as one of the top 25 global biodiversity hotspots, the Succulent Karoo biome, which is home to relatively high percentage of both animal and plant endemics (Fortuin, 2011; Burke, 2006; Brooks et al., 2002; Myers et al., 2000; Cowling, 1999; Pallet, 1995). In the strip mining process, the topsoil which contains essential requirements for plant growth such as nutrients and microorganisms is lost, leaving no suitable substrate for plant growth (Miller & Spoolman, 2009; Burke, 2008; Burke, 2004b; Pallet, 1995). In addition, important slopes and Aspects and altitudes, soil texture and rockiness (Figure 2) which may be important in plant growth are also altered in the mining process (Wassenaar, 2010).

Figure 2. Example of slopes and Aspects supporting plant life at Sendelingsdrif which may be lost in the new mining operations.

NAMDEB started with the construction of a new mine along the Orange River at Sendelingsdrif in early 2012, in an area where there are plant species of conservation importance (Fortuin, 2011). This new mining operation may have negative impacts on the environment (Fortuin, 2011). Amongst the plant species of conservation importance at Sendelingsdrif are *Brownanthus arenosus, Euphorbia gummifera, Eberlanzia ebracteata, J. albata, Zygophyllum patenticaule, Hartmanthus pergamentaceus, Cephalophyllum herrei* and *Euphorbia chersina* (Fortuin, 2011;

Mannheimer, 2010). Although all these species are found both in the mining and surrounding areas, a significant proportion (39%) of the total global population of *J. albata* is found within the mining area (Burke, 2004b). This means that the population of *J. albata* may be significantly affected by this new mining operation. Therefore the present study was carried out to understand the biology of *J. albata* with the view to facilitate restoration of its population during and after mining (Fortuin, 2011).

2.4 Restoration ecology and its application in restoration of disturbed lands

Ecological restoration is an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability (van Andel & Aronson, 2005; Clewell, Aronson, & Winterhalder, 2004). An ecosystem requires restoration after it has been damaged, degraded or transformed by both human and natural activities such as mining and agricultural practices, floods, wildfires, volcanic eruptions and storms to the point where it cannot or takes too long to recover naturally by itself (van Andel & Aronson, 2005; Clewell et al., 2004). Ecological restoration aims at returning a degraded ecosystem to its (near) old state or its historic trajectory (Clewell & Aronson, 2007; Clewell et al., 2004; Bradshaw, 1997). A distinction should be drawn between restoration ecology and ecological restoration where the latter is the practice of restoring ecosystems as performed by practitioners at specific sites, whereas the former is the science upon which the practice itself is based (van Andel & Aronson, 2005; Clewell et al., 2004).

2.4.1 Some case studies in restoration ecology

Several studies in restoration ecology have been conducted both in Namibia and abroad to address ecosystem disturbances due to anthropogenic and natural activities (e.g. Phama, Panagos, Myburgh & Pfab, 2014; Burke, Newton, Boyce, Kolberg & Brunner, 2011; Pueyo, Alados, Garcia-Avila, Kefi, Maestro & Rietkerk, 2009; Lalley & Viles, 2008). Similar studies to what was done in the present study are briefly discussed below.

Amongst others, a study was carried out in the Namib Desert to determine recovery rates of lichen-dominated soil crusts in a hyper-arid desert following human disturbances (Lalley & Viles, 2008). The study revealed that variables that most strongly influenced recovery rates included the following: the overall cover of lichen growth and total number of lichen species in the bordering undisturbed areas, the extent of soil compaction in the disturbed area, altered soil surface micro-relief and vitality of subsurface soil crust components. The study estimated recovery time of the disturbed ecosystems and these ranged from 5 to 530 years (Lalley & Viles, 2008).

Another study was carried out to reestablish a keystone species, the Saltbush (*Salsola nollothensis*) in an arid coastal environment in Namibia following disturbances by alluvial diamond mining at NAMDEB (Burke et al., 2011). This study showed that seed quality of Saltbush species deteriorates quickly if stored at ambient conditions and storage under controlled conditions. Consequently, seed harvesting just before restoration was recommended. The study also recommended that seeds must not be buried too deeply for seedling emergence and that a set of environmental conditions (right moisture and temperature) must be met to achieve recovery or restoration of this species (Burke et al., 2011).

In Spain, a study was carried out to compare direct abiotic amelioration and facilitation as tools for restoration of semi-arid grasslands (Pueyo et al., 2009). Seedlings and seeds of *Lygeum spartum* and *Salsola vermiculata* were planted and sown in a stably degraded semi-arid area in Northeast Spain. Two levels of direct abiotic amelioration (ploughing and damming) and indirect abiotic amelioration through facilitation by *Suaeda vera* nurse shrubs were compared with a control with no amelioration treatment. The control treatment showed low plant establishment, confirming the practical irreversibility of the degraded state. Plant establishment was significantly higher in the three treatments with interventions than in the control treatment (Pueyo et al., 2009).

In South Africa, a study was carried out at Magaliesberg Mountain Range in the north of the Gauteng Province to establish area of occupancy, population structure, and past population trends of the IUCN Endangered endemic plant *Aloe peglerae* (Phama, et al., 2014). This biological information was required to accurately classify *Aloe peglerae* according to IUCN Red List categories. The study results showed that area of occupancy of *Aloe peglerae* ranged in size from 7 ha to 67 ha and the population structure of subpopulations of *Aloe peglerae* occupying different sites did not significantly differ (Phama et al., 2014). The study further revealed that the population size structure of *Aloe peglerae* was found to be dominated by mature plants, followed by juvenile plants and seedlings. The mean population density of *Aloe peglerae* showed a decline of 43% between 1999 and 2010 (Phama et al., 2014).

2.4.2 Planning and implementing a restoration ecology project

Setting up goals for management and restoration ecology project is an important initial step in designing and implementing a restoration ecology project. It is important to ensure that well defined project goals are put in place before starting with an ecological restoration project (Hobbs, 2003). These goals and aims must be achievable and have to be agreed upon by everyone involved in a project (van Andel & Aronson, 2005). Well defined goals can then be used as performance targets and they must be measurable (Hobbs, 2003). Setting goals depend on a prior assessment of current condition of the area or ecosystem being considered (van Andel & Aronson, 2005). One can ask the following questions in formulating restoration ecology project goals (Wassenaar, 2010):

a) What do we want to achieve with the restoration project?
b) How will we know whether we have achieved it (what are the reference states and conditions?)?
c) What must we do to achieve our objectives (what are the most important things that should be reinstated?)?
d) How will our approach work to restore the ecosystem (our best predictions of what will happen)?
e) What ecological tools do we have available?
f) How will we ensure that our aims are achieved?

Once goals are set a restoration ecology project can be implemented and success can be measured by looking at what is aimed for from initial conditions assessed (Clewell et al., 2004; Hobbs, 2003). After implementation of a project one has to develop method(s) to detect change in the condition being monitored. Before choosing a suitable monitoring method, one has to consider what ecological variables can be monitored, time, effort and money involved (Clewell & Aronson, 2007; Hobbs, 2003). On the basis of the project goals, it is important to choose monitoring methods that are easy to understand and carry out in order to obtain desired results (Clewell & Aronson, 2007; Hobbs, 2003). Adaptive management is an important tool in a successful restoration ecology project where managers need to realize that what they are doing may not be the right thing and that they can improve the project methodology if things do not work out as planned (Hobbs, 2003).

2.5 Environmental factors

Plants survive in an environment which has the right requirements for growth and survival (Yonavjak, Schoch & Mckinney, 2007; Barbour, et al., 1999). These requirements occur naturally in the habitats where plants grow and are collectively known as environmental factors (Barbour et al., 1999; Starr, 1991). A habitat is a physical space or place that provides or has a variety of conditions and resources (e.g. food, shelter and water) required for the growth and survival of organisms; both plants and animals (Starr, 1991; Barbour, Burk & Pitts, 1987). Environmental factors are any biotic or abiotic factors which influence living organisms (Enger & Smith, 2013; Smithson, Addison & Atkinson, 2002). These factors interact and determine whether a certain plant survives in a certain environment or not (Enger & Smith, 2013; Barbour et al., 1999).

In some environments plants develop characteristics and features in order to survive or adapt to changing or harsh environmental conditions (Keller & Botkin, 2005; Barbour et al., 1999). For example in the Namib Desert where plants live under extreme conditions such as high temperatures and droughts, plants such as the *Acanthosicyos horridus* do not have leaves (reduces water loss through transpiration) but instead photosynthesize through cells in the stems of the plant (Burke, 2012; Whitford, 2002). The following examples of environmental factors (the soil, plant nutrients, light, temperature, topography and water) that limit plant growth and survival of plants are briefly discussed (Barbour et al., 1999);

2.5.1 The soil

One of the most important environmental factors affecting the growth and survival of plants in an ecosystem is the soil (Whitford, 2002). Soil is pulverized rock to which has been added air, water, fungi, dead leaves and roots, dead bodies and dung of worms, insects and other animals (Esler, Milton, & Dean, 2006; Dean & Milton, 1995). Soil is formed as a result of complex interactions between lithological characteristics (geological history of the parent rock), climate and biological activity (Coleman, Crossley & Hendrix, 2004; Whitford, 2002; Fitzpatrick, 1986). A process of weathering leads to soil formation because it involves breaking down of rocks into soil through changing temperature and pressure, chemical reaction and the activities of animals, plants and people (Smithson et al., 2002; Barbour et al., 1999). Soil has many functions and importance such as providing the medium in which plants grow, water, nutrients, firmly fixes the roots of plants in the ground, support soil microorganisms with shelter and regulating water supplies and recycling material (Barbour et al., 1999; Cunningham & Saigo, 1997).

Soil has both physical and chemical properties and these properties determine whether certain plant species establishes or survives in a particular environment or not (Smithson et al., 2002; Brady & Weil, 2002). These properties vary greatly from place to place in line with different soil constituents (Smithson et al., 2002; Thompson & Coyne, 2006). Soil constituents are generally in three phases namely: solid (mineral particles together with some organic particles), liquid (solution of various salts in water) and gas phase (consisting of changing amounts of oxygen, carbon dioxide and nitrogen) (Coleman et al., 2004; Smithson et al., 2002). These three phases interact and determine the ability of the soil to support plant growth and survival (Smithson et al., 2002; Whitford, 2002).

2.5.1.1 Soil physical properties

Soil physical properties are composed of mineral and organic particles of varying sizes which are strongly bonded together and some physically mixed within it (Smithson et al., 2002). The mineral particles are classified into groups having definite size limits and each group is called a soil separate (Smithson et al., 2002; Plaster, 1997). Three basic separate fractions are recognized namely sand, silt and clay and the relative proportions of these separates determine the soil texture to give the textural name (Smithson et al., 2002; Whitford, 2002; Brady & Weil, 1999). Soil texture can be classified in the field by a simple technique of moistening a handful of soil, working it between the fingers and determining the texture by the feel of the moist soil (Smithson et al., 2002). Accurate determination using the principle of sedimentation can be performed in the laboratory using a hydrometer or a pipette (Smithson et al., 2002). Soil texture influences the ability of the soil to support plant growth and survival. For example clay has finer particles, which holds more water and thus improves the soil's water holding capacity which is necessary to support plant life (Coleman et al., 2004; Smithson et al., 2002; Barbour et al., 1999).

An additional important physical property is the soil structure which is the arrangement of individual soil particles into larger aggregates or peds of various sizes and shapes (Smithson et al., 2002; Barbour et al., 1999). Soil structure influences water infiltration rate, aeration and percolation in various ways (Nortcliff & Gregory, 2013; Passioura, 1991). For example, compacted larger aggregates or peds reduce water infiltration rate, aeration, percolation or can also make it hard for plant roots penetration into the soil which results in poor plant growth (Nortcliff & Gregory, 2013; Passioura, 1991).

Soil organic matter which comes from both living and dead sources (roots, leaves, microbes, and fauna) is another important soil physical property because of the role it plays in influencing soil properties (Coleman et al., 2004; Smithson et al., 2002). Organic matter can improve the water holding capacity of sand and can improve the drainage properties of clay resulting in enhanced plant growth (Smithson et al., 2002; Barbour et al., 1999). In addition, organic matter improves soil structure by creating spaces among soil aggregates and adding stability by holding these aggregates together resulting in enhanced plant growth (Nortcliff & Gregory, 2013).

Soil water is another important property of soil because it supports plant growth (Barbour et al., 1999). When it rains, soil porosity or the total volume of pore space in soil (also called air capacity) fills with water and this water is absorbed by plant roots to support plant growth (Coleman et al., 2004; Smithson et al., 2002; Brady & Weil, 1999). The amount of water which can be stored in the soil is determined by other soil physical properties such soil structure, soil texture and organic matter content because these factors have an effect on the size and distribution of the pore spaces (Smithson et al., 2002; Fitzpatrick, 1986). Soil moisture is one of the major factors limiting plant growth in many ecosystems across the globe especially the arid ones (Whitford, 2002; Wang, Fu, Gao, Yao & Zhou, 2012). Water is needed by plants for photosynthesis, tissue rigidity and to produce carbohydrates (Nortcliff & Gregory, 2013). Lack of soil moisture leads to reduced plant growth or mortality (Nortcliff & Gregory, 2013). Water content in the soil is determined by measuring the loss in weight when a moist soil is dried in an oven at 105 degrees Celsius overnight and it is expressed as a percentage of the oven dried soil (Smithson et al., 2002).

The soil's permeability which is the ability of the soil to allow excess gravitational water (water which quickly drains away) to drain away from soil in macropores or transmission pores larger than 0.05 millimeters diameter, is closely linked with soil texture and structure (Thompson & Coyne, 2006; Smithson et al., 2002). For example clay soils with high porosity usually have low permeability and vice versa with sandy soils. Infiltration rate (distance moved by water per unit time as it seeps through the soil) is low in clay soils and high in sandy soils (Ashman & Puri, 2002; Smithson et al., 2002; Plaster, 1997). Infiltration rates of soils can be measured in the field with a commercial infiltrometer or a homemade device such as a tin or plastic piping. The procedure is straight forward and it involves recording the time it takes a certain volume of water to completely infiltrate the soil (Smithson et al., 2002). Soils with higher water infiltration rate and permeability coupled with high contents of organic matter support more plant life (Nortcliff & Gregory, 2013; Parsons & Abrahams, 1994).

2.5.1.2 Soil chemical properties

Nutrient elements which are important to sustain plant life are found in the soil and plants must absorb them through their roots (Barbour et al., 1999). Soil pH, which is defined as the negative index of the logarithm of the hydrogen ion (H^+) concentration is an important chemical property of the soil (Smithson et al., 2002; Plaster, 1997). Soil pH determines the availability of soil nutrients and toxicity of certain metals on microbial activities (Smithson et al., 2002; Brady & Weil, 1999; Barbour et al., 1999). At lower soil pH toxic metals such as aluminum and manganese are soluble and hence toxic to plants. Availability of nutrients such as nitrogen, phosphorus, and sulfur, and the leachability of nutrients such as potassium are all influenced by soil pH (Smithson et al., 2002; Brady & Weil, 1999; Barbour et al., 1999). Availability of nutrients with low solubilities, such as phosphorus, is also drastically influenced by soil pH changes (Whitford, 2002; Smithson et al., 2002; Brady & Weil, 1999; Barbour et al., 1999). Nutrients such as calcium phosphates are less soluble as the soil pH increases, and iron and aluminum phosphates are less soluble as the pH drops (Whitford, 2002; Smithson et al., 2002; Brady & Weil, 1999; Barbour et al., 1999). In general, a near- neutral soil pH between 6.5 and 7.5 is best for the availability of most nutrients needed for plant growth (Whitford, 2002; Smithson et al., 2002; Brady & Weil, 1999; Barbour et al., 1999). Importance and functions of plant nutrients are briefly discussed below:

Plant nutrients are mineral elements and inorganic compounds that are required by plants for growth, metabolism and survival (Barbour et al., 1999; Wilkinson, 1994). Nutrients needed by plants have been categorized according to relative quantities required by plants for adequate nutrition (Smithson et al., 2002; Barbour et al., 1999; Wilkinson, 1994). Major nutrients are those required in large amounts and are referred to as macronutrients (Table 1). Those nutrients required in only small or trace amounts are minor nutrients and are collectively known as micronutrients (Larcher, 2001; Barbour et al., 1999; Wilkinson, 1994). When plant nutrients are not in the right combination and amount plants may develop deficiency symptoms (Crawley, 1986; Starr, 1991). Plant available nutrients must not be too few or too much since at high levels nutrients can be toxic which may lead to plant death (Crawley, 1986; Starr, 1991). Deficiency symptoms which plants may develop include new leaves that are distorted or irregularly shaped, wilting, yellowing of older leaves and stunted growth (Crawley, 1986; Starr, 1991). These symptoms may lead to plant death (Crawley, 1986).

Table 1. Essential plant nutrients, the form available to plants, mg/kg, or percent of dry weight (*Source*: Barbour et al., 1999).

Element	Principal form in which element is absorbed	Usual concentration in healthy plants (% or ppm of dry weight)	Important functions
Macronutrients			
Carbon	CO_2	~44%	Component of organic compounds.
Oxygen	H_2O or O_2	~44%	Component of organic compounds.
Hydrogen	H_2O	~6%	Component of organic compounds
Nitrogen	NO_3^- or NH_4^+	~1 -4 %	Component of amino acids, proteins, nucleotides, nucleic acids, chlorophylls, and coenzymes.
Potassium	K^+	~0.5 -6%	Involved in osmosis and ionic balance and in opening and closing of stomata; activator of many enzymes.
Calcium	Ca^{2+}	~0.2- 3.5%	Component of cell walls; enzyme cofactor; involved in cellular membrane permeability; component of calmodulin, a regular of membrane and enzyme activities.
Phosphorus	$H_2PO_4^-$ or HPO_4^{2-}	~0.1 – 0.8%	Component of energy - carrying phosphate compounds (ATP and ADP), nucleic acids, several essential coenzymes, phospholipids.
Magnesium	Mg^{2+}	~0.1 – 0.8 %	Part of the chlorophyll molecule: activator of many enzymes.
Sulfur	SO_4^{2-}	~0.05-1%	Component of some amino acids and proteins and of coenzyme A.
Micronutrients			
Iron	Fe^{2+} or FE^{3+}	25 – 300 ppm	Required for chlorophyll synthesis; component of cytochromes and nitrogenase.
Chlorine	Cl^-	100 -10 000 ppm	Involved in osmosis and ionic balance; probably essential in photosynthetic reactions that produce oxygen.
Copper	Cu^{2+}	4 – 30 ppm	Activator or component of some enzymes.
Manganese	Mn^{2+}	15 – 800 ppm	Activator of some enzymes; required for integrity of chloroplast membrane and oxygen release in photosynthesis.
Zinc	Zn^{2+}	15 -100 ppm	Activator of component of many enzymes.
Molybdenum	MoO_4^{2-}	0.1 – 5.0 ppm	Required for nitrogen fixation and nitrate reduction.
Boron	$B(OH)_3$ or $B(OH)_4^-$	5- 75 ppm	Influences Ca^{2+} utilization, nucleic acid synthesis, and membrane integrity.
Elements essential to some plants or organisms			
Sodium	Na^+	Trace	Involved in osmotic and ionic balance; probably not essential for many plants; required by some desert and salt- marsh species and may be required by all plants that utilize C_4 pathway of photosynthesis.
Cobalt	Co^{2+}	Trace	Required by nitrogen - fixing microorganisms.

An additional important soil chemical property is the Cation Exchange Capacity (CEC) which is a measure of the number of negatively charged sites on soil particles that attract exchangeable cations that is, positively charged ions (such as Ca^{2+} , Mg^{2+} and Na^{+}) available for plant uptake (Smithson et al., 2002; Barbour et al., 1999). Factors that strongly influence the CEC of a soil are its clay content (such as alumina and silica), the kinds of clay content, the kinds of clay minerals or amorphous colloids it contains (such as kaolinite, montmorillonite, chlorite and mica) its humus content, and its pH (Smithson et al., 2002; Thompson & Coyne, 2006; Barbour et al., 1999). For example soils with low organic matter will have low CEC resulting in poor plant growth (Smithson et al., 2002; Barbour et al., 1999).

Other important environmental factors affecting the survival of organisms in their habitats include light, temperature, topography and water (Barbour et al., 1999; Jackson & Jackson, 1996). Light is the source of energy for plant life in most if not all terrestrial ecosystems; light is needed by plants for food production in photosynthesis. Temperature regulates rates of physiological processes and influences growth and development of plants. Water is needed by plants to help seeds germinate, it is needed in photosynthesis for plant food production and in the transport of mineral and nutrients from the soil (Keller & Botkin, 2000; Nelson, Beaton, Haulin & Tisdale, 1993).

Topography is an important environmental factor because it can result in features such as slopes which differ in soil characteristics and water availability and therefore support differing plant communities (Esler et al., 2006; Whitford, 2002). For example in the Succulent and Nama Karoo, establishment of vegetation occurs in response to availability of water, nutrients and solar energy which are all influenced by topography (Dean & Milton, 1999). In addition, topography may result in favorable habitats with different rock covers and soil depths. For instance rocks and boulders on koppies in the Karoo may become pockets of deeper soils which can trap moisture which is good for grasses and trees to become established (Esler et al., 2006; Dean & Milton, 1995).

2.6 Population Ecology

Population Ecology is concerned with changes in the population and the population structure and factors that affect populations (Barbour et al., 1999). In plants, population ecology deals primarily with describing the structure of a population and the distribution of individuals in order to understand plant dynamics (Barbour et al., 1999). A population is defined as a collection of individuals belonging to the same species living in the same area (Charlesworth & Silvertown, 2001). For example all members of one species in a farm constitute a population (Esler et al., 2006). Plant population structure may refer to any of the five aspects; plant performance, age, spacing, height and genetic structure and all these facets are interrelated, so that an alteration in one facet generates alterations in the others (Burke, 2012; Crawley, 1986).

Density is the number of individuals per unit area, such as 300 sugar maples (*Acer saccharum*) per hectare in a Michigan forest or *J. albata* plants per square meter

(Barbour et al., 1999). Differences between crude and ecological densities should be noted. Crude density is the individuals per unit total space e.g. number of *J. albata* plants in all land in its range (Vijayakumar & Paulsamy, 2010). It includes all the land or space within organisms' ranges (Kohli, Singh & Batish, 2007). Ecological density is the individuals per unit of habitat space i.e. available space which can actually be colonized by organisms (Vijayakumar & Paulsamy, 2010; Kohli, Singh & Batish, 2007). It is not necessary to count every individual in an area to get the density value but one may subsample randomly to get a close estimate. A method for sampling to estimate plant density depends on the pattern of how individuals in a population are distributed within the study area (Elzinga, Salzer, Willoughby & Gibbs, 2001; Barbour et al., 1999).

Three statistical distributions, random, regular and clumped, are recognized and plant populations in a certain area may follow them (Elzinga et al., 2001; Barbour et al., 1999). In a random pattern, the allocation of any one plant has no bearing on the location of another of the same species, in a clumped pattern, the presence of one plant increases the probability of finding another nearby and in a regular pattern, the presence of one plant decreases the probability, relative to random chance alone, of finding another very nearby or very far away (Elzinga et al., 2001; Barbour et al., 1999). These three statistical distributions are driven largely by food supply and other resources such as water and sunlight (Skarpe, 1991; MacMahon & Phillips, 1981). In random patterns, resources such as soil nutrients, water and light are distributed evenly in the habitat which means there is limited competition among plants following this pattern (Weiner, 1993; Skarpe, 1991). Clumped patterns occur in habitats where resources needed by plants occur in productive patches (Skarpe, 1991; MacMahon & Phillips, 1981). Plants aggregate around resources such as soil nutrients in a habitat resulting in clumped patterns forming (Skarpe, 1991; MacMahon & Phillips, 1981). In regular patterns, there are limited resources in the habitat and as a result there is very high competition among plants for available resources (Weiner, 1993; Skarpe, 1991).

A population of organisms including plants is subject to change because new individuals must replace old and dying ones, otherwise the population will disappear (Esler et al., 2006; Miller & Ricklefs, 1999; Dean & Milton, 1995). A population in both plants and animals is affected by age structure (Charlesworth & Silvertown, 2001). A population with matured reproducing individuals will increase and young individuals indicate future population increase. This is only guaranteed if young individuals are able to survive to mature stage (Esler et al., 2006; Charlesworth & Silvertown, 2001). Young individuals in plants do not always reach maturity as their growth rates are highly dependent on the local environment and it can also vary between genetically identical individuals (Charlesworth & Silvertown, 2001).

Movement of individuals into the population is termed immigration and together with birth or recruitment of new individuals, may lead to population increase. Movement of individuals out of the population is termed emigration and together with death of individuals, may lead to population decrease (Esler et al., 2006; Miller & Ricklefs, 1999). Also, grazing may reduce plant populations or increase the death rate of forage plant population but animals may also increase plant populations by increasing opportunities for seedling establishment through seed dispersal (Esler et al., 2006).

Seed dispersal which is the movement of plant seeds from one area to another with the help of water, animals or wind or explosion of pods, may contribute to plant population increase (Croteau, 2010). For example, if dispersed plant seeds are viable and successfully germinate in an environment they can lead to plant population increase (Esler et al., 2006). Rainfall contributes to plant population increase through inducing seed germination, growth and development. In periods of drought plant population may drastically decrease (Esler et al., 2006). Lastly, climate change may lead to the following detrimental or beneficial effects which may result in the decrease or increase in the plant populations (Esler et al., 2006; Harris, Hobbs, Higgs & Aronson, 2006; Low, 2005; Miller, 2004; Dean & Milton, 1995):

a) Changes in rainfall cycles and annual temperature fluctuations.
b) Increased diseases and pest populations.
c) Increased exotic plant species populations.
d) A rise in global sea level.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study area

The study was conducted at NAMDEB's Sendelingsdrif diamond mine (28° 9'26.00"S, 16°51'42.74"E) situated on the northern bank of the lower Orange River in the southern Namib Desert and within the Sperrgebiet National Park (Figure 3). The study area is located ±10 km to the south of the town of Rosh Pinah and 20 km to the north of Debaras mine at NAMDEB (Figure 3). The mine is located in the northern parts of the Succulent Karoo biome (Figure 4) which is the only arid land to qualify as one of the top 25 global biodiversity hotspots and has protected IUCN Red Data book endemic plant and animal species (Fortuin, 2011; Loots, 2005; Brooks et al., 2002; Myers et al., 2000; Cowling, 1999). The study area is situated in a succulent shrubland that has sparse shrubs in which the dominant species include *B. arenosus, E. gummifera, E. ebracteata, J. albata, Z. patenticaule, H. pergamentaceus, C. herrei* and *E. chersina* (Fortuin, 2011; Mannheimer, 2010). Animals such as *Oryx gazelle, Raphicerus campestris, Antidorcas marsupialis, Ctenolepisma luederitzi, Opisthopthalmus adustus* and *Petromys typicus* occur in the study area (Fortuin, 2011; Wassenaar, 2010; Mendelsohn, Jarvis, Roberts & Robertson, 2002).

The geology of the study area belongs to the two deposits namely: Proto-Orange deposits (dated at 17 to 19 million years old) and Meso-Orange deposits (dated at 2 to 5 million years old) (http://www.namdeb.com/about_prod_overview.php). Soils in the study area are loamy to sandy in some places (Wassenaar, 2010). Thirteen habitat types (Figure 6) were identified in the study area based on topography, geology and soil depth of the area (Fortuin, 2011; Wassenaar, 2010). These habitats included Braided channels, Broad sandy wash, Lower terrace, Smothered proto terrace, Meso terrace, Proto terrace, Orange river, Riparian, Rocky hills, Seep, Shallow soil on ridges, Sheltered gully and Uplands (Figure 6). The land use for the study area is mining for diamonds but it will be used for nature-based tourism after it has been restored post mining (Fortuin, 2011). Rainfall, which occurs primarily in winter (June to August), is less than 100 mm per year and fog occurs occasionally (Wassenaar, 2010; Cowling, 1999; Cowling, et al., 1997). Summer (December to February) temperatures may reach 40°C and the average winter minimum may be as low as 12°C. Prevailing summer winds are south and south-westerly, but hot easterly bergwinds also occur and most common in winter (Wassenaar, 2010; Mendelsohn, at., 2002).

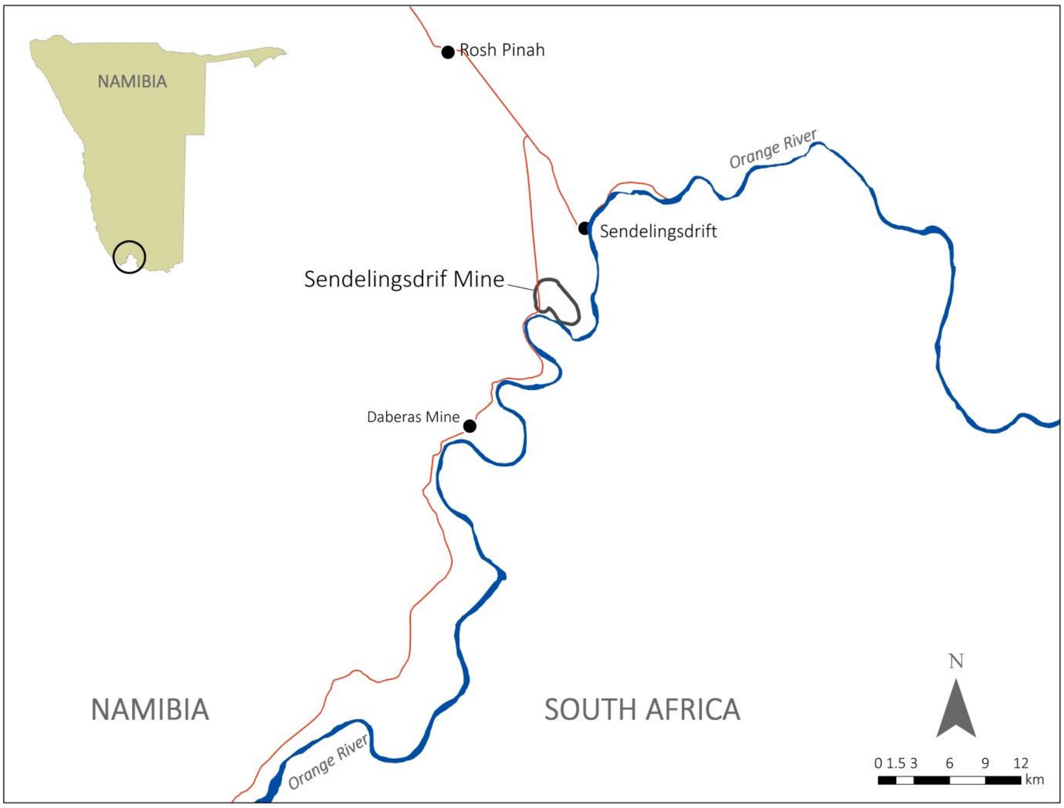

Figure 3. An overview map of the area where Sendelingsdrif diamond mine is located showing its position relative to Rosh Pinah and Daberas mine (*Source*: Wassenaar, 2010).

Figure 4. Map of the Succulent Karoo, a biodiversity hotspot in which the study area is located (*Source:* http://www.cepf.net/where_we_work/regions/africa/succulent_karoo/Pages/default.aspx).

3.2 Research design

The study was divided into two components: a) the field survey and b) the heap experiment which was carried out outside the greenhouse in the mining area at Sendelingsdrif diamond mine. The two components of this study were designed to collect quantitative data. For the field survey, seventy one (71) random points were generated using ArcGIS software in seven habitat types in the study area namely: Sheltered gully (n=11), Broad sandy wash (n=10), Rocky hills (n=10), Shallow soil on ridges (n=10), Proto terrace (n=10), Meso terrace (n=10) and Lower terrace (n=10) (Figure 6) (also described in this Chapter in section 3.3 and 3.4.1) to survey the whole mining area and its surroundings for *J. albata* plants. The seven habitats were selected because mining for diamonds will be carried out on these and hence directly impacted (Fortuin, 2011; Wassenaar, 2010).

In the heap experiment, *J. albata* was grown on twelve experimental heaps that comprised a mixture ratio (1:1:1) between fine tailings (post mining soil particles which are less than or equal to 2 mm in size), coarse tailings (post mining rocks which are more than 2 mm to 25 mm in size) and oversize tailings (post mining rocks which are more than 25 mm to 50 mm in size) obtained from the current exploration plant at Sendelingsdrif diamond mine. The experimental layout followed a factorial experimental design. The two factors were: slope at two levels (steep and gentle slope experimental heaps which were both made up of the above described post mining materials where steep slope experimental heaps had an average slope angle of 27° and 20° for gentle slope experimental heaps) and Aspect at nine different levels (namely: north, south, west, east, southwest, northwest, northeast, southeast and level (top part of each experimental heap where the slope angle is 0°)) (Figure 5). Six experimental heaps had gentle slopes and the other six had steep slopes respectively (Figure 5). The experimental heaps were erected in two rows 30 m apart and spaced about 15 m apart within each row (Figure 5). The position of each experimental heap was randomly determined using random numbers generated between one and twelve in Microsoft Excel.

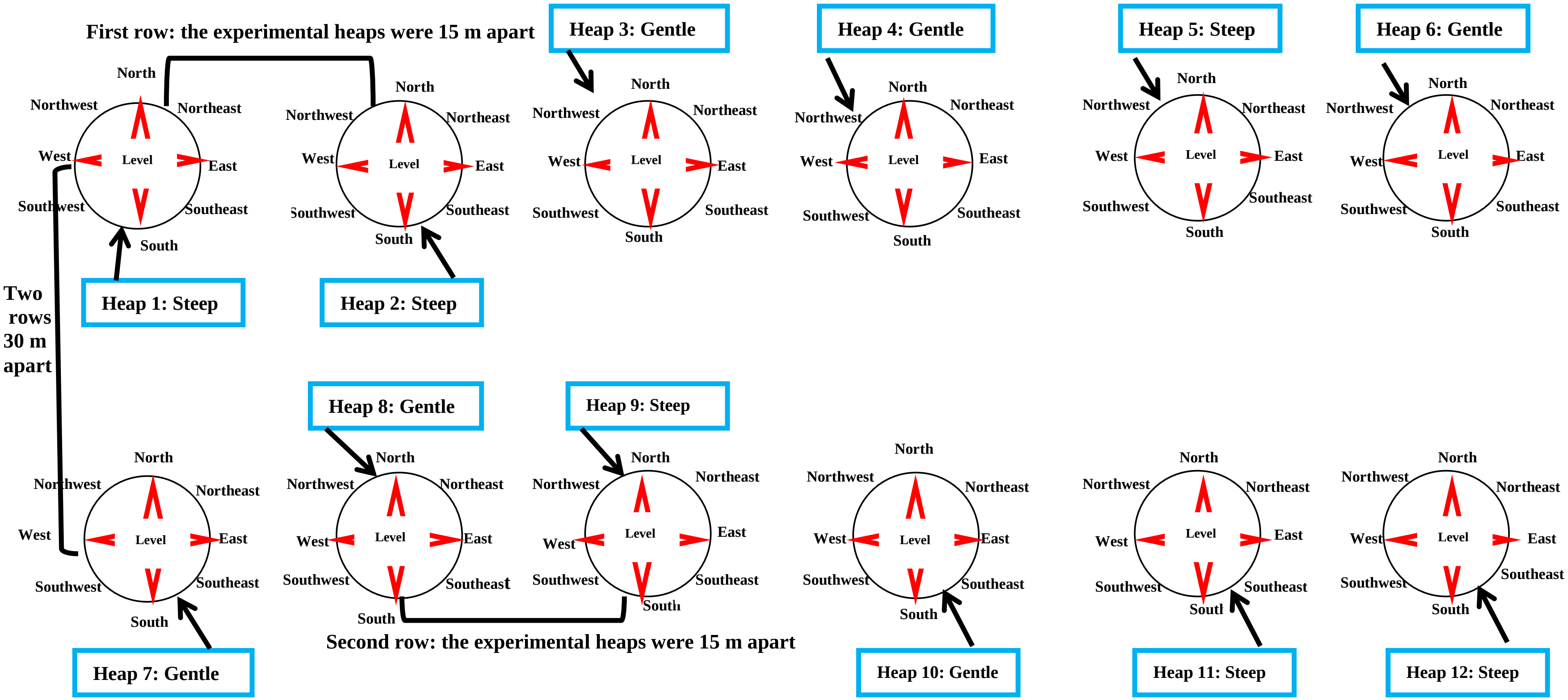

Figure 5. The heap experimental layout followed a factorial experimental design. The experiment consisted of twelve experimental heaps, six gentle slope heaps and six steep slope heaps (indicated by 12 circles), which were placed in two rows, 30 m apart. The heaps were spaced about 15 m apart within each row. Each heap was then divided into nine Aspects (namely: north, south, west, east, southwest, northwest, northeast, southeast and level) as indicated in this figure.

3.3 Population

Thirteen habitat types (Figure 6) were identified at Sendelingsdrif diamond mine based on topography, geology and soil depth of the area. *Juttadinteria albata* occur in some of these 13 habitat types (Fortuin, 2011; Wassenaar, 2010). These habitats included Braided channels, Broad sandy wash, Lower terrace, Smothered proto terrace, Meso terrace, Proto terrace, Orange river, Riparian, Rocky hills, Seep, Shallow soil on ridges, Sheltered gully and Uplands (Figure 6). The population from which samples were drawn consisted of all *J. albata* plants in seven selected habitat types namely: Sheltered gully, Broad sandy wash, Rocky hills, Shallow soil on ridges, Proto terrace, Meso terrace and Lower terrace (Figure 6). The seven habitats were selected because mining for diamonds will be carried out on these and hence directly impacted (Fortuin, 2011; Wassenaar, 2010).

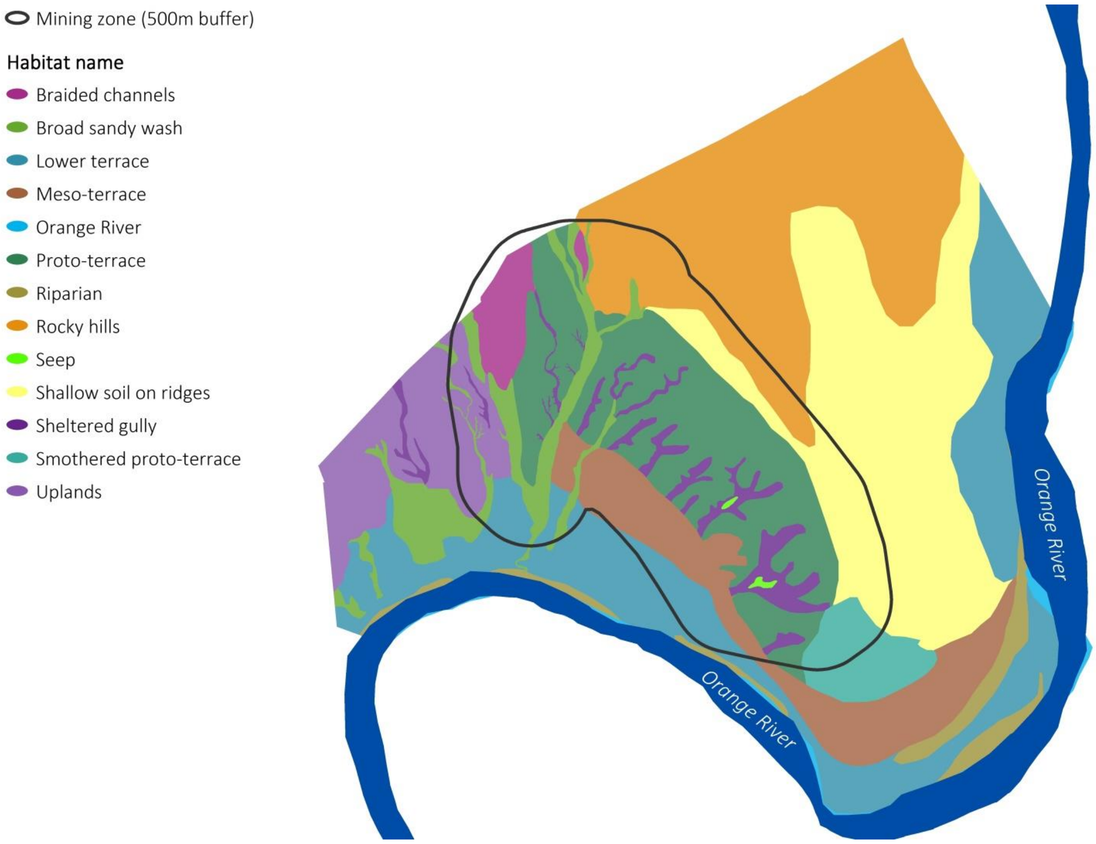

Figure 6. Map showing habitats at Sendelingsdrif diamond mine (*Source*: Wassenaar, 2010).

3.4 The Field Survey

3.4.1 Sampling procedures

Seventy one (71) random points were generated using ArcGIS software in seven habitat types namely: Sheltered gully (n=11), Broad sandy wash (n=10), Rocky hills (n=10), Shallow soil on ridges (n=10), Proto terrace (n=10), Meso terrace (n=10) and Lower terrace (n=10) (Figure 6). At each random point a 4 m x 4 m random quadrat (random because a random point from ArcGIS was in the centre of this quadrat (Figure 7)) was laid down and selected environmental factors were measured and recorded as described below in section 3.4.3. *Juttadinteria albata* has an apparent rarity and aggregated distribution pattern in the study area and it was for this reason that a method was developed to improve the chances of finding this plant (Burke, 2004b).

Searching was done around each 4 m x 4 m random quadrat (since all the 4 m x 4 m random quadrats were not near or next to *J. albata* plants) in a circle of 150 m radius to find the nearest *J. albata* plant (Figure 7). Then this nearest plant was used as a starting point to lead to the highest density of *J. albata* within a 50 m x 50 m quadrat (Figure 7). This nearest plant was also determined randomly since it is associated with 4 m x 4 m random quadrats which are direct results of random points generated in ArcGIS. Some 4 m x 4 m random quadrats in these habitats had no *J. albata* plants growing in their vicinities of 150 m radius and as a result no associated 50 m x 50 m quadrats were laid down around them. In a prior study, *J. albata* plants were on average observed to be aggregated in 50 m x 50 m subpopulation sizes within their range hence the choice of 50 m x 50 m quadrats (Burke, 2004b). Subpopulation sizes refer to, in this regard, *J. albata* plants found aggregated or clumped in spaces of sizes 50 m x 50 m within its range (Burke, 2004b).

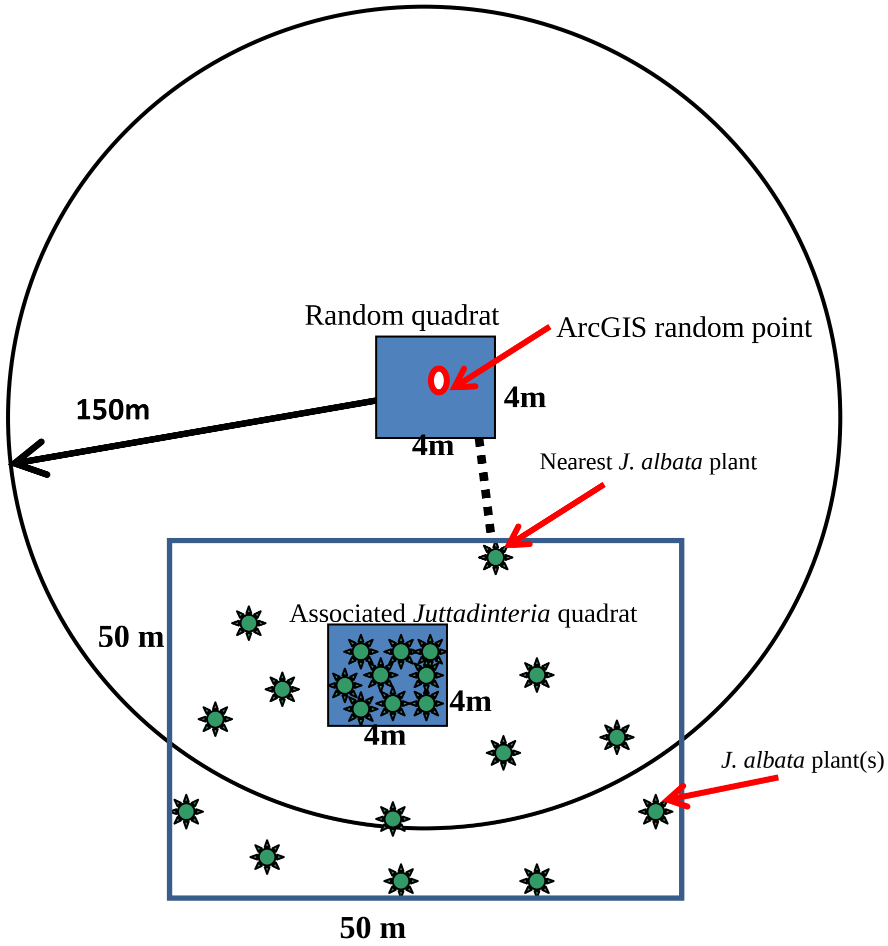

Figure 7. Diagram explaining sampling procedures. A circle of radius 150 m with a 4 m x 4 m random quadrat (with a random point generated using ArcGIS) in the centre is indicated. The nearest *J. albata* plant and 50 m x 50 m quadrat as well as associated 4 m x 4 m *Juttadinteria* quadrat are also indicated. The green stars are representing *J. albata* plants.

There were eight 50 m x 50 m quadrats in Rocky hills, 11 in Sheltered gully, 10 in Shallow soil on ridges, 8 in Proto terrace, 2 in Broad sandy wash, 1 in both Meso terrace and Lower terrace. Each of these 50 m x 50 m quadrats resulted in associated 4 m x 4 m *J. albata* quadrats (*Juttadinteria* quadrats) which were then laid down where the highest density of *J. albata* was found (Figure 7). There were eight 4 m x 4 m *Juttadinteria* quadrats in Rocky hills, 11 in Sheltered gully, 10 in Shallow soil on ridges, 8 in Proto terrace, 2 in Broad sandy wash, 1 in both Meso terrace and Lower terrace. In each 4 m x 4 m *Juttadinteria* quadrats, selected environmental factors which may be associated with *J. albata* and variables to describe its population structure in the study area were measured and recorded as described in this Chapter in section 3.4.2 and 3.4.3. The purpose of doing this was to obtain data from as many *J. albata* plants as possible hence this method of searching for *J. albata* randomly ensured that areas with highest density of the plant were adequately surveyed (Figure 7). The purpose of the paired 4 m x 4 m quadrats (the random 4 m x 4 m quadrat and its associated 4 m x 4 m *Juttadinteria* quadrat) was to detect the differences in habitat characteristics for presence and absence of the species.

3.4.2 Population structure of *J. albata* in the study area

In each 4 m x 4 m *Juttadinteria* quadrat, *J. albata* plants (juveniles and adults) were identified, counted and measured to allow calculation of canopy volume in order to help explain population structure in the study area (Phama et al., 2014). The count data was also used to calculate the density of *J. albata* in the study area. *Juttadinteria albata* plants were regarded as juveniles if their height were equal to or less than 5 cm and one of their canopy diameters was less than 6 cm (Coleen Mannheimer, personal communication, March 16, 2014). This combination was chosen because *J. albata* plants can be fully mature at more than the stated combination (Coleen Mannheimer, personal communication, March 16, 2014). Canopy diameter (in cm) measurements were recorded from each live *J. albata* plant rooted in each 4 m x 4 m *Juttadinteria* quadrat along two axes at right angles to each other and used to calculate the canopy volume according to the formula: $\pi LW/4*h$ where L and W refer to the two canopy diameters and h is the height of *J. albata* plants (Esler &

Cowling, 1992). The height of each live *J. albata* plant that was rooted in each 4 m x 4 m *Juttadinteria* quadrat was measured from the soil surface following Ellis & Weis (2006). Both the height and canopy diameters of *J. albata* plants were measured to the nearest cm.

In order to determine the spatial distribution pattern of *J. albata* in the study area three line transects each 1 km long were laid out. Three points were randomly selected one each in Proto terrace, Shallow soil on ridges and Sheltered gully to serve as starting points for these transects because these habitats were the ones where *J. albata* plants were most abundant. A total of five hundred 2 m x 2 m quadrats were laid down next to each other on each transect. In each 2 m x 2 m quadrat live *J. albata* plants were simply counted without any measurement taken and these count data were then used to determine the spatial distribution pattern of *J. albata* in the study area (Ludwig & Reynolds, 1988).

3.4.3 Environmental factors associated with *J. albata* in the study area

In the present study, rockiness referred to the percentage of soil surface area covered by rocks. It was calculated from measurements of rock diameters along systematically placed 1 m rulers at the centre and four corners of each 4 m x 4 m *Juttadinteria* and 4 m x 4 m random quadrat (five per quadrat). The length of the ruler covered by rocks was translated into percent rock cover (Esler & Cowling, 1992). Rocks less than two centimeters covering each ruler were simply estimated without any measurement taken by looking at how much of these rocks covered each ruler and given a percentage estimate. The slope angle of each 4 m x 4 m *Juttadinteria* and 4 m x 4 m random quadrat was determined using an angle locator instrument (home-made clinometer). In the study, Aspect of each 4 m x 4 m *Juttadinteria* and 4 m x 4 m random quadrat was determined using a compass. Soil infiltration rate, which is defined as the speed at which water infiltrate the soil per unit time (Smithson et al., 2002; Plaster, 1997), in all 4 m x 4 m *Juttadinteria* and 4 m x 4 m random quadrats was measured using a mini disk infiltrometer (an instrument designed to measure infiltration rate of the soil).

After removing the surface litter, soil samples were taken from each corner and at the centre of every 4 m x 4 m *Juttadinteria* and 4 m x 4 m random quadrat at a depth of 10 cm, and sieved through a 2 mm fraction mesh (Mapaure, Chimwamurombe, Mapani & Kamona, 2011; Midgley & Musil, 1989). These sub samples were mixed to form one sample per 4 m x 4 m *Juttadinteria* and 4 m x 4 m random quadrat (1 kg). A total of 82 soil samples were obtained from the investigated habitats (there were 16 soil samples in Rocky hills, 22 in Sheltered gully, 20 in Shallow soil on ridges, 16 in Proto terrace, 4 in Broad sandy wash, 2 in both Meso terrace and Lower Terrace).

Due to budget restrictions only 48 samples were selected and analyzed in the laboratory. These were randomly selected from 4 m x 4 m *Juttadinteria* (24 soil samples) and associated 4 m x 4 m random quadrats (24 soil samples) in Rocky hills (n=12), Sheltered gully (n=12), Shallow soil on ridges (n=12) and Proto terrace (n=12). Random selections of these soil sample pairs were done individually in each of these habitats which made it possible to obtain equal sample sizes for the analysis in the laboratory. In each of these habitats all soil sample pairs were assigned numbers upon which random selection was done using Microsoft Excel. These four habitats were selected because this is where *J. albata* was most abundant (Cornelis van der Waal, personal communication, December 23, 2013; Fortuin, 2011). Prior to analysis in the laboratory, soil samples were sieved through a 2 mm fraction mesh sieve and air dried (Analytical Laboratory Services cc Summarized Manual, 2012).

The following tests were performed on each of these soil samples. Soil pH was determined in a 1:2.5 soil: water extract of the soil using deionized water where samples were stirred and allowed to equilibrate after adding water; the actual determination was made using a hydrogen selective electrode and reported with one decimal (Analytical Laboratory Services cc Summarized Manual, 2012). This analysis was done on all randomly selected soil samples. Total nitrogen was tested using the Kjeldahl method and extractable phosphorus was determined using a UV - VIS Spectrophotometer (UV mini - 1240) method and these analyses were done on all randomly selected soil samples (Analytical Laboratory Services cc Manual, 2012). Organic carbon was measured using the Colorimetric Walkey - Black Method and soil texture was determined using a pipette method and reported as percent clay, percent sand and percent silt and these analyses were done on all randomly selected soil samples (Analytical Laboratory Services cc Summarized Manual, 2012). Nutrients such as calcium, iron and magnesium were measured using ammonium acetate (1M) extractions and these analyses were done on all randomly selected soil samples (Analytical Laboratory Services cc Summarized Manual, 2012; Ministry of Agriculture, Water and Forestry Laboratory Manual, 2012; Ellis & Weis, 2006).

3.5 The Heap Experiment

3.5.1 Erection of experimental heaps and sowing of *J. albata* seeds

The heap experiment involved erection of twelve experimental heaps each with a basal diameter of 5 m, average slope angle of 27° (steep slope) and 20° (gentle slope) and spaced about 15 m apart (Figure 5). The experimental heaps comprised a mixture ratio (1:1:1) between fine tailings (post mining soil particles which are less than or equal to 2 mm in size), coarse tailings (post mining rocks which are more than 2 mm to 25 mm in size) and oversize tailings (post mining rocks which are more than 25 mm to 50 mm in size) obtained from the current exploration plant at Sendelingsdrif diamond mine. These mining waste materials are used to back-fill mined areas after decommissioning of diamond mines. The experimental heaps were erected in two rows, 30 m apart in order to allow free air movement and to avoid a possibility of shading effects which might affect the outcomes of the experiment (Figure 8; Figure 5). The position of each experimental heap was randomly determined using random numbers generated between one and twelve in Microsoft Excel (Figure 5).

Figure 8. Photo showing part of the experimental heaps at Sendelingsdrif diamond mine.

A total of 30 *J. albata* seeds were sown in each of the nine Aspects (namely: north, south, west, east, southwest, northwest, northeast, southeast and level) on each experimental heap and watered with one litre of water for three alternating days per week (Cornelis van der Waal, personal communication, January 17, 2013; Ellis & Weis, 2006). This was carried out for seven weeks to facilitate germination. However, no germination occurred mainly due to unfavorable weather conditions such as high temperatures and as a result the experiment was restarted after seeking advice from NBRI on how to facilitate germination of *J. albata* seeds outside the greenhouse (Silke Rügheimer, personal communication, March 29, 2013).

Re-sowing of *J. albata* seeds was undertaken after an opportunistic rainy event in each of the nine Aspects on each experimental heap. In addition, just after this rainy event each experimental heap was watered with 160 litres of water to further increase moisture on the experimental heaps to increase chances of *J. albata* seeds germination. The number of seeds was increased to 50 to increase chances of obtaining seeds that will germinate. General watering was also increased to two litres of water per day for five consecutive days per week and this was carried out for five weeks. Subsequently, watering was reduced to two litres five weeks after re-sowing of *J. albata* seeds, three alternating days per week for five weeks in each sown Aspect on the experimental heaps. Despite all these treatments and watering regimes, no *J. albata* seed germinated after two trials. Seeds used in the present study were obtained from NBRI were they have been stored under controlled conditions. New seeds were collected from live *J. albata* plants in the study area prior to re-sowing but no germination occurred (Silke Rügheimer, personal communication, March 29, 2013).

3.5.2 Transplanting of cuttings and whole *J. albata* plants on experimental heaps

In the present study, since there was difficulty in germinating *J. albata* seeds outside the greenhouse, 500 rescued *J. albata* plants (rescued from areas where strip mining for diamonds will be undertaken) were transplanted on the experimental heaps. Some of these plants were divided into cuttings which were also transplanted on the experimental heaps. This was done to allow observing post mining slopes and Aspects which may be suitable for *J. albata* in this study. Transplanting of cuttings and whole *J. albata* plants on the experimental heaps was carried out after an opportunistic rainy event referred to in section 3.5.1 above and the subsequent watering of 160 litres in order to facilitate plant establishment. Prior to transplanting, cuttings and whole *J. albata* plants were air dried in the greenhouse for 24 hours to reduce the risk of infections to the plants when transplanted on the experimental heaps (Cornelis van der Waal, personal communication, February 28, 2013).

Three cuttings and one whole *J. albata* plant were transplanted in each of the nine Aspects (namely: north, south, west, east, southwest, northwest, northeast, southeast and level) on each experimental heap, just below the area where seeds were sown in earlier treatments referred to in section 3.5.1 above. Five litres of water was poured on each of these Aspects on the experimental heaps where cuttings and whole *J. albata* plants were transplanted on three alternating days a week for three weeks. The watering regime on each experimental heap was subsequently changed to four litres, once a week for four weeks then finally to four litres twice a month for two months.

The following measurements were made on cuttings and whole *J. albata* plants that established in different Aspects and slopes (namely: gentle and steep) on the experimental heaps. Canopy diameter (in cm) measurements were recorded from each cutting and whole *J. albata* plant rooted on each experimental heap along two axes at right angles to each other and used to calculate the canopy volume according to the formula: $\pi LW/4*h$ where L and W refer to the two canopy diameters and h is the height of a cutting or whole *J. albata* plant (Esler & Cowling, 1992). The height of each cutting and whole *J. albata* plant that was rooted on each experimental heap was measured from the soil surface of each experimental heap following Ellis & Weis (2006). The number of leaves on each cutting and whole *J. albata* plant were also counted.

These measurements and observations were done four times in nine months (during March 2013, May 2013, September 2013 and November 2013 respectively) to allow possible changes to occur on cuttings and whole *J. albata* plants on different slopes and Aspects on experimental heaps. The canopy volumes and number of leaves were used in the present study as growth performance indicators of cuttings and whole *J. albata* plants in different Aspects and slopes on experimental heaps (Ellis & Weis, 2006; Cummings, Reid, Davies & Grant, 2005). The heap experiment lasted for a period of nine months.

3.6 Data analyses

STATISTICA (version 7.1) software was used to analyze the data collected from the study area on both the field survey and heap experiment. All data were tested for normality using the Shapiro-Wilk test (Elzinga et al., 2001; Dytham, 1999). Homogeneity of variances were tested using Levene's test in the data which were analyzed using statistical tests that required meeting this assumption (namely: MANOVA, ANOCOVA and One-way ANOVA) (Elzinga et al., 2001; Dytham, 1999; Gomes & Gomes, 1984). Results of both Shapiro-Wilk and Levene's tests are presented in Appendices, section 1.1; Table 8, Table 9 and section 1.2; Table 10, Table 11 respectively. Data which were not normally distributed were transformed using either common logarithm or square root to normalize them (Elzinga et al., 2001; Dytham, 1999). The means obtained from transformed data were reported in untransformed forms in the thesis. The following data were transformed using common logarithm:

a) Infiltration rate and slope angle data in a total of forty one paired quadrats (4 m x 4 m *Juttadinteria* and associated random quadrats described in Chapter 3; section 3.4.1).

b) Concentrations of iron, total nitrogen, organic carbon and magnesium in the soil data in a total of twenty four paired quadrats (*Juttadinteria* and associated random quadrats).

c) Number of leaves and canopy volumes of cuttings and whole *J. albata* plants data in different Aspects and slope types on experimental heaps.

The following data were transformed using square root:

a) Canopy volumes of juvenile and adult *J. albata* plants data calculated in seven different habitats in the study area.

Results of the Shapiro-Wilk tests as presented in appendices, section 1.1; Table 8, Table 9 showed that data collected from both the field survey and heap experiment including log and square root transformed data were all normally distributed. These data were then analyzed using parametric statistical tests (Weiss, 2008; Ashcroft & Pereira, 2003; Elzinga et al., 2001; Dytham, 1999; Bailey, 1995; Gomes & Gomes, 1984). Lists of parametric statistical tests which were used to analyze data in the present study are given below alongside field survey and heap experiment data which were analyzed by each test:

3.6.1 The Field Survey

3.6.1.1 Paired *t*-tests

Paired *t*-tests were used to analyze data for the following as presented in Chapter 4; section 4.1.1:

a) Comparisons of mean rockiness cover, infiltration rate and slope angle between 4 m x 4 m *Juttadinteria* and associated random quadrats (described in Chapter 3; section 3.4.1) in the study area.

b) Comparisons of mean concentrations of total nitrogen, organic carbon, calcium, iron, magnesium and extractable phosphorus in the soil between *Juttadinteria* and associated random quadrats in the study area.

3.6.1.2 One-way Analysis of Variance (ANOVA)

One-way ANOVA test was used to analyze data for the following as presented in Chapter 4; section 4.1.2:

a) Comparisons of mean densities of *J. albata* plants calculated in different Aspects in the study area.

3.6.1.3 Chi-square test

Chi-square test (nonparametric test) was used to analyze data for the following as presented in Chapter 4; section 4.1.4 (Elzinga, Salzer & Willoughby, 1998):

a) Comparisons of soil textures in a total of twenty four paired quadrats (in *Juttadinteria* quadrats and those found in associated random quadrats) in the study area.

3.6.1.4 Multivariate Analysis of Variance (MANOVA) test

MANOVA test was used to analyze data for the following as presented in Chapter 4; section 4.2.1:

a) Comparisons of population age structure of *J. albata* plants in seven different habitats in the study area.

3.6.2 The Heap Experiment

3.6.2.1 Analysis of Covariance (ANOCOVA) tests

ANOCOVA test was used to compare mean number of leaves and canopy volumes of cuttings and whole *J. albata* plants in nine different Aspects (namely: north, northwest, west, southwest, south, southeast, east, northeast and level) and on two different slope types (namely: gentle and steep) on experimental heaps at the end of heap experiment. Interactions between Aspects and slopes on experimental heaps in terms of mean number of leaves and canopy volumes of cuttings and whole *J. albata* plants were also tested for. ANOCOVA test measures changes in a dependent variable over time and how it is affected by other continuous variables (covariates) (Gomes & Gomes, 1984). The number of leaves and canopy volumes of cuttings and whole *J. albata* plants in nine different Aspects and on two different slopes at the beginning of heap experiment were included in the ANOCOVA tests as covariates.

In the study, the level of significance was set at 0.05 and post hoc comparisons between the means obtained from ANOCOVA tests were done using Bonferroni test (Dytham, 1999; Gomes & Gomes, 1984).

3.6.3 Determining spatial distribution pattern of *J. albata* in the study area

In order to determine the spatial distribution pattern of *J. albata* plants in the study area, variance and mean of *J. albata* plants in a total of 1,500 continuous 2 m x 2 m quadrats in the study area were calculated. A method derived from Dytham (1999); Ludwig & Reynolds (1988) was used to decide the spatial distribution pattern of *J. albata* plants in the study area. If variance equals the mean then the population is randomly distributed, if variance is greater than the mean, then the population has a clumped distribution pattern and if variance is less than the mean, then the population is uniformly dispersed (Dytham, 1999; Ludwig & Reynolds, 1988).

CHAPTER 4: RESULTS

4.1 The relationship between density of *J. albata* and rockiness cover, infiltration rate, slope angle, Aspect, soil texture and soil chemistry of the topsoil in the study area

4.1.1 Comparisons of rockiness cover, infiltration rate and slope angle in 4 m x 4 m *Juttadinteria* and associated 4 m x 4 m random quadrats

Paired *t*-tests compared rockiness cover, slope angle and infiltration rate calculated in paired 4 m x 4 m quadrats (*Juttadinteria* quadrats and associated random quadrats described in Chapter 3; section 3.4.1). The aim to compare these variables in the paired quadrats was to find out whether or not *J. albata* plants (found in *Juttadinteria* quadrats only) were associated with specific slope angle, infiltration rate and rockiness cover. Results showed that *Juttadinteria* quadrats had significantly higher mean rockiness cover (t=6.40, df=40, $P<0.001$) and slope angle (t=6.30, df=40, $P<0.001$) than those calculated in associated random quadrats. Results also showed that random quadrats had significantly higher (t=-3.19, df=40, $P<0.01$) mean water infiltration rate than that calculated in associated *Juttadinteria* quadrats (Table 2).

Table 2. Mean (±standard error (SE)) rockiness cover (%), infiltration rate (cm/s) and slope angle (°) in 4 m x 4 m *Juttadinteria* and random quadrats, sample sizes (n), degrees of freedom (df), *t* statistics, differences in means (*Juttadinteria* quadrats - random quadrats) and P values.

***Juttadinteria* quadrats**	**Random quadrats**	***t* statistic**	**Difference**	**n**	**P value**
Rockiness cover (%)					
Mean	Mean	*t*(40) = 6.40	31.43	41	***
69.98±3.41	38.54±3.80				
Infiltration rate (cm/s)					
Mean	Mean	*t*(40) = -3.19	-0.01	41	**
0.01±0.002	0.02±0.01				
Slope angle (°)					
Mean	Mean	*t*(40) = 6.30	8.17	41	***
14.07±1.26	5.90±1.15				
**significant at p<0.01 ***significant at p<0.001					

4.1.2 Aspect

One-way ANOVA test compared the mean densities of *J. albata* calculated in different Aspects in the study area. The results showed that there were no significant differences (F=1.12, df=6, P=0.37) in the mean densities of *J. albata* calculated in different Aspects (namely: level, south, southeast, southwest, west, east and northeast) where *J. albata* plants were found growing (Figure 9). Additionally, there were no *J. albata* plants found growing in the northern and northwestern Aspects in the study area.

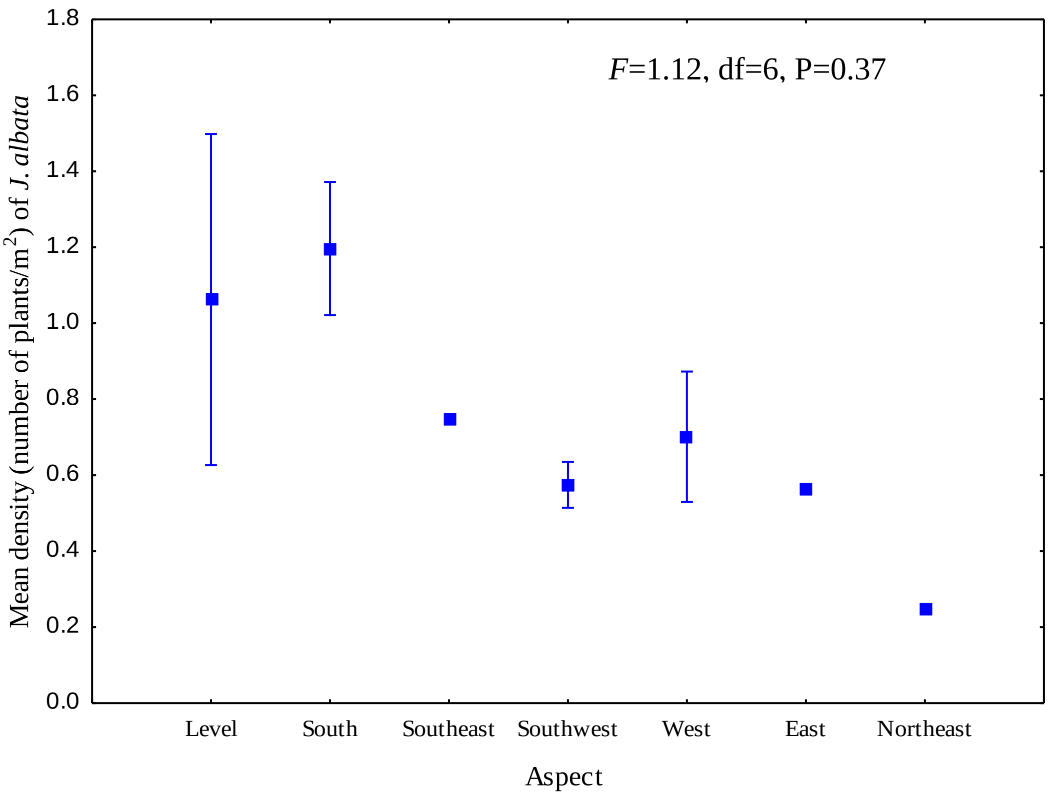

Figure 9. Mean density (number of plants/m^2) of *J. albata* in different Aspects in the study area. Vertical bars denote ±SE.

4.1.3 Soil chemistry of the topsoil

4.1.3.1 Comparisons of concentrations of total nitrogen, organic carbon, extractable phosphorus, calcium, iron and magnesium in the soil in 4 m x 4 m *Juttadinteria* quadrats and associated 4 m x 4 m random quadrats

In the present study, concentrations of total nitrogen, organic carbon, calcium, magnesium, iron and extractable phosphorus in the soil found in paired quadrats (random quadrats and associated *Juttadinteria* quadrats) were compared by Paired *t*-tests. The main aim to compare variables in these paired quadrats was to find out whether or not *J. albata* plants (found in *Juttadinteria* quadrats only) were associated with soils with specific concentrations of total nitrogen, organic carbon, calcium, magnesium, iron and extractable phosphorus. Results showed that *Juttadinteria* quadrats had significantly higher (t=3.84, df=23, P<0.01) mean concentrations of organic carbon in the soil than that found in associated random quadrats (Table 3). Furthermore, results showed that there were no significant differences in the mean concentrations of calcium (t=0.77, df=23, P=0.45), magnesium (t=1.56, df=23, P=0.13), iron (t=-0.63, df=23, P=0.54), total nitrogen (t=0.43, df=23, P=0.67) and extractable phosphorus (t=0.58, df=23, P=0.57,) in the soil in *Juttadinteria* quadrats and those found in 4 m x 4 m random quadrats (Table 3).

Table 3. Mean (±SE) concentrations of total nitrogen (mg N /kg), organic carbon (% m/m C), extractable phosphorus (mg P /kg), calcium (mg Ca/kg), iron (mg Fe/kg) and magnesium (meq/L) in the soil in 4 m x 4 m *Juttadinteria* and random quadrats, sample sizes (n), *t* statistics, degrees of freedom (df), differences in means (*Juttadinteria* quadrats - random quadrats) and P values.

***Juttadinteria* quadrats**	**Random quadrats**	***t* statistic**	**Difference**	**n**	**P value**
Total nitrogen (mg N /kg)					
Mean	Mean	*t*(23) = 0.44	-16.49	24	0.67
267.59±17.05	284.09±35.41				
Organic carbon (% m/m C)					
Mean	Mean	*t*(23) = 3.84	0.04	24	**
0.11±0.01	0.07±0.01				
Extractable phosphorus (mg P /kg)					
Mean	Mean	*t*(23) = 0.58	0.41	24	0.57
5.50±0.51	5.09±0.59				
Calcium (mg Ca/kg)					
Mean	Mean	*t*(23) = 0.77	2072.50	24	0.35
11554.20±1897.69	9481.70±1959.28				
Iron (mg Fe/kg)					
Mean	Mean	*t*(23) = -0.63	24.82	24	0.54
85.19±34.91	60.37±19.76				
Magnesium (meq/L)					
Mean	Mean	*t*(23) = 1.56	1.01	24	0.13
5.42±1.16	4.41±0.92				
**significant at p<0.01					

4.1.4 Soil texture

Results of the Chi-square test showed that there was no significant difference (χ^2=0.14, df=2, P=0.93) in the soil textures found in *Juttadinteria* quadrats (namely: sand, loamy sand and sandy loam) and those found in associated random quadrats (namely: sand and loamy sand).

4.2 Population structure of *J. albata*

4.2.1 Population age structure of *J. albata* plants occupying different habitats in the study area

The canopy volumes of juvenile and adult *J. albata* plants were used in the present study to define population age structure of *J. albata* in seven different habitats in the study area (Cousins et al., 2014; Ouedraogo et al., 2013). This was done to explain the population structure of *J. albata* in the study area (Phama et al., 2014; Cousins, Witkowski & Pfab, 2014; Ouedraogo, Kakai & Thiombiano, 2013). MANOVA test results showed that there were no significant differences in the mean canopy volumes of juvenile (*F*=0.86, df=6, P=0.53) and adult (*F*=0.69, df=6, P=0.65) *J. albata* plants found in different habitats in the study area (Table 4).

Table 4. Mean (±SE) canopy volumes (cm^3) of juvenile and adult *J. albata* plants, *F* statistics, degrees of freedom (df), sample sizes (n) and P values found in different habitats in the study area.

J. albata	**Juvenile plants**			**Adult plants**			
Habitat	**Mean**	***F* statistic**	**P value**	**Mean**	***F* statistic**	**P value**	**n**
Rocky hills	24.95±30.11	*F*(6) = 0.86	0.53	12098.18±2842.88	*F*(6) = 0.69	0.65	8
Sheltered gully	27.20±25.69			10048.89±2424.42			11
Shallow soil on ridges	93.32±26.94			11946.94±2542.75			10
Proto terrace	69.98±30.11			7104.23±2842.88			8
Broad sandy wash	0.00			4804.73±5685.77			2
Meso terrace	0.00			9337.98			1
Lower terrace	0.00			18153.75			1

4.2.2 Spatial distribution pattern of *J. albata* in the study area

In the study, results showed that the variance=0.32 in the number of *J. albata* plants in a total of 1,500, continuous 2 m x 2 m quadrats exceeded the mean=0.07. According to the method derived from Dytham (1999); Ludwig & Reynolds (1988) defined in Chapter 3 (under data analyses section 3.6.3) the population of *J. albata* plants in the study area followed a clumped pattern of distribution.

4.3 The Heap Experiment

4.3.1 The effect of slope and Aspect on the number of leaves of *J. albata* in experimental heaps

ANOCOVA test was used to compare mean number of leaves of cuttings and whole *J. albata* plants in different Aspects and slope types on the experimental heaps at the end of heap experiment. The number of leaves of cuttings and whole *J. albata* plants in nine different Aspects and on two different slopes at the beginning of heap experiment were included in the ANOCOVA tests as covariates.

4.3.1.1 Mean number of leaves of cuttings of *J. albata*

Results showed that there was no significant difference (F=3.45, df=1, P=0.07) in the mean number of leaves of cuttings of *J. albata* on gentle and steep slope experimental heaps at the end of heap experiment. There were also no significant interactions (F=0.69, df=8, P=0.70) between different Aspects and slope types on experimental heaps in terms of mean number of leaves of cuttings of *J. albata* at the end of heap experiment. Furthermore, results showed that there were significant differences (F=6.07, df=8, P<0.001) in the mean number of leaves of cuttings of *J. albata* in nine different Aspects on experimental heaps at the end of heap experiment (Figure 10). A post hoc analysis was undertaken using Bonferroni test (obtained from ANOCOVA test) to statistically determine which of the means of number of leaves of cuttings of *J. albata* were significantly different at the end of heap experiment and the results are presented in Table 5. Mean number of leaves of cuttings of *J. albata* in each Aspect on experimental heaps at the end of heap experiment are presented in Figure 10.

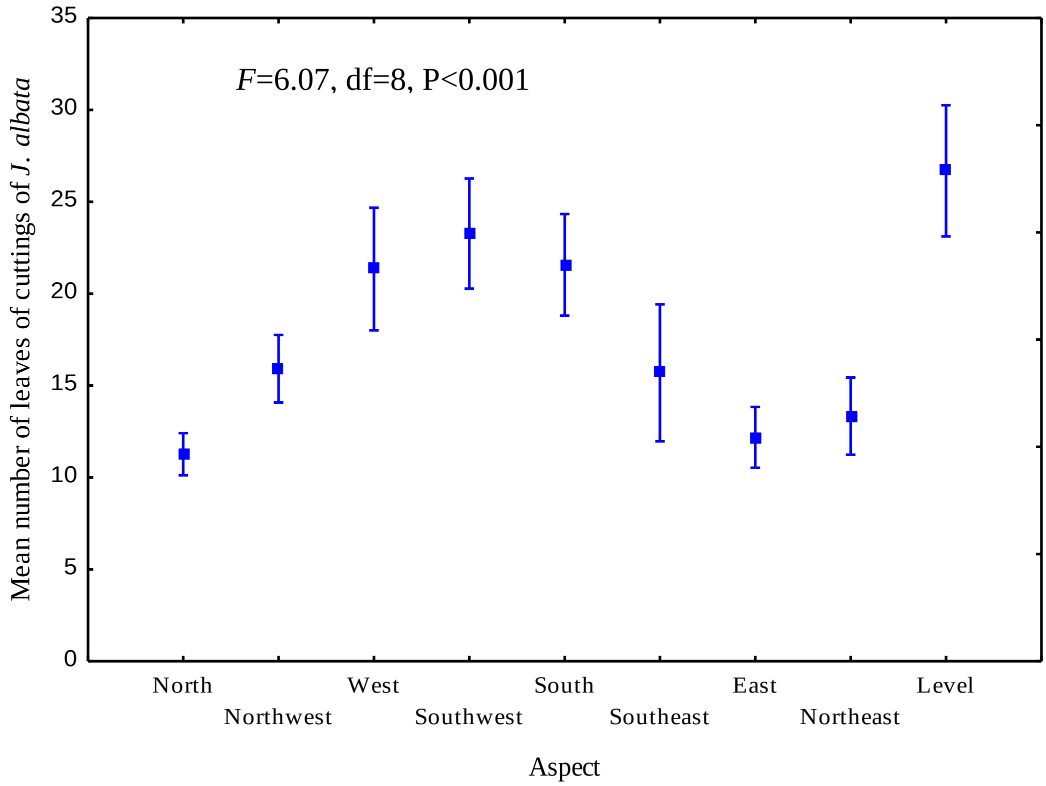

Figure 10. Mean number of leaves of cuttings of *J. albata* in different Aspects at the end of heap experiment. Vertical bars denote ±SE.

Results of the post hoc test (using Bonferroni test) as presented in Table 5 showed that level Aspect (mean=26.69±3.57 SE) had a significantly higher mean number of leaves of cuttings of *J. albata* than those found in northern (mean=11.27±1.15 SE), eastern (mean=12.18±1.66 SE) and northeastern (mean=13.34±2.10 SE) facing Aspects.

Table 5. The P values from post hoc analysis (Bonferroni test) for the differences in the mean number of leaves of cuttings of *J. albata* in different Aspects at the end of heap experiment.

Aspect	**North**	**Northwest**	**West**	**Southwest**	**South**	**Southeast**	**East**	**Northeast**	**Level**
North									
Northwest	1.00								
West	0.36	1.00							
Southwest	0.08	1.00	1.00						
South	0.31	1.00	1.00	1.00					
Southeast	1.00	1.00	1.00	1.00	1.00				
East	1.00	1.00	0.68	0.17	0.58	1.00			
Northeast	1.00	1.00	1.00	0.39	1.00	1.00	1.00		
Level	***	0.22	1.00	1.00	1.00	0.18	*	*	
Mean (±SE) number of leaves of cuttings of *J. albata*	11.27±1.15	15.92±1.83	21.34±3.33	23.27±2.99	21.57±2.76	15.70±3.73	12.18±1.66	13.34±2.10	26.69±3.57

*Significant at p<0.05
***Significant at p<0.001

4.3.1.2 Mean number of leaves of whole *J. albata* plants

Results of the present study showed that there was no significant difference (F=0.69, df=1, P=0.41) in the mean number of leaves of whole *J. albata* plants on gentle and steep slope experimental heaps at the end of heap experiment. There were also no significant interactions (F=0.88, df=8, P=0.54) between different Aspects and slope types on experimental heaps in terms of mean number of leaves of whole *J. albata* plants. Furthermore, results showed that there were significant differences (F=4.91, df=8, P<0.001) in the mean number of leaves of whole *J. albata* plants in nine different Aspects on experimental heaps at the end of heap experiment (Figure 11).

A post hoc analysis was undertaken using Bonferroni test (obtained from ANOCOVA test) to statistically determine which of the means of number of leaves of whole *J. albata* plants were significantly different at the end of heap experiment and the results are presented in Table 6. Mean number of leaves of whole *J. albata* plants in each Aspect on experimental heaps at the end of heap experiment are presented in Figure 11.

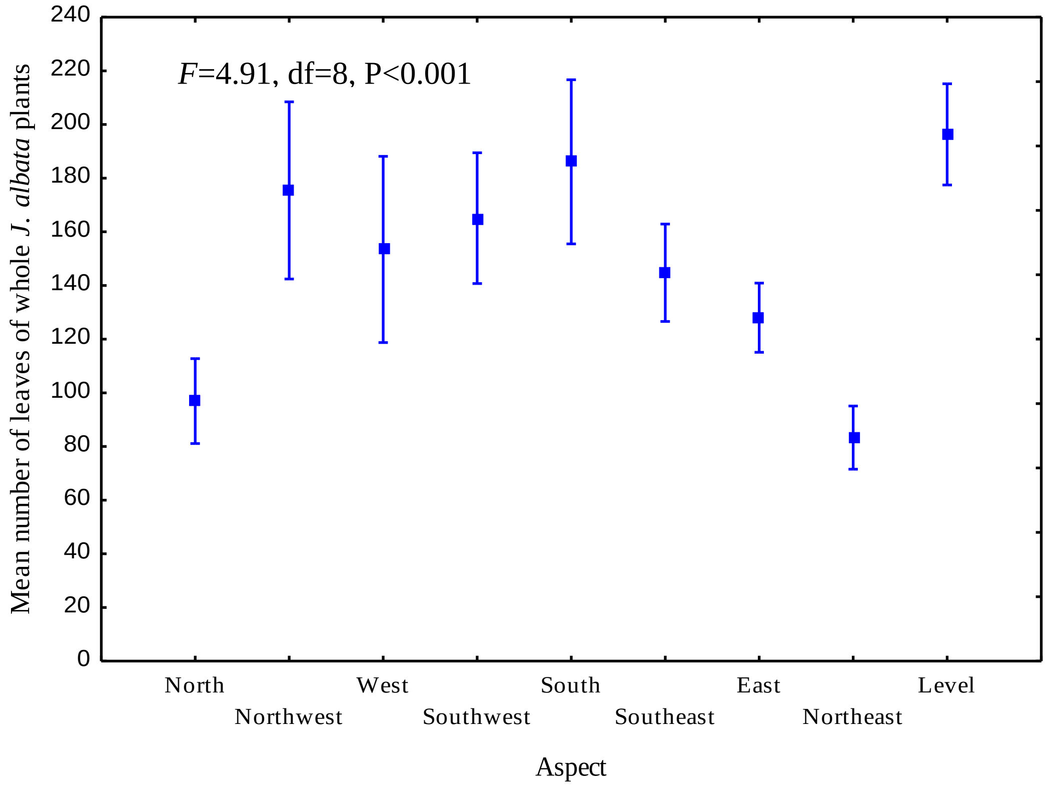

Figure 11. Mean number of leaves of whole *J. albata* plants in different Aspects at the end of heap experiment. Vertical bars ±SE.

Results of the post hoc test (using Bonferroni test) as presented in Table 6 showed that level Aspect (mean=196.33±18.87 SE) had significantly higher mean number of leaves of whole *J. albata* plants than that found in the northeastern (mean=83.31±11.78 SE) facing Aspect.

Table 6. The P values from post hoc analysis (Bonferroni test) for the differences in the mean number of leaves of whole *J. albata* plants in different Aspects at the end of heap experiment.

Aspect	North	Northwest	West	Southwest	South	Southeast	East	Northeast	Level
North									
Northwest	0.76								
West	1.00	1.00							
Southwest	1.00	1.00	1.00						
South	0.33	1.00	1.00	1.00					
Southeast	1.00	1.00	1.00	1.00	1.00				
East	1.00	1.00	1.00	1.00	1.00	1.00			
Northeast	1.00	0.26	1.00	0.59	0.10	1.00	1.00		
Level	0.14	1.00	1.00	1.00	1.00	1.00	1.00	*	
Mean (±SE) number of leaves of whole *J. albata* plants	96.92±15.82	175.46±33.01	153.44±34.69	165.10±24.35	186.10±30.57	144.75±18.15	128.00±12.89	83.31±11.78	196.33±18.87
*Significant at p<0.05									

4.3.2 The effect of slope and Aspect on canopy volume of *J. albata* in experimental heaps

ANOCOVA test was used to compare mean canopy volumes of cuttings and whole *J. albata* plants calculated in different Aspects and slope types on the experimental heaps at the end of heap experiment. The canopy volumes of cuttings and whole *J. albata* plants in nine different Aspects and on two different slopes at the beginning of heap experiment were included in the ANOCOVA tests as covariates.

4.3.2.1 Mean canopy volume of cuttings of *J. albata*

Results showed that mean canopy volume of cuttings of *J. albata* on steep slope experiment heaps was significantly higher (F=12.05, df=1, $P<0.001$) than that on gentle slope experimental heaps at the end of heap experiment. The mean canopy volumes of cuttings of *J. albata* calculated for the two slope types, gentle and steep, on the experimental heaps at the end of heap experiment are presented in Figure 12.

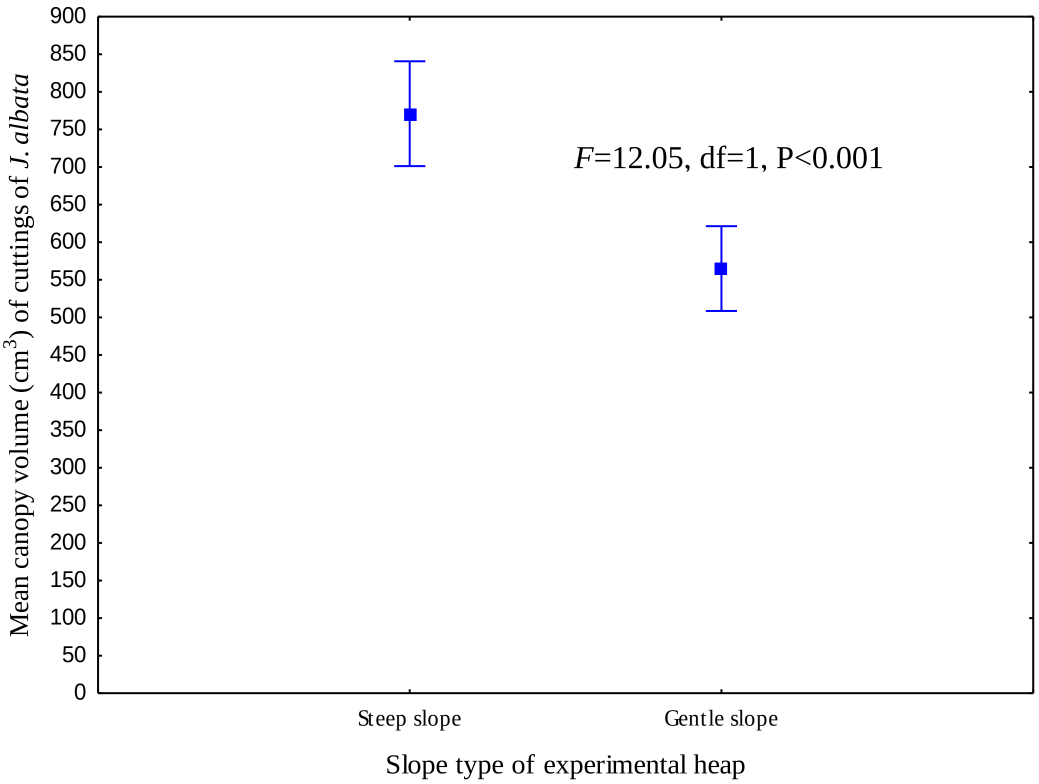

Figure 12. Mean canopy volumes (cm^3) of cuttings of *J. albata* on gentle and steep slope experimental heaps at the end of heap experiment. Vertical bars denote ±SE.

Furthermore, results showed that there were significant differences (F=4.25, df=8, P<0.001) in the mean canopy volumes of cuttings of *J. albata* in nine different Aspects on experimental heaps at the end of heap experiment (Figure 13). A post hoc analysis was undertaken using Bonferroni test (obtained from ANOCOVA test) to statistically determine which of these means of canopy volumes of cuttings of *J. albata* were significantly different and the results are presented in Table 7. Mean canopy volumes of cuttings of *J. albata* calculated for each Aspect on experimental heaps at the end of heap experiment are presented in Figure 13.

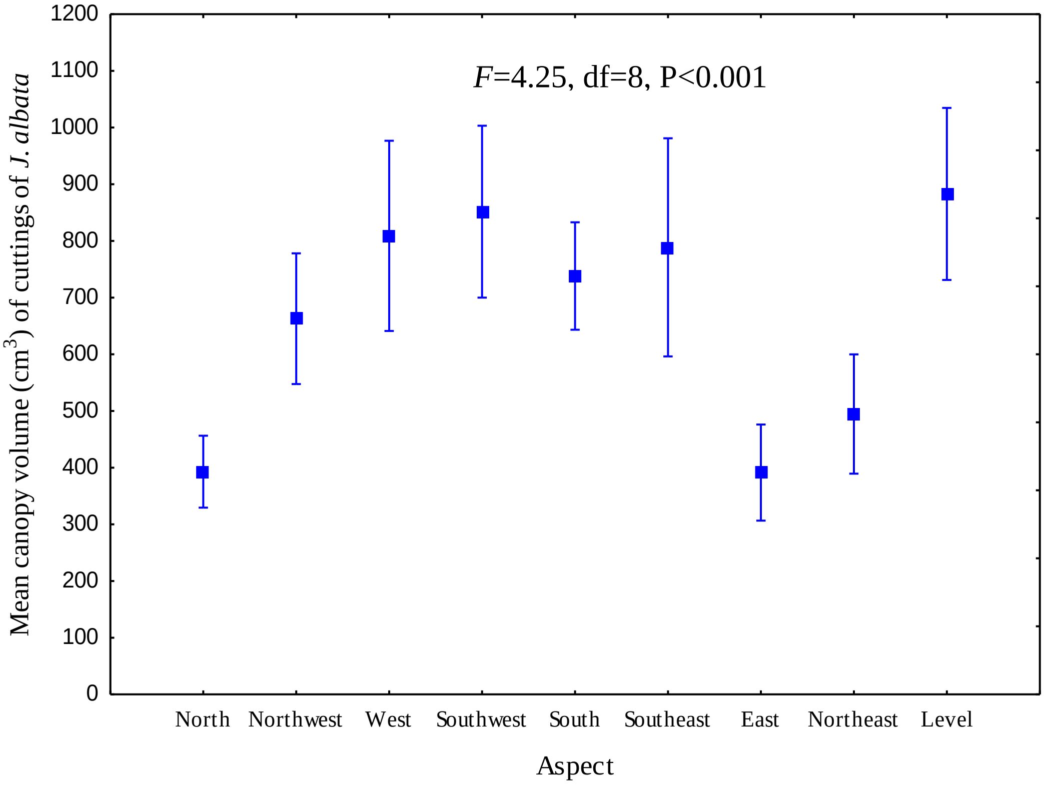

Figure 13. Mean canopy volumes (cm^3) of cuttings of *J. albata* in different Aspects at the end of heap experiment. Vertical bars denote ±SE.

Results of a post hoc test (using Bonferroni test) as presented in Table 7 showed that level (mean=882.85±151.76 SE) Aspect had significantly higher mean canopy volumes of cuttings of *J. albata* than those in the northern (mean=392.95±63.45 SE) and eastern (mean=391.31±84.86 SE) facing Aspects.

Table 7. The P values from post hoc analysis (Bonferroni test) for the differences in the mean canopy volumes of cuttings of *J. albata* in different Aspects at the end of heap experiment.

Aspect	North	Northwest	West	Southwest	South	Southeast	East	Northeast	Level
North									
Northwest	1.00								
West	0.99	1.00							
Southwest	0.56	1.00	1.00						
South	1.00	1.00	1.00	1.00					
Southeast	1.00	1.00	1.00	1.00	1.00				
East	1.00	1.00	0.97	0.54	1.00	1.00			
Northeast	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
Level	*	1.00	1.00	1.00	1.00	1.00	*	1.00	
Means (±SE) of canopy volumes of cuttings of *J. albata*	392.95±63.45	662.76±115.29	808.94±167.82	851.54±151.62	738.14±94.82	788.75±192.38	391.31±84.86	494.61±105.26	882.85±151.76
*Significant at p<0.05									

There were no significant interactions (*F*=1.86, df=8, P=0.55) between different Aspects and slope types on experimental heaps in terms of the mean canopy volumes of cuttings of *J. albata* at the end of heap experiment.

4.3.2.2 Mean canopy volume of whole *J. albata* plants

Results of the study revealed that there was no significant difference (*F*=0.33, df=1, P=0.57) in the mean canopy volume of whole *J. albata* plants on gentle and that on steep slope experimental heaps at the end of heap experiment. There were also no significant interactions (*F*=0.43, df=8, P=0.89) between different Aspects and slope types on experimental heaps in terms of the mean canopy volume of whole *J. albata* plants at the end of heap experiment. Furthermore, results showed that there were no significant differences (*F*=0.40, df=8, P=0.52) in the mean canopy volumes of whole *J. albata* plants in nine different Aspects on experimental heaps at the end of heap experiment (Figure 14). Mean canopy volumes of whole *J. albata* plants calculated in each Aspect on experimental heaps at the end of heap experiment are presented in Figure 14.

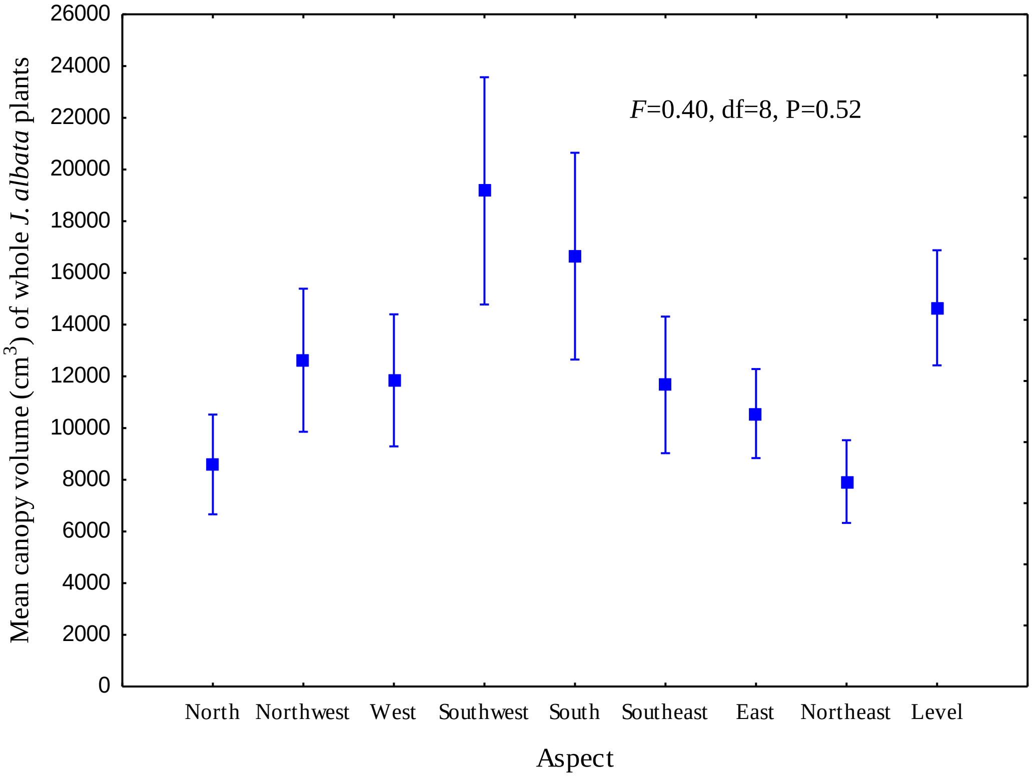

Figure 14. Mean canopy volumes (cm^3) of whole *J. albata* plants in different Aspects at the end of heap experiment. Vertical bars denote ±SE.

4.3.3 Germination, survival and growth rates of *J. albata* in experimental heaps

There were no germinations of seeds of *J. albata* in nine different Aspects (namely: north, northwest, west, southwest, south, southeast, east, northeast and level) and on two different slope types (namely: gentle and steep) on experimental heaps. Germination, survival and growth rates of *J. albata* could therefore not be statistically tested since seeds of *J. albata* did not germinate in the heap experiment.

CHAPTER 5: DISCUSSION

5.1 The Field Survey

5.1.1 Rockiness cover, slope angle, infiltration rate and soil texture

In the present study, one of the objectives was to determine the rockiness cover, slope angle, infiltration rate and soil texture which may be associated with *J. albata* in the study area. The results of the study as presented in Table 2 can be explained by many reasons for example, there are pockets of deeper soil among the rocks that trap water and hence suitable habitats for plants to become established (Porembski, 2007; Esler et al., 2006; Whitford, 2002; Dean & Milton, 1995). Rocky soils are hardly eroded as compared to non-rocky soils and that water is more evenly spread and lost by evaporation much faster in non-rocky soils which results in few vegetation in non-rocky soils (Whitford 2002; Dean & Milton, 1995). In a study by Benkobi, Trlica, & Smith (1993) it was shown that rockiness cover and vegetation prevents soil erosion and this aids establishment of plants. Other important functions of rocks in an ecosystem which results in plants such as *J. albata* at sites with significantly higher rockiness cover are given below.

Stones provide habitats to soil animals such as termites and ants which improve soil nutrient content, including organic carbon, through decomposition of organic matter (Crous, Samways & Pryke, 2013; Esler, et al., 2006; Whitford, 2002). Rocks also play an important role in arid and semi-arid regions in capturing litter such as dead leaves and animal feces, or organic matter during run-off forming litter dams which are favorable sites for seeds germination and hence plant establishment (Crous, et al., 2013; Whitford, 2002). Also, rocks provide protection against wind and excessive sunlight to plant juveniles helping them to survive to maturity (Crous, et al., 2013; Whitford, 2002).

Furthermore, there are many reasons for the density of *J. albata* plants at sites in the study area with steep slopes (Table 2). For example, some steep slopes are known to be less grazed and trampled by browsing and grazing animals than surrounding areas. This is due to their inaccessibility by these animals and this result in higher plant cover (Burke & Wittneben, 2008; Mwendera & Mohamed, 2007; Esler, et al., 2006; Whitford, 2002). Steep slopes are also effective at receiving cool moist air creating suitable habitat for plants to become established (Burke & Wittneben, 2008; Dean & Milton, 1995). Steep slopes are often higher than gentle slopes and this makes them effective at intercepting cool moist winds.

Soil infiltration rate is significantly reduced by many factors such as soil depth (Esler, et al., 2006; Whitford, 2002). For example, when the soil is shallow there will be reduced infiltration rate because soil macropores quickly fill with water (Whitford, 2002). Soil depths in *Juttadinteria* quadrats could be shallow due to slope steepness these quadrats have as reported in the present study resulting significantly lower infiltration rate (Whitford, 2002; Esler, et al., 2006). Soils on steep slopes are usually shallow because water continually moves loose soil down slope when it rains (Esler et al., 2006).

Soil texture determines water holding capacity and infiltration rate of soil which influences the ability of the soil to support plant life (Le Maitre, Milton, Jarmain, Colvin, Saayman & Vlok, 2007; Maestre, Huesca, Zaady, Bautista & Cortina, 2002). For example, sand has higher infiltration rate and poor water holding capacity which results in poor plant growth and survival (Smithson et al., 2002; Hillerislambers, Rietkerk, van der Bosch, Prins, de Kroon, 2001; Barbour et al., 1999). Results in the present study suggest that soil texture was not an important soil physical property in determining density of *J. albata* in the study area since soil texture was found to be uniform in the study area (Wassenaar, 2010).

5.1.2 Aspect

Another objective of this study was to determine the Aspects which may be associated with *J. albata* in the study area. It has been documented that different Aspects have or receive different temperature, rainfall, fog and sunlight intensities and the prevailing wind direction is experienced differently in different Aspects (Wassenaar, 2010; Esler et al., 2006; Dean & Milton, 1995; Olivier, 1995). In addition, Aspects provide warmer or cooler, wetter or drier habitats for plants which results in differing plant communities among different Aspects (Burke & Wittneben, 2008; Esler et al., 2006; Cowling, et al., 1997; Dean & Milton, 1995).

For example, at Sendelingsdrif diamond mine strong south and south-westerly wind is commonly experienced. This could be directing similar amounts of moisture from the adjacent Orange River in the southern, southeastern, southwestern, western and level Aspects which could have resulted in the presence of *J. albata* in those Aspects in the study area (Wassenaar, 2010). Also, south and south-westerly wind could be directing fog and rainfall in those Aspects which could have also resulted in the presence of *J. albata* (Wassenaar, 2010; Burke & Wittneben, 2008; Cowling, et al., 1997).

Eastern, northeastern, northern and northwestern Aspects face away from the adjacent Orange River and the direction in which the fog comes in the study area. These Aspects especially northern and northwestern are very warm because they face the sun and therefore receive excessive sunlight than others (Wassenaar, 2010). Eastern and northeastern Aspects face the sun in morning hours when sunlight intensity is low and this explains presence of *J. albata* plants in those two Aspects (Burke & Wittneben, 2008; Esler et al., 2006; Cowling, et al., 1997; Dean & Milton, 1995). Northern and northwestern Aspects face the sun in the afternoon when sunlight intensity is too high which explains absence of *J. albata* in these two Aspects (Burke & Wittneben, 2008; Esler et al., 2006; Cowling, et al., 1997; Dean & Milton, 1995). These Aspects also faces away from the direction in which moist wind (south and south-westerly wind) and rainfall comes in the study area (Wassenaar, 2010).

5.1.3 Concentrations of different soil elements in the soil and density of *J. albata* in the study area

The present study also had an objective of determining the soil elements which may be associated with *J. albata* in the study area. Most shrubs in arid and semi-arid regions capture or trap windblown sources of organic matter (which is the main source of organic carbon) such as dead leaves and grasses under their canopies (Whitford, 2002; Schlesinger & Pilmanis, 1998; Fowler, 1986). This leads to the accumulation of organic carbon around these shrubs in the habitat (Whitford, 2002; Schlesinger & Pilmanis, 1998; Fowler, 1986). Dead shrubs or their dead parts also contribute to the accumulation of organic carbon in the habitat after decomposing (Fowler, 1986; Barth & Klemmedson, 1978).

In the present study, it could be that adult *J. albata* plants in the study area capture windblown sources of organic carbon under their canopies. This could have led to significantly higher concentrations of organic carbon (Table 3) in the soil in *J. albata* habitat (Schlesinger & Pilmanis, 1998). *Juttadinteria albata* plants or their dead parts could have also contributed significantly through decomposition to the observed significantly higher concentrations of organic carbon in the soil in the habitat (Schlesinger & Pilmanis, 1998; Charley & West, 1975).

Dry climate (such as deserts) soils are known to contain little organic matter which is needed for the supply of nutrients to the plants and this could have resulted in the observed insignificant differences (Esler et al., 2006; Dean & Milton, 1995). Most desert soils are slightly basic to very basic and this is in agreement with the mean soil pH found in the study area (pH =7.68 and SE=0.04) (Whitford, 2002; Larcher, 1995). Soil pH influences the availability of many plant nutrients which changes with changes in pH values and this could have also resulted in the observed insignificant differences (Wright & Boorse, 2011; Thomson & Coyne, 2006; Bridges, 1978). For instance, nutrients such as total nitrogen, organic carbon, phosphorus, magnesium and calcium all have reduced availability at low pH values as well as at high pH values (Whitford, 2002; Cresser, Killham & Edwards, 1993). At high soil pH, nutrients such as iron are also reduced in availability (Ashman & Puri, 2002; Wilkinson, 1994; Cresser, Killham & Edwards, 1993). Results of the present study suggest that concentrations of calcium, total nitrogen, magnesium, iron and phosphorus in the soil were not important in determining density of *J. albata* in the study area since they were found to be uniform in the study area.

5.1.4 Distribution of population age structure and spatial distribution pattern of *J. albata* in the study area

One of the objectives in this study was to determine or document population structure of *J. albata* in the study area. The results (Table 4) suggest that juvenile and adult *J. albata* plants were distributed evenly in all seven different habitats in the study area. These results suggest that the study area is characterized by productive patches which may be occurring in a clumped pattern in these seven different habitats. These patches could have soil properties (e.g. significantly higher concentrations of organic carbon in the soil as reported in the present study) which could be favorable for *J. albata* seed germination and hence plant establishment (van der Maarel, 2006; Whitford, 2006; Esler et al., 2006; Dean & Milton, 1995).

Desert systems are usually characterized by productive patches which are a result of interactions between animals and the environment particularly soil, for example termites collect dead leaves and twigs which improves soil organic matter and nutrient contents (Whitford, 2006; Esler et al., 2006; Hillerislambers et al., 2001; Dean & Milton, 1995). Other burrowing animals such as porcupine (*Hystrix austro-africanae*), rats and scorpions improve the soil organic matter contents by trapping dead leaves, litter, dung and seeds and loosen the soil improving its water holding capacity (Esler et al., 2006; Gurevitch et al., 2002; Dean & Milton, 1995; Barbour et al., 1987).

Plant facilitation and mode of seed dispersal in plants found in arid and semi-arid regions lead to clumped distribution patterns (Brooker et al., 2008; Holmgren, Scheffer & Huston, 1997; Fowler, 1986). Plant facilitation involves presence of nurse plants which help other plants or juveniles to establish or survive to maturity in the habitat in various ways (Padilla & pugnaire, 2006; Scheffer & Huston, 1997; Fowler, 1986). Nurse plants provide shade to juvenile plants through their canopies, protection against predation and trampling or they also accumulate organic matter under their canopies and as a result clumped distribution patterns forms in the habitat

(Padilla & Pugnaire, 2006; Scheffer & Huston, 1997; Fowler, 1986). In desert environments seed dispersal lead to clumped spatial distribution patterns in plants if viable seeds fall near to the parent plants (Fowler, 1986; Ellner & Shmida, 1981). Adult *J. albata* plants in the study area could be playing similar roles as those for nurse plants which could have resulted in the observed clumped distribution patterns (Holmgren, Scheffer & Huston, 1997). The study area has also other shrubs (such as *E. chersina*, *Z. patenticaule* and *E. ebracteata*) which could also be playing the roles of nurse plants. Additionally, seeds of *J. albata* are in enclosed in capsules which protect the seeds against agents of dispersal such as wind, water, air and animals (Burke, 2004b; Ellner & Shmida, 1981). The capsules open only upon wetting and germinate when conditions are favorable near to the parent plants, a phenomenon common in desert plants which leads to clumped distribution patterns (Ellner & Shmida, 1981).

5.2 The Heap Experiment

The heap experiment in this study had an objective of determining, as part of a trial planting, the most suitable post mining slopes and Aspects for the growth of *J. albata* that would be applied during its ecological restoration. Results on the mean number of leaves and canopy volumes of cuttings and whole *J. albata* plants in nine different Aspects (namely: north, south, west, east, southwest, northwest, northeast, southeast and level) and on two different slopes (namely: steep and gentle) on experimental heaps are discussed below:

5.2.1 The effect of slope on the number of leaves and canopy volume of *J. albata* in experimental heaps

The duration of heap experiment may have not been sufficient to induce noticeable changes in the mean number of leaves of cuttings and whole *J. albata* plants on gentle slope experimental heaps and those found on steep slope experimental heaps. This reason also explains the mean canopy volume of whole *J. albata* plants on gentle slope experimental heaps and that found on steep slope experimental heaps. It could be that these plants needed more time to react to differences in cool moist air (moisture in the air mainly from the adjacent Orange River and fog) which is experienced differently on gentle and steep slopes in the study area (Wassenaar, 2010). As mentioned earlier in this Chapter section 5.1.1, steep slopes are effective at receiving cool moist air creating suitable habitat for plants to become established (Burke & Wittneben, 2008; Dean & Milton, 1995). Steep slopes are often higher than gentle slopes and this makes them effective at intercepting cool moist winds.

The results obtained on cuttings of *J. albata* (Figure 12) suggest that slope steepness was effective at receiving cool moist air (moisture in the air mainly from the adjacent Orange River and fog) brought in by strong south-westerly winds commonly experienced at Sendelingsdrif mine. This could have resulted in significantly higher canopy volume of cuttings of *J. albata* on steep slope experimental heaps (Wassenaar, 2010; Burke & Wittneben, 2008; Esler, et al., 2006; Cowling, et al., 1997; Dean & Milton, 1995). The results also suggest that cuttings of *J. albata* reacted effectively to differences in cool moist air (moisture mainly from the adjacent Orange River and fog) which is experienced differently on gentle and steep slopes in the study area (Wassenaar, 2010).

5.2.2 The effect of Aspect on the number of leaves and canopy volume of *J. albata* in experimental heaps

The duration of heap experiment may have not been sufficient to induce noticeable changes in the mean canopy volume of whole *J. albata* plants in different Aspects on experimental heaps. It could be that whole *J. albata* plants needed more time to react to differences in environmental factors such as sunlight intensity, rainfall and cool moist air (moisture mainly from the adjacent Orange River and fog), in terms of canopy volumes, which is experienced differently in different Aspects in the study area (Wassenaar, 2010). Different Aspects receive varying levels of environmental factors such as moisture and sunlight intensity and this result in differences in plant growth and development in different Aspects (Wassenaar, 2010; Sternberg & Shoshany, 2001; Cowling, et al., 1997).

For example, northern, eastern and northeastern Aspects on the experimental heaps in the study area face the sun and are therefore warmer than other Aspects which could explain poor performance of *J. albata* in those Aspects (Figure 10; Figure 11; Figure 13; Figure 14). Northern Aspect faces the sun in the afternoon receiving intense sunlight while eastern and northeastern Aspects faces the sun during morning hours receiving less intense sunlight. These Aspects also faces away from the direction in which moist wind and rainfall comes in the study area (south and south-westerly wind) (Wassenaar, 2010). Water infiltration rate during general watering could have been significantly higher in the level Aspect (because this Aspect had a slope angle of 0°) on experimental heaps (Huat, Ali & Low, 2006). This could have resulted in the observed significantly higher mean number of leaves of cuttings and whole *J. albata* plants as well as canopy volume of cuttings of *J. albata* in that Aspect (Hillerislambers et al,. 2001).

5.2.3 Germination, survival and growth rates of *J. albata* in experimental heaps

Seeds of *J. albata* sown in nine different Aspects (namely: north, northwest, west, southwest, south, southeast, east, northeast and level) and on two different slope types (namely: gentle and steep) on experimental heaps did not germinate after two trials. This is mainly due to unfavorable weather conditions in the study area such as high temperatures which may reach 40°C (Wassenaar, 2010). Such high temperatures in the study area resulted in high evaporation rate on the experimental heaps and this made it impossible for germination of seeds of *J. albata* to occur in the present study.

Germination in the wild is possible because seeds of *J. albata* are in enclosed in hygrochastic capsules which open only upon wetting and germinate when conditions are favorable near to the parent plants (Burke, 2004b; Smith et al., 1998; Ellner & Shmida, 1981; Ellner & Shmida, 1981). Seeds of *J. albata* germinate very well in the greenhouse when soil in the pots is kept moist until germination occurs (Silke Rügheimer, personal communication, March 29, 2013).

5.3 Implications of the study results for ecological restoration of *J. albata*

The results of the present study imply that *J. albata* plants may not do well during ecological restoration if there are no steep rocky slopes in the mined areas, and especially if these do not face the cool Aspects namely: west, southwest, south, southeast, east, northeast and level because these plants were found growing naturally under those conditions. *Juttadinteria albata* plants may perform well in all investigated habitats in the present study (namely: Sheltered gully, Broad sandy wash, Rocky hills, Shallow soil on ridges, Proto terrace, Meso terrace and Lower terrace) during ecological restoration since the plants were found growing in all of these habitats.

In the present study, it was established that *J. albata* plants occurred in a clumped distribution pattern which suggest that the plants may perform well if grown in a clumped layout in ecological restoration. Planting of native nurse plants such as *E. chersina*, *Z. patenticaule*, *E. gummifera* and *E. ebracteata* in all mined areas before planting *J. albata* plants can assist its establishment, growth and survival in desired sites. Nurse plants provide shade to juvenile plants through their canopies, protection against predation and trampling or they can also accumulate organic matter under their canopies helping juvenile plants to survive to maturity (Padilla & Pugnaire, 2006; Scheffer & Huston, 1997; Fowler, 1986). Transplants and cuttings of *J. albata* are likely to perform better in mined areas than seeds in the medium term during ecological restoration of mined areas, since there was no germination of seeds of *J.*

albata in the heap experiment done outside the greenhouse using post mining waste materials.

The addition of organic mulch to improve the organic carbon content of the post mining soils may assist *J. albata* growth and survival (Beukes & Cowling, 2003; Burke, 2003). Various sources of organic mulch can be used in ecological restoration of *J. albata* in mined areas (e.g. Beukes & Cowling, 2003; Thurston, 1997). In a restoration ecology study in the Karoo in South Africa by Beukes & Cowling, (2003) thatching reed (Restionaceae) was used as organic mulch by spreading it onto designated blocks and *Acacia karroo* branches laid on top to stop it blowing away. The plots were fenced with 60 cm high wire mesh to exclude animals such as Steenbok (*Raphicerus campestris*) (a very small antelope), tortoises, hares and rodents which would otherwise disturb the experiments.

Plants in the areas that will be mined can be cut and mulched on mined areas where *J. albata* will be planted to supply organic carbon (Thurston, 1997). Organic mulch can improve water infiltration rate of post mining soils which increases soil water needed for plant establishment and growth (Carrick & Krüger, 2007). Lastly, transplants and cuttings are likely to perform better than seeds in the medium term during ecological restoration of mined areas, since there was no germination of *J. albata* in the heap experiment done outside the greenhouse using post mining waste materials.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

The following main findings were revealed from the present study:

a) *Juttadinteria albata* plants were found at sites with significantly higher rockiness cover, slope angle and concentrations of organic carbon in the soil accepting the research hypothesis. *Juttadinteria albata* plants were also found in the western, southwestern, southern, southeastern, eastern, northeastern and level Aspects but not in the northern and northwestern Aspects in the study area rejecting the research hypothesis. Rocks play important roles in a habitat which helped in the establishment, growth and survival of *J. albata* at rocky sites. These roles include capturing of litter such as dead leaves and animal feces during run-off which forms favorable sites for germination, slowing down or reducing evaporation rate, providing protection against wind and excessive sunlight to plant juveniles helping them to survive to maturity. Steep slopes are much higher than gentle slopes and this makes them effective at intercepting cool moist air (moisture in the air mainly from Orange River and fog) and this resulted in higher density of *J. albata* on those slopes. In arid and semi-arid habitats shrubs such as *J. albata* captures organic matter under their canopies and this together with its dead parts could have contributed to significantly higher organic carbon in the habitat. Northern and northwestern Aspects in the study area face the sun in the afternoon when sunlight intensity is very high and are therefore very warm than other Aspects. These Aspects also faces away from the direction in which the wind comes (south and south-westerly wind) and the adjacent Orange River which plays an important role in sustaining plant life in the study area. These conditions resulted in absence of *J. albata* plants in those Aspects.

b) Secondly, the population structure of *J. albata* in seven different habitats in the study area did not significantly differ rejecting the research hypothesis. Also, *J. albata* plants in the study area were found to follow a clumped distribution pattern accepting the research hypothesis. The results suggest that the study area is characterized by productive patches which are found in all habitats in the study area. These patches can have soil characteristics (e.g. significantly higher concentrations of organic carbon in the soil) which are favorable for *J. albata* germination, establishment, growth and survival. Adult *Juttadinteria albata* plants together with other shrubs in the study area such as *E. chersina*, *Z. patenticaule* and *E. ebracteata* could be playing roles of nurse plants by providing shade, protection against wind and predation to *J. albata* juveniles. Nurse plants capture organic matter under their canopies creating suitable sites for *J. albata* germination, growth and survival. These are common phenomenon to shrubs growing in arid and semi-arid areas which leads to clumped distribution patterns in plants in those areas.

c) Finally, the mean canopy volume of cuttings of *J. albata* on steep slope was significantly higher than that on gentle slope experimental heaps at the end of heap experiment accepting the research hypothesis. Additionally, the mean number of leaves of cuttings of *J. albata* in the level Aspect was significantly higher than those in the eastern, northeastern and northern Aspects on experimental heaps at the end of heap experiment rejecting the research hypothesis. Steep slope experimental heaps were much higher than gentle slope experimental heaps making them effective at intercepting cool moist air (moisture in the air mainly from the Orange River and fog) than gentle slope heaps. Northern, eastern and northeastern Aspects on the experimental heaps are warm because they face the sun and therefore receive excessive sunlight which resulted in poor growth of *J. albata* in those Aspects. In addition, water infiltration rate during general watering could have been significantly higher in the level Aspect (because this Aspect had a slope angle of 0°) on experimental heaps. There were also no germinations of seeds of *J. albata* sown in different Aspects and slopes on the experimental heaps rejecting the research hypothesis. This is mainly due to unfavorable weather conditions in the study area such as high temperatures which resulted in high evaporation rate on the experimental heaps.

6.2 Recommendations

6.2.1 Environmental factors associated with *J. albata* in the study area

The following points are recommended from the results obtained on the environmental factors associated with *J. albata* in the study area:

a) *Juttadinteria albata* should be transplanted on rocky steep slopes and in the western, southwestern, southern, southeastern, eastern, northeastern and level

Aspects during ecological restoration. This is because *J. albata* plants were found growing naturally in those Aspects and on those slopes in the study area.

b) Organic mulch should be added to post mining soils to improve the organic carbon content of the soils because this can assist *J. albata* growth and survival (Beukes & Cowling, 2003; Burke, 2003; Thurston, 1997). Plants in the areas that will be mined should be cut and mulched on mined areas where *J. albata* will be planted to supply organic carbon (Thurston, 1997). Mined areas where organic mulch is applied should be fenced to keep animals away.

6.2.2 Population structure of *J. albata*

The following points are recommended from the results obtained on the population structure of *J. albata* in the study area:

a) *Juttadinteria albata* should be planted in clumped layouts in all mined areas during ecological restoration. It is recommended that native nurse plants such as *E. chersina*, *Z. patenticaule, E. gummifera* and *E. ebracteata* must be planted in all mined areas before planting *J. albata* to assist its establishment, growth and survival in desired sites. Nurse plants provide shade to juvenile plants through their canopies, protection against predation and trampling or they also accumulate organic matter under their canopies helping juvenile plants to survive to maturity (Padilla & Pugnaire, 2006; Scheffer & Huston, 1997; Fowler, 1986).

6.2.3 The Heap Experiment

The following points are recommended from the results obtained on the heap experiment in the present study:

a) Seeds of *J. albata* should be germinated in the greenhouse and then transplant *J. albata* in the mined areas during ecological restoration. This is because *J. albata* seeds did not germinate outside the greenhouse in the heap experiment despite efforts to germinate it. *Juttadinteria albata* germinates very well in the greenhouse when soil in the pots is kept moist until germination occurs (Silke Rügheimer, personal communication, March 29, 2013). The seed capsules of *J. albata* burst open and eject the seeds when conditions for germination are favorable. Placement of intact seed capsules in mined areas could allow natural seed dispersal to occur, and this option should be investigated in future field trials.

b) *Juttadinteria albata* plants must be rescued from areas that will be impacted by mining activities for transplantations in mined areas during ecological restoration. Cuttings of *J. albata* are recommended in transplanting since they effectively responded to differences in environmental factors such as sunlight and moist winds in different Aspects on the experimental heaps in the present study. Whole *J. albata* plants can also be transplanted in mined areas since the duration of the study may have not been sufficient to induce more noticeable changes in these plants on different slopes and Aspects on experimental heaps.

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APPENDICES

1.1 Results of Shapiro-Wilk tests for normality of Field Survey and Heap Experiment data

Results of Shapiro-Wilk tests for data collected from the field survey and heap experiment in the present study are presented in Table 8 and Table 9 respectively. These are the results referred to in Chapter 3; section 3.6. These data were all normally distributed (P>0.05).

1.1.1 The Field Survey

Table 8. The *W* statistics, degrees of freedom (df) and P values obtained from Shapiro-Wilk tests of normality of the field survey data.

Variable	**4 m x 4 m *Juttadinteria* quadrat**			**4 m x 4 m random quadrat**		
	***W* statistic**	**df**	**P value**	***W* statistic**	**df**	**P value**
Mean densities of all *J. albata* plants in all seven habitats in the study area	0.96	41	0.15	N/A	N/A	N/A
Mean rockiness cover in 41 paired quadrats	0.96	41	0.12	0.99	41	0.99
Mean infiltration rate in 41 paired quadrats	0.98	41	0.52	0.98	41	0.73
Mean slope angle in 41 paired quadrats	0.98	41	0.75	0.97	41	0.35
Mean total nitrogen in 24 paired quadrats	0.96	24	0.48	0.94	24	0.21
Mean organic carbon in24 paired quadrats	0.98	24	0.80	0.92	24	0.06
Mean calcium in 24 paired quadrats	0.92	24	0.05	0.95	24	0.23
Mean magnesium in 24 paired quadrats	0.99	24	0.99	0.97	24	0.58
Mean iron in 24 paired quadrats	0.93	24	0.11	0.94	24	0.13
Mean extractable phosphorus in 24 paired quadrats	0.97	24	0.68	0.96	24	0.49
Mean canopy volumes of adult *J. albata* plants in all 7 different habitats	0.96	41	0.11	N/A	N/A	N/A
Mean canopy volumes of juvenile *J. albata* plants in all 7 different habitats	0.96	41	0.06	N/A	N/A	N/A

N/A stands for not applicable meaning that a variable was only recorded in 4 m x 4 m *Juttadinteria* quadrat but not in associated 4 m x 4 m random quadrat.
df for degrees of freedom.

1.1.2 The Heap Experiment

Data on number of leaves and canopy volumes of cuttings and whole *J. albata* plants obtained from two different slopes (namely: gentle and steep) and nine different Aspects (namely: north, northwest, west, southwest, south, southeast, east, northeast and level) on experimental heaps at the beginning and end of heap experiment were all normally distributed (P>0.05). Results of Shapiro-Wilk tests for normality of these data are presented in Table 9.

Table 9. The *W* statistics, degrees of freedom (df) and P values obtained from Shapiro-Wilk tests for normality of heap experiment data at the beginning and end of heap experiment.

Variable	**Mean number of leaves**			**Mean canopy volume**		
J. albata	***W* statistic**	**df**	**P value**	***W* statistic**	**df**	**P value**
Beginning of heap experiment data						
Cuttings of *J. albata* (Slope and Aspect)	0.99	108	0.61	0.99	108	0.69
Whole *J. albata* plants (Slope and Aspect)	0.99	108	0.35	0.99	108	0.31
End of heap experiment data						
Cuttings of *J. albata* (Slope and Aspect)	0.98	108	0.11	0.98	108	0.09
Whole *J. albata* plants (Slope and Aspect)	0.99	108	0.33	0.98	108	0.22
df for degrees of freedom						

1.2 Results of Levene's tests for homogeneity of variances of Field Survey and Heap Experiment data

Results of Levene's tests for homogeneity of variances for the field survey and heap experiment data which were analyzed using statistical tests which required this assumption to be met (namely: ANOCOVA, MANOVA and One-way ANOVA) are presented in Table 10 and Table 11. These are the results referred to in Chapter 3; section 3.6. Levene's tests were all not significant (P>0.05).

1.2.1 The Field Survey

Table 10. The *F* statistics, degrees of freedom and P values obtained from Levene's tests for homogeneity of variances of the field survey data which were analyzed using parametric statistical tests that required meeting this assumption.

Variable	**Statistics**		
	***F* statistic**	**df**	**P value**
Mean densities of all *J. albata* plants in different Aspects in all 7 habitats combined	1.85	40	0.12
Mean canopy volumes of adult *J. albata* plants in all 7 different habitats	0.89	40	0.51
Mean canopy volumes of juvenile *J. albata* plants in all 7 different habitats	0.88	40	0.50
df for degrees of freedom			

1.2.2 The Heap Experiment

Table 11. The *F* statistics, degrees of freedom and P values obtained from Levene's tests for homogeneity of variances of the heap experiment data.

Variable	**Mean number of leaves**			**Mean canopy volume**		
J. albata	***F* statistic**	**df**	**P value**	***F* statistic**	**df**	**P value**
Beginning of heap experiment data						
Cuttings of *J. albata* (Slope and Aspect)	1.68	107	0.06	1.68	107	0.06
Whole *J. albata* plants (Slope and Aspect)	1.49	107	0.12	1.21	107	0.27
End of heap experiment data						
Cuttings of *J. albata* (Slope and Aspect)	1.59	107	0.08	1.08	107	0.39
Whole *J. albata* plants (Slope and Aspect)	1.31	107	0.20	1.52	107	0.11
df for degrees of freedom						