

THE DISTRIBUTION, ABUNDANCE AND REPRODUCTIVE STATUS OF THE
INVASIVE ALIEN PLANT, *DATURA INNOXIA* MILL., IN THE CITY OF
WINDHOEK, NAMIBIA

BY

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INVASIVE ALIEN PLANT, *DATURA INNOXIA* MILL., IN THE CITY OF
WINDHOEK, NAMIBIA

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BY

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April 2008 **ABSTRACT**

Invasive alien species (IAS) are non-native species that cause, or have the potential to cause, harm to the environment, economies, or human health. The threat to biodiversity due to invasive alien species is considered second to that of habitat loss. The focus of the

study was on one of the invasive alien plant *Datura innoxia*. The study was conducted in the City of Windhoek, the capital of Namibia, situated at 22.56°S, 17.09°E.

The aim of the research project was to study the distribution, abundance and reproductive status of the invasive alien *D. innoxia* in the City of Windhoek. The information gathered will contribute to the knowledge and understanding of weedy invasive aliens in the City.

Data was collected 121, 25 0000 m² grids that were randomly sampled in the City. The City of Windhoek grided map was used to locate the specific grids. The grids were subdivided into sixteen 15625 m² plots to ease observations. In each plot, all *D. innoxia* were recorded including their height, crown width, number of capsules and number of flowers. Within a radius of one-meter, other organisms and plants associated with *D. innoxia* were also recorded. The presence and absence of other plant species found in the plots were recorded. ArcView 3.2 was used to develop the distribution map and SPSS 15 was used to analyze the data.

The study revealed that *D. innoxia* is widely distributed along riverbanks, disturbed areas and around human settlement. A high infestation of *D. innoxia* was observed in the drainage lines and within the built-up areas. The occurrence of *D. innoxia* is influenced by the different types of activities and is associated with disturbances. The study also showed that *D. innoxia* is a perennial trailing or bushy herb plant with a continuous floral development with no significant difference ($\chi^2_{\text{F}}(3) = 7, p > 0.05$) in the number of *D. innoxia* in the different reproductive status within the geo-morphological landforms.

However, there was a significant difference ($\chi^2_{\text{F}} (2) = 5, p < 0.05$) in the number of *D. innoxia* with the construction and no construction area and within the open spaces and built-up areas. Therefore, *D. innoxia* is a cosmopolitan opportunistic weed that is abundant in construction areas, drainage lines and around human settlements.

The Hierarchical Cluster Analysis revealed that *Acacia mellifera*, *Dichrostachys cinerea*, *Boscia albitrunca* and *Senecio windhoekensis* were the dominant woody and herbaceous vegetation in all the clusters. The City of Windhoek is situated in the highland savanna vegetation, all the dominant species characterizing the highland savanna were present. Variation within the vegetation composition was attributed to the different land uses within the City of Windhoek and not to the presence of *D. innoxia*.

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Dedication

This work is dedicated to my daughter Likeleli Zuvee Katjirua and my late aunt, Gay Murangi, your spirit is guiding me as you always believed in me.

DECLARATION

I declare that this thesis is my own investigation, except where it is specifically indicated to the contrary in the text. The thesis has not been previously submitted for any degree of any other University.

Joyce Katjirua

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

An alien species is a species that becomes established in a new environment outside its natural distribution. Alien species that multiply and spread in ways that are destructive to human interest are considered invasive (Smit and Steenkamp, 2002). Invasive alien

species (IAS) are non-native species that cause, or have the potential to cause, harm to the environment, economies, or human health. The threat to biodiversity due to invasive alien species is considered second only to that of habitat loss (McNeely, 2001). They are thus a serious impediment to conservation and sustainable use of global, regional and local biodiversity, with significant undesirable impacts on the goods and services provided by ecosystems (GISP, 2004).

The direct costs of IAS to a single country can be in the billions of US dollars annually (McNeely *et al.*, 2001). Water hyacinth is the world's worst aquatic weed and often clogs irrigation canals and pumps (Navarro and Phiri, 2000). It also impacts on agricultural production and the economical cost to some African countries range between US\$ 20- 50 million per year (GISP, undated; McNeely *et al.*, 2001). However, the costs to society greatly exceed those that can be measured in currency. They include impacts on infrastructure, food and water shortages, environmental degradation, loss of biodiversity, increased rates and severity of natural disasters, illness, and loss of lives. An example of this is in South Africa's Western Cape Province, where poor households in townships and informal settlements are dependent on wood collection from invading *Acacia longifolia* and *Acacia cyclos* forest for construction poles and firewood. However, these forests also pose some risk to the immediate safety and survival of the inhabitants. Criminals use the vegetation cover to pounce on innocent victims. IAS invade natural ecosystems, as well as grazing and productive agricultural lands (Noemdoe, 2001; Van Wilgen *et al.*, 2001). At the same time, human-driven changes in land use and climate render some habitats more susceptible to invasion. Invasive alien species are thus a growing problem, and one

that will have to be managed in perpetuity (<http://www.gisp.org/-02/09/06>). Failure to address the underlying causes of biological invasion and mitigate the impacts of IAS will result in both losses and gains. For example, numerous species, genetic resources, and quite possibly the entire concept of "protected" areas will be lost. Poverty, malnourishment, human migration, and disease epidemics will, on the other hand, increase (<http://www.gisp.org/02/09/06>).

Biological invasion by alien species is recognized as one of the major threats to native species and ecosystems, yet awareness of the problem is low. The effects on biodiversity are immense and often irreversible. In the Galapagos, the dense impenetrable strands of *Lantana camara* threaten the removal of rare composite species. Most countries have only recently begun to recognize the scope and significance of the IAS problem (GISP, 2004). While a few governments are investing in national policies and programmes to address the problem, many are prevented from doing so by a lack of scientific, technological, and financial resources. Efforts of most governments to limit the spread of IAS are so poorly coordinated that ministries within a single government, trading partners, and neighboring countries are often unaware of each other's policies and practices. Non-governmental and intergovernmental organizations face similar challenges and have few mechanisms to develop a holistic approach to the problem (Munthali, 2004).

1.2 SPECIES DESCRIPTION

1.2.1 The genus *Datura*

The genus *Datura* belongs to the family Solanaceae and has eleven (11) herbaceous species, namely, *D. stramonium*, *D. forex*, *D. quercifolia*, *D. pruinosa*, *D. leichhardtii*, *D. meteloides*, *D. innoxia*, *D. discolor*, *D. metel*, *D. ceratocaula* and *D. wrightii*. Crosses between *D. metel*, *D. innoxia*, *D. meteloides* and *D. wrightii* quite often produce viable seeds. A most vigorous species in this regard is *D. leichhardtii*, which can be successfully crossed with almost any herbaceous *Datura* species (Avery *et al.*, 1950).

Today the *Datura* species are distributed throughout the world. Due to the worldwide distribution of *Datura* species there is some dispute concerning their origin. The greatest variety of *Datura* species occurs in Mexico and Central America. Other sources suggest that their original home could be found somewhere in the vicinity of the Caspian Sea from where it spread south to Africa and east to Asia, eventually arriving in Europe, supposedly with the gypsies sometime during the Middle Ages (Burkill, 2000).

Datura species are frequently found in semi-dry deserts where there is a good supply of water and fertilizers. However some species of *Datura* establish populations or successfully grow under poor conditions. In general *Datura* is typically an integrated part of the vegetation belts of the riverbanks, flood plains and dry beds and can frequently be found in spots where the soil is able to maintain its moisture in a considerable period of time (Jansen, 1998).

Datura has adapted successfully to the semi-arid environment through quick germination, rapid growth, early flowering and early maturing of fruits and seeds (Jansen, 1998). When the environmental factors are favourable, these plants produce several hundred flowers succeeded by as many fruits. Drought, however, is the major factor that prevents growth and reproduction of *Datura* (Jansen, 2001).

Globally, in the past three hundred years, vast areas were turned into ecologically disturbed areas as large amounts of land were cleared to give space for field crops, grassland, mining industry and transportation roads. Flood plains were turned under the plough and many rivers, were partly destroyed due to building of dams, artificial canals and irrigation ditches (Rykiel, 1985). Large and irreplaceable plant populations in the vegetation belts of the lower rivers were destroyed due to insufficient water supplies. New and artificial vegetation belts were established along the dams, canals and ditches (Jansen, 1998). These ecologically disturbed sites have provided *Datura*, and many other plant species, with an environment containing extraordinary favorable conditions for establishment of permanent populations, especially the water canals and ditches, where the water level is plenty all year. Here the *Datura* species have optimal conditions both for seedling establishment and long-lasting growth (Jansen, 2001).

Datura species are adapted to an xeric environment. However, it would be an error to regard them as xerophytes. In many aspects of morphology it would be more accurate to consider them to be mesophytes. Only *D. innoxia*, *D. meteloides* and *D. wrightii* have a morphological character in common with some xerophytes: the swollen and enlarged

stem base situated above the tap root (Jansen, 1998). This character enables these species to survive a period of severe drought, which would put to misery any other *Datura* species. The plant parts above the ground simply die back to the roots and start shooting again when the conditions are favorable (Jansen, 2001).

The herbaceous *Datura* species have a developed tap root system, which is able to extend to 1.5 m. or more into the underlying soil layers. Both from within the tap roots and from the root collar grow lateral roots. The tips of these lateral roots have small, sometimes nearly invisible, root hairs (Avery *et al.*, 1950). Stem and branches are slender and tend to become hollow with age. In older specimens the stem basis tends to develop the same kind of woodiness as can be found in the species of *Brugmansia*. This especially applies to *D. innoxia*, *D. meteloides* and *D. wrightii*, but the remaining species also forms, what could be determined as "secondary woodiness" (Henderson, 2001). The leaf biomass is considerable both with regard to leaf number and leaf size. In some species the leaf is covered with soft hairs to prevent excessive evaporation. In other species the leaf has fairly cut margins to allow the wind to slip through. The shape of the lamina, leaf margin and of the angle of the venation is important in determination of a *Datura* species. This also applies to the length and the pubescence of the petiole (Henderson, 2001).

After a short vegetative period, *Datura* begins to produce a flower at the node of each branch. Flowers are short-lived (one to several days), fragrant in some varieties, and are almost always followed by a developing fruit. The tube shaped calyx protects the undeveloped flower bud against insect attack and prevents it from drying out. The

trumpet shaped flowers not only arouse the interest of night moths, they also serve as a platform for these nocturnal beings, while sucking nectar from the corolla tube. *Datura* is self-fertile, meaning seeds are produced through fertilization of the flower from its own pollen or from pollen of a flower from the same plant. However, certain species of *Datura* can be cross-pollinated (Jansen, 2001).

A spiny fruit of a size of a wall-nut develops after the corollas. The mature fruit of *D. stramonium* opens in 4 regular valves and afterwards the capsule becomes hard and dry. Seeds are shed by wind. Mature fruits of other *Datura* species burst open due to cell destruction. The outer fruit wall falls apart in smaller fragments and thereby releasing the seeds in the ground. In *D. ceratocaula* this mechanism is carried to an extreme, where the entire fruit falls to the ground, decomposes and then releases its seeds for germination (Jansen, 2001). The spines on the *Datura* fruit prevent larger animals from eating the fruits. The seed coat protects the embryo from being eaten by mammals or insects. When dry, the seed coat enables the seeds to be dispersed some distance by aid of wind or water (Jansen, 1998).

Datura is extremely susceptible to various viral attacks that afflict the potato family (Solanaceae). Since it can act as a source of infection, it should not be grown near potatoes or tomatoes (Jansen, 1998).

1.2.2 The species *Datura innoxia*

Datura innoxia, commonly known as downy thorn apple is an herbaceous perennial trailing or bushy herb that can grow up to 2 m high. It has softly gray velvety texture on all parts. The leaves are coarse with whole margin and are gray-velvety turning dark green. Flowers of *D. innoxia* are white, solitary, large funnel shaped and up to 200 mm in length (Henderson, 2001; Klein and Bredenkamp, 1998). They are monoceious (have both staminate and carpellate flowers on one plant) and are mostly pollinated by night-flying sphinx moths, which look and act like small hummingbirds (Jansen, 2001). But honeybees and other insects are attracted to the flowers too, and often manage to squeeze into them before they have opened. The fruits are brown hard spherical- shaped capsules, densely covered in slender spines less than 10mm long (Plate 1.1).

The seed usually germinates in 1-3 weeks at 30°C and there is no need to pre-soak them (Avery *et al.*, 1950). The whole plant and seeds are poisonous and can cause irritation of the skin. They are poisonous to people as well as to cattle, horses and sheep (Henderson, 2001).



Plate 1.1: Single *D. innoxia* individual, indicating the funnel shaped flower and the hard spherical- shaped capsule

Datura innoxia is a cosmopolitan weed occurring in all temperate, subtropical and tropical parts of the world. Due to the worldwide distribution of *Datura* species, it is believed that the plant occurs in Central America and Mexico, where it grows in well-drained soils. *D. innoxia* has become a serious problem in southern and central Africa. *D. innoxia* was brought into Namibia as a garden ornamental plant in the late 1980's. It is best used in background planting or adjacent to structures. The plant invades riverbeds, roadsides, watersides and wastelands (disturbed land) and it is highly competitive in watercourse (Boyer *et al.*, 1989, Handerson, 2001).

1.3 SCOPE AND RATIONALE OF STUDY

Namibia has several invasive alien species and at national level, little is known about their biology, ecology and problems that they cause. Current knowledge of invasive alien species in Namibia is largely from *ad hoc* observations and few structured investigations. Hence the need for proper scientific studies cannot be overemphasized.

Datura innoxia has the ability to colonize areas of various land uses. As an invasive alien species, *D. innoxia* is also found growing with other plant species. It is not well understood whether it has an influence on the indigenous plant species.

Therefore, this study intended to fill the gap in the knowledge of *D. innoxia* and to provide answers to some unanswered questions about the invasive alien species. Apart from knowing its ability to reproduce, the nature of its reproductive status is also not known in the City of Windhoek and Namibia. Understanding the reproductive status of *D. innoxia* will assist in the management plans, as sites with high seeds to be dispersed are identified. The study of ecology of this invasive alien species will contribute to knowledge and understanding of weedy invasive aliens.

1.4 AIMS AND OBJECTIVES

The aim of the research project was to study the distribution, abundance and reproductive status of the invasive alien *D. innoxia* in the City of Windhoek.

Specific objectives

The study was done to specifically:

- a. Document the distribution and abundance of *D. innoxia* in the City of Windhoek.
- b. Compare the abundance of *D. innoxia* in the three identified geo-morphological landforms (drainage line, denudated plains and slope and ridges), type of human

activities (constructions vs no construction) and location (built up areas and open spaces) in the City of Windhoek.

- c. Determine and document the reproductive status (no inflorescence, inflorescence and inflorescence with capsules) of *D. innoxia* in the City of Windhoek.
- d. Compare the reproductive status of *D. innoxia* in the three identified geomorphological landforms (drainage line, denudated plains and slope and ridges), type of human activities (constructions vs no construction) and location (built up areas and open spaces) in the City of Windhoek.
- e. Determine relationship between the height and crown width of *D. innoxia* and the number of flowers and capsules.
- f. Document the plant species composition in habitats here *D. innoxia* was growing in the City of Windhoek.
- g. Identify and document organisms that are associated with *D. innoxia*

1.5 KEY QUESTIONS AND HYPOTHESES

Key questions

- a) Where does *D. innoxia* grow and how is it distributed within the identified geo-morphological landforms (drainage line, denudated plains and slope and ridges), type of human activities (constructions vs no construction) and location (built up areas and open spaces) in the City of Windhoek.

- b) Is there a significant difference in the abundance of *D. innoxia* within the identified geo-morphological landforms (drainage line, denudated plains and slope and ridges), type of human activities (constructions vs no construction) and location (built up areas and open spaces)?
- c) During the months of April 2006 to September 2006, in what reproductive status is *D. innoxia* individuals in the City of Windhoek?
- d) Is there a significant difference in the reproductive status of *D. innoxia* in the three identified geo-morphological landforms (drainage line, denudated plains and slope and ridges), type of human activities (constructions vs no construction) and location (built up areas and open spaces)?
- e) Is there any association between the height and crown width for *D. innoxia* and its flowers or capsules?
- f) What is the plant species composition in habitats where *D. innoxia* is growing?
- g) What are the plants and animals that are associated with *D. innoxia* in the City of Windhoek?

Hypotheses

- a) Due to its opportunistic nature, *D. innoxia* is a weedy competitive plant, and is likely to occur mainly along riverbanks, disturbed areas and around human settlements.
- b) The distribution and abundance of *D. innoxia* is associated with disturbance and there will be no significant differences in the abundance of *D. innoxia* as per the three identified geo-morphological landforms, type of human activities and the location in the City of Windhoek.
- c) Since *D. innoxia* has a continuous floral development and it flowers without stopping once it starts flowering, most plants observed will have an inflorescence reproductive status.
- d) *D. innoxia* is a perennial plant with a continuous floral development and there will be no significant difference in the reproductive status of *D. innoxia* within the geo-morphological landforms (drainage line, denudated plains and slope and ridges), type of human activities (constructions vs no construction) and the location (built up areas and open spaces).
- e) Depending on environmental condition and as a survival strategy of many invasive to ensure reproduction, *D. innoxia* as an invasive alien plant, will produce flowers and capsules at any height and crown width. Therefore, there will be no association between the height and crown width and the flowers and capsules.
- f) *D. innoxia* competes and co-exists with other organisms and there will be other organisms associated with it.

CHAPTER 2

LITERATURE REVIEW

2.1 INVASIVE ALIEN SPECIES (IAS) – A GLOBAL PERSPECTIVE

Invasive alien species are one of the most significant drivers of environmental change worldwide. The water hyacinth in African freshwater ecosystems, the rabbit and fox in Australia, the macaque monkey in Mauritius and the zebra mussel in North American Great Lakes are among the better known examples of invasive species that damage native ecosystems (<http://www.iucn.org/themes/ssc/news/invasives.htth-25/08/06>).

Invasive alien species represent a major disruption of terrestrial and aquatic, managed and wild biotic systems. Invaders can have enormous economic and human health impacts. Invasive alien species have altered evolutionary trajectories, disrupted community and ecosystem processes, and caused large economic losses (Mooney *et al.*, 2005). The varroa mite (*Varroa jacobsoni* and *V. destructor*) invaded New Zealand and required a mitigation plan that was expected to cost US \$ 1.3 million for its initial stage (Matthews and Brand, 2004). There is a long list of ways that invasives can threaten the goods and services provided by natural systems and upon which society depends. Invasives can disrupt fire cycles, deplete water supplies, cause disease, decimate crops, forests and fisheries, impede navigation, clog water works, destroy grazing lands, homes and gardens, eliminate species, and even cause noise pollution (McNeely *et al.*, 2001).

Invasives pose special challenges for their control and eradication. Invasive microorganisms and insects, in particular, can quickly evolve responses to control efforts.

Invaders alter and respond to community interactions in complex ways. As the global movement of people and goods increases, so too does the movement of potential invasive material. At the same time, other global changes such as climate change, mostly favor invasives (Mooney and Hobbs, 2000). Climate change is likely to lead to frequent and extreme events such as floods and droughts, which will create severe disturbances. For an example, floods disturb river banks and re-route water courses, therefore providing recruitment sites for colonizing plants with water-borne propagules such as *Acacia mearnsii* (Le Maitre, 2004).

Our information base for predicting, preventing, and controlling invasives is far from adequate. Public awareness of the problem is also inadequate. Our responses to invasives are complicated by the lag times that commonly occur before their adverse effects are seen, rendering efforts to control them too little or too late (Bazzaz, 1990).

The spread of invasive alien species is creating complex and far-reaching challenges that threaten both the natural biological riches of the earth and the well being of its citizens. While the problem is global, the nature and severity of the impacts on society, economic life, health, and natural heritage are distributed unevenly across nations and regions. Thus, some aspects of the problem require solutions tailored to the specific values, needs, and priorities of nations while others call for consolidated action by the larger world community (Noemdoe, 2001).

2.2 FACTORS CONTRIBUTING TO THE INTRODUCTION AND SPREAD OF ALIEN INVASIVE SPECIES

Biological invasions are human-assisted. Humans intentionally and unintentionally introduce species into new areas or alter ecosystems in ways that promote invasions.

Global factors, both primary and secondary, that facilitate the introduction and spread of alien invasive species include:

2.2.1 Economics and trade

The openness of a country's economy and the composition of its trade routes enhance the vulnerability of nations to biological invasions. Invasions are also enhanced by the national importance of agriculture, forest and tourism sectors; a high importance generally leads to increases in the resources allocated to quarantine and protection. However it also increases the opportunities for introduction and spread (Carlton and Geller, 1993).

Globalization has led to more and faster trade, new travel and trading routes, and increased trade in livestock, pets, nursery stock, agricultural produce and forest products; all of which can facilitate the introduction and spread of alien invasive species. Weed seeds, plant pathogens, larval or adult arthropods and other invertebrates, and even some vertebrate species can be transported on such commodities (Carlton and Geller, 1993). Sand, gravel, coal and metal ores, and other inorganic commodities can also be contaminated with seeds, arthropods and pathogens. Unprocessed wood, wood products and nursery stock are also a major source of forest pests and diseases (Delfino and Simmons, 2000).

In addition to the possibility of the commodities themselves carrying alien invasive species, the containers and vehicles in which they are transported can also facilitate invasions. Wood packaging material made of unprocessed raw wood, including pallets, crates, drums, skids, cases, and dunnage, can be a pathway for the introduction and spread of pests, in particular forest pests. Containerized cargo can shelter alien species from microorganisms to reptiles and mammals and since inspection of such freight is very difficult and costly, many alien invasive species may enter a country undetected. Vehicles, including cars, trucks, trains, planes and ships, may also be contaminated with all types of pests and since the commercial and recreational movement of vehicles across international boundaries has increased, the threats are considerable (Delfino and Simmons, 2000).

2.2.2 Climate change

Global climate change has many environmental consequences including changes in species distributions and in their abundance within existing distributions as a result of direct physiological impacts on individual species and changes in abiotic factors, reproduction and recruitment opportunities, and interspecific interactions (Dukes, 2000).

Climate change may alter production patterns and trade in agricultural and forestry commodities by species being grown more competitively in higher latitudes and altitudes. Since alien invasive species establish more easily in habitats disturbed by

human and other factors, such changes can provide more opportunities for them to invade. Climate change also affects the frequency and intensity of extreme climatic events, which disturbs ecosystems and thus provides increased opportunities for dispersal and growth of invasive species (National Assessment Synthesis Team, 2000).

In addition to the effects of climate change, increasing concentrations of greenhouse gases can have significant effects on the success of alien invasive species as well. Higher concentrations of carbon dioxide increase photosynthetic rates and water use efficiency of plants and ecosystems and the resulting increased soil moisture has the potential to provide habitat for late-season annuals, which may be invasive (Vitousek *et al.*, 1997). Substantial changes in the species composition and dynamics of terrestrial ecosystems would be expected since increased levels of CO₂ affect not all plant species in the same way (Dukes, 2000).

2.2.3 Conflict and reconstruction

According to Perrings (2000), conflict and civil unrest can contribute to the introduction and spread of alien invasive species as a result of:

- a) the breakdown of phytosanitary and animal health controls and the loss of supply lines for materials;
- b) the displacement of large numbers of people and their belongings can be a dispersal mechanism for, or the source of, alien invasive species;

- c) the lack of inspections and border controls and the increased unregulated movement of military personnel and refugees;
- d) increased smuggling;
- e) border areas may be difficult to survey because of landmines and other hazards;
- f) military transport, equipment and supplies, often covered with dirt or mud from the field, can introduce alien invasive species into new environments;
- g) foreign food aid which may be contaminated with pests and diseases;
- h) emergency relief, reconstruction efforts, and humanitarian assistance after wars and disasters.

2.2.4 Regulatory regimes

A country's lack of regulatory regimes, including resources for prevention and enforcement measures as well as attitudes and views regarding risks, make it more vulnerable to invasions (Malan, 2003).

2.2.5 Tourism

With millions of tourists crossing international borders every year, the opportunities for the introduction and spread of alien invasive species is profound and increasing. Travelers can intentionally transport living plant and animal species that can become invasive or they can carry fruits and other living or preserved plant materials that contain potentially invasive insects and diseases that can have profound effects on agriculture, forestry and other sectors. Travelers

themselves can also be the vectors of parasites and diseases between countries (Perston *et al.*, 2000).

2.2.6 Biological control of pests

Another source of alien invasive species is the intentional importation and release of insects, snails, plant pathogens and nematodes for biological control of pests. Such species can escape into other unintended areas and become pests themselves (McDonald *et al.*, 1987). For example, when the mongoose was introduced to Hawaii in order to control the rat population, it preyed on the endemic birds of Hawaii, especially their eggs, more often than it ate the rats (Wiedenmann, 2000).

2.3 IMPACT OF INVASIVE ALIEN SPECIES

Invasive alien species occur in all major taxonomic groups, which include viruses, bacteria, fungi, algae, mosses, ferns, vascular plants, invertebrates, fish, amphibians, reptiles, birds and mammals. In each taxa, many species have the potential to invade other ecosystems and affect native biota in a direct or indirect way (Mooney *et al.*, 2005).

Some impacts caused by invasive species in natural ecosystems are described below:

2.3.1 Creation of a homogenous world:

Invasive species dominate vast areas and replace native species. The increased domination threatens to create a homogenous area rather than the ones

characterized by great biological diversity and local distinctiveness (McNeely *et al.*, 2001). In the British Isles, *Rhododendron ponticum* has invaded a vast range of habitats and when conditions are suitable, it forms dense, impenetrable stands. These stands prevent the regeneration of the native species. Consequently they remove the habitat for birds and other animals (Cronk and Fuller, 2000). *Salvinia molesta* spreads and dominates many freshwater systems and forms dense and floating mats that spread to cover the whole water body. These mats reduce light and oxygen levels, resulting in the displacement of the native animals and plants (Bethune *et al.*, 2004).

2.3.2 Extinction of endangered and other species:

Invasion has posed direct threats to the native fauna and in some cases leading to the extinction of endangered species. *Lantana camara* forms dense impenetrable strands in the Galapagos and threatens to remove the breeding sites of an endangered dark-rumped petrel bird and several rare composite plant species (Matthews and Brand, 2004). In South Africa the invasion and spread of *Acacia saligna* directly threaten the regeneration capability of the fynbos shrub lands (GISP, 2004).

Although some species are negatively affected by the invasion, there are some that are positively affected. In South Africa, there is a considerable extension of the range the pied-barbet bird by increased provision of nesting sites and fruits from the introduced *Acacia* thickets (Cronk and Fuller, 2000).

2.3.3 Transformation of structure and species composition of ecosystems:

Invasion can transform the structure and composition of species in an ecosystem by suppressing or excluding the native species. Repressing or exclusion can be directly by out-competing the native for resources or indirectly by altering the way nutrients are cycled through the system (NEPAD, 2004). In Hawaii, *Myrica faya* enriches the volcanic soil with nutrients by fixing nitrogen in its root nodules. This has serious long-term consequences for this naturally poor nutrient ecosystem. The nutrient enriched soil may facilitate the invasion of other alien species that are unable to invade due to the low nutrient level (Cronk and Fuller, 2000).

2.3.4 Alteration of fire regime:

Plant invasion can change both the fire frequency and intensity. Fire frequency is a function of both the frequency of dry periods, ignition events and the flammability of the vegetation, which determines the success rate of the ignition events (Mapaure, 2005). In plants, competitive relationship with other plants is important and to many fire-adapted species, fire gives them the competitive advantage (Mooney and Hobbs, 2000). They have adaptations such as the production of volatile oil or standing dead matter to increase the frequency of successful ignition (D'Antonio, 2000).

Hakea species have seeds with delayed dispersal and fire promotes their release, leading to rapid accumulation of large quantities of inflammable matters. In South

Africa, the dense infestation by *Hakea* species has increased the intensity of fires. By encouraging regeneration and the release of seed by *Hakea* species, regular burning in non-inflammable vegetation can have dramatic effects on species composition. These will prevent the regeneration of native species that are not adapted to regular burning (Cronk and Fuller, 2000).

2.3.5 Impact on human economic interest:

Invasive species have many negative impacts on the human economic interest. Considerable uncertainty remains about the total economic costs of invasions, but the estimates of the economic impacts on particular sectors indicate the seriousness of the problem. Tourists unwittingly introduce alien plants into national parks where they degrade the protected ecosystems and drive the management cost high. Weeds reduce crop yield, increase control costs and decrease water supply by degrading water catchment areas and freshwater systems. Pest and pathogens of crops and livestock reduce yields and increase the control cost (McNeely, 2001)

The discharge of ballast water introduces harmful aquatic organisms, including diseases, bacteria and viruses to both marine and freshwater ecosystems, thereby degrading commercially important fisheries. And recently spread disease organisms continue to kill or disable millions of people each year, with profound social and economic implication (McNeely *et al.*, 2001).

2.4 FACTORS THAT INFLUENCE THE GROWTH AND SPREAD OF INVASIVE ALIEN SPECIES

2.4.1 Broad native range:

Species that are widely distributed are logically more likely to be able to colonise a wide variety of habitats with different conditions (Munthali, 2004).

2.4.2 Absence of natural enemies:

Most plants and animals are fed on by something or host parasites, but when they are moved out of their natural habitats. The natural enemies are often left behind and there is nothing in their new niche that is quite as effective at controlling the growth of these plants and animals. As a result they do very well and soon out compete indigenous plants that are subject to herbivores or pests (Munthali, 2004). The large-mouth bass (*Micro salmoides*) is a voracious predator and have a damaging effect on the native fish and other aquatic animals (NEPAD, 2004).

Rapid growth rates:

In less tropical areas, sunlight may be a factor limiting growth and when plants from these areas find themselves in a sunny tropical climate, such as Namibia, they take advantage of the increased light, or longer growing seasons and do really well, thus out-competing indigenous species that are not able to utilize increasing amounts of light (Mooney and Hobbs, 2000). Depending on the climate *S. molesta* may be either a perennial or an annual. In non-tropical regions it may function as an annual but it will still produce significant growth during the summer period. In nutrient rich waters it may reach a density of 30 000 small plants per m² and under ideal growth conditions it can double its biomass in two days (NBII and ISSG, 2000)

2.4.4 Availability of nutrients:

Plant growth is often limited by the availability of nutrients such as phosphorus, nitrogen and in the case of terrestrial plants also potassium (Salisbury. and Ross, 1992). When these nutrients (the ingredients of most fertilizers) are more available perhaps as a result of eutrophication or pollution, the alien plants are sometimes better able to take advantage of this and thus grow better too (Bethune *et al.*, 2004).

2.4.5 Reproductive strategies:

Plants that can reproduce vegetatively from plant fragments as well as by spores or seeds have an advantage over those that are tied to sexual reproduction and the seasonality that bearing spores or seeds impose. Many aquatic weeds are very good at vegetative reproduction and so even few plants can potentially infest new areas or re-infest cleared areas. Others that have seeds that remains viable for many years or are resistant to frost or desiccation are also better able to colonize new areas. The production of large numbers of seeds, small easily dispersed seeds and seeds that remains viable for many years contribute to the rapid spread and establishment of invasive plants. Studies show that water hyacinth seeds remain viable up to 15 years, allowing seeds deposited in seldom-flooded areas to remain viable for prolonged dry periods (Brown *et al.*, 1985).

2.4.6 Difference to indigenous competitors:

Invasiveness of alien species may also be correlated with how different the alien species is to the indigenous species found in the same habitat. This is referred to as the “unlike

invader” hypothesis. For instance *Opuntia* species, although sharing many adaptations to herbivory and aridity with the indigenous species in the highland savanna, have a growth form, armoury and vegetative reproduction strategy that may well give them a competitive edge (Bethune *et al.*, 2004).

2.4.7 Ability to colonize new habitats:

In addition to resistant seeds and spores mentioned above and the ability to reproduce vegetatively, some invasive plants have special colonizing growth forms. An example is *Salvinia molesta* that when young has flatter, more open leaves that allow it to float well and so be easily translocated to new areas. Both *Salvinia* and *Pistia stratiotes* have “roots” and “stolons” that become easily entangled and so promote mat formation, a strategy that shades out competing indigenous water plants (Ruiz and Carlton, 2003).

2.4.8 Human activities:

People alter habitats and translocate plants to new areas. For water plants the increased utilization of water bodies and the construction of artificial ones, be they impoundments or irrigation canals, create new habitats where water weeds can flourish. Increasing pollution and land clearing are further factors creating ideal conditions for problem plants to flourish (Cronk and Fuller, 2000).

2.4.9 Lack of awareness and vigilance:

A general lack of awareness regarding the identification and problems caused by invasive alien species promotes their inadvertent spread, particularly via the horticultural, aquacultural, and recreational industries. Botswana has introduced an Aquatic Weeds (Control) Act No 58 of 1987 that strictly controls boat traffic to prevent the spread of aquatic weeds. For several years Namibia undertook voluntary boat inspections at border checkpoints to assist Botswana with this effort to prevent the spread particularly of *Salvinia molesta* (Bethune *et al.*, 2004).

2.4.10 Susceptibility of habitats:

Some habitat types appear to be more susceptible to invasion than others, and successful invasion is a function of both the invasiveness of a species and the invasibility of a habitat. Mature forests, arid (but not necessarily semi-arid), montane and salt marsh habitats are less likely to be invaded, whilst riparian habitats and islands are most susceptible (Cronk and Fuller, 2000).

2.5 PROCESS OF INVASION

The invasion of species has three main elements, the source, pathway and vectors and destination. Source population is found where the species naturally forms part of the native ecosystem. Some species maybe an endangered icon or flag species in its natural habitat but become a concern pest in its new range (McNeely *et al.*, 2001).

The pathways and vectors that transport the invader are important links in an invasion. Most vectors are human-assisted transport mechanisms that move organisms across their natural barriers. Most plant and vertebrate species introductions have been intentional for various reasons, for example, plants as ornamentals, mammals as game, birds as delight for the spirit and the senses, fish for sport fishing. On the other hand, most invertebrates (including marine organisms) and microbe introductions have been accidental, often attached to other species introduced intentionally (Richardson *et al.*, 2000). Often agricultural weeds have been introduced as contaminants of crop seeds, whereas most of the environmental weeds were purposefully planted as ornamentals, for soil stabilization, for firewood, etc. sometimes supported by ill-guided aid programmes or commercial ventures (Mooney *et al.*, 2005).

Whether an alien species becomes invasive at its destination depends on what ecological role the species may play, and on other factors such as:

- a) the stage at which the immigrant species arrives at a time to tolerate the environmental conditions that are being expressed;
- b) its rate and direction of spread;
- c) its population dynamics and phenology;
- d) its interaction with native organisms in the new range; and
- e. the type of ecosystem it is invading.

The process of invasion involves various stages and they can be divided into:

- Introduction: The translocation of living organisms from one region into another, either accidentally or intentionally. By introduction, the species has overcome the geographic barrier.

- Naturalization: the alien species becomes established beyond the site of initial introduction to form large self-sustained populations in the natural environment. The establishment of alien species depends on the competition that exists. Disturbances provide windows of opportunities for alien plant invasions, as it could reduce predation and grazing, creating microclimates that facilitate establishment (Richardson *et al.*, 2000).

- Facilitation: the selection of the fittest individuals through genetic adaptation to the new environment. An alien species may remain a rarity unless facilitated in a way that it spreads. The introduction of suitable dispersal agent, pollinator, disturbance in an ecosystem or a lack of pest and diseases are examples of facilitators (McNeely *et al.*, 2001).

- Spread: when the spread of an alien species has been facilitated, the rate of spread depends on the inherent growth and growth rate of the species. The nature of invaded habitat, including suitable places for reproduction also plays a role in the spread of the species. In plants, a successful invader often has adapted to short- and long distance dispersal, the short-distance bulking up existing populations and

long-distance establishment of new foci for further spread, remote from the original site of invasion (McNeely *et al.*, 2001).

- Interaction with animals and other plants: Once the alien species starts to spread, it will encounter the native (including other aliens) species. The outcome of the encounter will determine whether it will be an invasive alien species or not and therefore whether it will have a significant effect on the ecosystem processes, composition and structure. In some cases competition may restrict the alien species to disturbed areas where the native species are unable to survive due to extreme environmental conditions (Cronk and Fuller, 2000).

- Stabilization: Some invasions appear to stabilize as single or near single species strands. Whether stabilization is an illusion is uncertain as many invasions are recent and it is possible that the populations will eventually undergo senescence (Cronk and Fuller, 2000).

2.6 THE GLOBAL STRATEGIES TO ADDRESS THE PROBLEM OF INVASIVE ALIEN SPECIES

Under the Convention of Biological Diversity, during the 5th Conference of Parties, the parties agreed to set interim guiding principles to the problem of invasive alien species. Considering the principles, during its Phase 1 synthesis Conference, GISP developed strategies responses to the problem. These strategies have ten (10) elements which were

intended to guide policy-makers in their responses to the growing challenges of invasive alien species (Barnard and Waage, 2004; McNeely *et al.*, 2001).

- I. Build management capacity: To successfully address the problem of IAS requires both the national will and the capacity to act. Due to the global nature of the problem, it is a high priority to build management and operational capacity in all countries. At national level, capacity-building initiatives can draw upon experience of others counties.
- II. Build research capacity: The current knowledge on IAS must be further developed with a cross-sectoral and multi-disciplinary approach in order to provide the tools needed to address this pervasive issue.
- III. Promote sharing of information: Considerable information regarding IAS is available. The information that could alter management agencies to the potential dangers of new introductions is either not well known, or is not widely shared or is available in inappropriate format to enable governments to take prompt actions.
- IV. Develop economic policies and tools: Invasions are a consequence of economic decisions and have impact on the economy. While prevention, eradication, control, mitigation and adaptation all yield economic benefits, they are public goods. If left only to the market, the control of IAS, like the control of communicable human diseases, will be inadequately provided for. Since

biological invasions indicate the failure of the market, an important part of any strategy to manage IAS is to make markets work for conservation, and to provide alternative solutions if the market does not exist and can not be created.

V. Strengthen national, regional and international legal and institutional frameworks:

National legal measures have evolved in a reactive and piecemeal manner, responding to new problems and pathways relating to IAS. However, isolated unilateral actions by individual countries can never be sufficient to manage the full range of activities and process that generates invasions. Coordination and co-operation between relevant institutions are needed to address possible gaps, weaknesses and inconsistencies, and promote greater harmonization between the many international instruments that address IAS.

VI. Institute a system of environmental risk analysis: Risk Analysis and

Environmental Impact Assessment procedures have already been adopted in many countries and mandated by certain international instruments. The challenge now is to apply these to address the prevention, eradication and control of IAS. This should involve shifting the burden of proof to those individuals proposing the intentional introduction of a potentially invasive species.

VII. Build public awareness and engagement: Active public engagement is important

to successfully manage invasive species. This strategy is intended to help countries and organizations engage the public successfully and to coordinate their

effort for bigger global benefit. This will lead to an informed public that will support ongoing actions to reduce the threats caused by IAS and key stakeholders who are engaged in implementation of IAS solutions.

- VIII. Prepare national strategies and plans: The problem of IAS is cross sectoral as it spreads through many economic sectors, both public and private sectors. Addressing the problem of IAS successfully will require effective collaboration among these various institutions. Relevant agencies should collaborate through an open consultative process to prepare strategies and action plans for dealing with IAS.
- IX. Build invasive IAS issues into global change initiatives: Human activities are changing the earth in unprecedented ways. These changes are altering the atmospheric composition, changing the climate, increasing the utilisation of natural resources and changing land uses, and deliberately and inadvertently moving species around the globe. The interaction of IAS with other elements of global change may occur in complex and unpredictable ways, acting as drivers of further changes. Global changes result from cumulative impact of local decision, and therefore the issue needs to be addressed both at international and local levels.
- X. Promote international co-operation: A wide range of approaches, strategies, models, tools and potential partners are available for international co-operation. The most relevant approaches vary for each situation.

2.7 INVASIVE ALIEN SPECIES – NAMIBIAN PERSPECTIVE

In 1984 during an annual professional officers meeting of the then Directorate of Nature Conservation and Recreation Resorts, the problem of invasive alien species was highlighted. A series of detailed field surveys had been undertaken nationally, and the results of these surveys were presented at this annual research meeting and subsequently published. Until the establishment of specialist working groups under the National Biodiversity Task Force about five years ago, little took place in the field of invasive species research other than the ongoing biological control of *Salvinia molesta*.

The main achievements of the two working groups that dealt directly with invasive alien species, the Alien Invasive Species Working Group and the Agricultural Biodiversity Working Group, were:

- the publication of two posters (“Namibia’s Nasty Nine – Alien Invasive Species” and “Help Protect Namibia-The ecological and economical threats caused by IAS) by Smit and Steenkamp (2001) and Katjirua and Smit (2004), respectively,
- publication highlighting the distribution dynamics of fountain grass (*Pennisetum setaceum*) by Joubert and Cunningham, (2002),
- Publication by Cunningham *et al.* (2004), highlighting the distribution and invasive potential of *Dodonaea angustifolia* to the Auas Mountains.
- a Ph.D. study on *Prosopis* by Smit (2006). The study highlighted the impact and changes of *Prosopis* on the landscape. Also highlighting the management challenges and economic opportunities of *Prosopis*.

- the inclusion of the necessity to “reduce the threat to biological diversity from invasive alien species” as a strategic aim in Namibia’s ten-year strategic plan of action for sustainable development through biodiversity conservation – Biodiversity and Development in Namibia 2001 – 2010” (Barnard *et al.*, undated),
- a national review of invasive alien species by Bethune *et al.* (2004), attempts made to review the legislative framework, and in recent years, annual, national, one-day workshops.
- To a lesser extent, the projects of students and scholars reveal an ongoing awareness of and concern regarding the problem of invasive alien species (Bethune *et al.*, 2004).

Despite this, invasive alien species are not generally perceived to be a major problem in Namibia. This rather complacent perception of invasive and potentially invasive alien species can be attributed to:

- a) Namibia’s aridity: relatively few alien species are likely to become invasive in a very hot and dry area such as Namibia.
- b) Namibia’s paucity of research capacity in terms of qualified biological research personnel. Studies of invasive organisms have been relatively few and far between and has focussed on the distribution of relatively few species.
- c) Little information available on the recent distribution and population dynamics of invasive species,

- d) Little is known about the socio-economic and ecological impacts of invasive species. What is reported in the literature is largely inferred from observations and studies elsewhere.

In 2004, the Directorate of Environmental Affairs commissioned a consultancy to review the status of invasive alien species in Namibia. The consultancy report includes annotated checklist of the most important invasive alien species in the country, identifies and describes the 15 most important invasive alien plant species and the 11 most important invasive alien animals. The annotated checklists was developed in the review to help in the process of assessing and categorising what is known about invasive alien species in Namibia. Similarly the information formed the basis for the proposed database on plant and animal invasive aliens. In 2006, based on the National Review of Invasive Alien Species in Namibia, a national database on invasive alien species was developed and is hosted by the National Botanical Research Institution. In due course, the information will be expanded with data obtained from field surveys, museum and herbarium records and the wetland database to develop an invasive alien species atlas for Namibia.

There is an urgent need to determine the invasiveness under local conditions of all the species, starting with those most likely to impact on vulnerable ecosystems and those most likely to have adverse economic impacts. Future threats include new introductions via the nursery trade, reforestation programmes, game farming and expanding aquaculture enterprises. Because of the aridity of much of the country, the lack of detailed research on invasive alien species, the paucity of information regarding their

present distribution, population dynamics, and their social, economic and ecological impacts under local conditions, such species are not generally perceived to be a major problem in Namibia. A scientifically sound review of the invasiveness of each alien species and the susceptibility of local natural ecosystems to invasion is needed in Namibia and will allow for more effective management and control (Barnard, 1998).

Invasive alien species, alien species and potentially invasive alien species constitute a major threat to biodiversity, both nationally and globally. Although present legislation rarely specifically mentions invasive alien species, the general issue is fairly well covered within the broad definitions pertaining to environmental health, sustainable utilisation and the preservation of Namibia's array of biodiversity in the broadest sense. Although there is legislation in place that implicitly covers invasive alien species (such as the Nature Conservation Ordinance of 1975), there is nevertheless an urgent need to introduce legislation which explicitly refers to invasive alien species, and that it might be in Namibia's best interests to consider drawing on relevant clauses in South Africa's National Environmental Management: Biodiversity Act. Given recent legislative developments, there are excellent opportunities to incorporate relevant clauses in legislation now being drafted or still under consideration. Attention in this regard should be given to the draft Parks and Wildlife Management Bill, particularly the section on alien and invasive species; the draft Water Resources Management Bill; the draft Conservation of Agricultural Resources Bill; the pending Environmental Management Bill; and pertinent regulations being developed for the Inland Fisheries Resources Act

and the Aquaculture Act (Malan, 2003). The following steps are recommended to improve present legislation:

- a) the development of a national policy on invasive alien species;
- b) the inclusion of explicit clauses on invasive alien species in legislation and policies currently being drafted;
- c) the development of appropriate regulations and guidelines on invasive alien species to complement existing legislation;
- d) the setting out of practical guidelines appropriate to existing natural resource legislation;
- e) the strengthening of awareness and enforcement of relevant legislation; and
- f) the promotion of ratification of and compliance with international and regional conventions, agreements and protocols, particularly the International Plant Protection Convention and the African Convention on the Conservation of Nature and Natural Resources.

The Namibia's Second Development Plan, NDP 2, shows that although environmental sustainability is a common theme in the plans of the natural resource sectors, no specific mention is made of any projects focusing on invasive alien species. It is recommended that this shortcoming be addressed in the planning for NDP 3, which should at least recognise and incorporate the objectives and activities outlined in Namibia's ten-year strategic plan of action for sustainable development through biodiversity conservation with regard to invasive alien species.

The problem of invasive alien species is multi-sectorial and the three lead governmental institutions are the Ministry of Environment and Tourism (MET), the Ministry of Agriculture, Water and Forestry (MAWF) and the Ministry of Fisheries and Marine Resources (MFMR). There is a lack of coordination among the different directorates in the line Ministries, the Directorate of Forestry continues to promote the planting of invasive alien species such as *Melia azedarach* and the Phytosanitary Unit approved the import of the alien *Jatropha* for bio-fuel projects. In its various tree-planting initiatives around the country, the Directorate of Forestry actively plants alien trees, including species that are known to be invasive, and also propagates and supplies these trees to schools and members of the public.

Two tertiary education institutions, the Polytechnic of Namibia and the University of Namibia (UNAM), have lecturers and students actively involved in research and training pertaining to invasive alien species. Other relevant institutions are those involved in the trading of alien species, for example plant nurseries, game dealers, farmers (represented by their unions) and institutions such as the National Museum of Namibia and the National Herbarium, which house and monitor natural history collections. Local authorities such as the City of Windhoek are responsible for urban issues and townlands, and generally take the management of invasive alien species seriously, while the water supply parastatal, NamWater, is responsible for protecting ecosystems, although it tends to deal with issues such as invasive alien species only if they affect water supply operations.

A variety of non-governmental organisations (NGOs) are concerned with environmental issues that may include invasive alien species. These include the Desert Research Foundation of Namibia (DRFN), the Gobabeb Training and Research Centre (GRTC), the Namibian Nature Foundation (NNF), Integrated Rural Development and Nature Conservation (IRDNC), and the Southern African Institute for Environmental Assessment (SAIEA). Also important, particularly in terms of raising public awareness, are national environmental groups such as the Namibia Environmental and Wildlife Society (NEWS) and Earthlife-Namibia, while in the urban setting, Greenspace – Friends of Avis and the Third Windhoek Scouts include control of invasive alien species in their activities. A high level of awareness has been engendered on the part of its members by the Namibia Professional Hunting Association (NAPHA).

CHAPTER 3

MATERIALS AND METHODS

3.1 STUDY AREA

3.1.1 City of Windhoek

The study was conducted in the City of Windhoek, the capital of Namibia, situated at 22.56°S 17.09°E as illustrated in Fig 3.1 and within the semi-desert climatic region. The human population size of Windhoek is about 252 000 (CBS, 2005) which is 14% of the National population (City of Windhoek, 2001). Windhoek was founded in 18 October 1890 and developed slowly, with only the most essential government and private buildings being erected. After 1907, development accelerated, people migrated from various corners of the country to the City. With Namibia's independence in 1990, the City experienced a new wind of change that led to accelerated growth and development (www.windhoekcc.org-22/10/06). The rate of urbanization of the City of Windhoek (5.44%) is higher than the national urbanization rate of 3.75% (City of Windhoek, 2001).

3.1.2 Development of infrastructure

The land use in Windhoek City varies greatly, it includes residential, commercial, hospitality industry; professional, public services, industrial, transport, educational, sewage treatment, water infrastructure, open space, community services, and undetermined land use. The Botanical Garden is an example of a least disturbed or near natural area within the City of Windhoek (City of Windhoek, 2001).

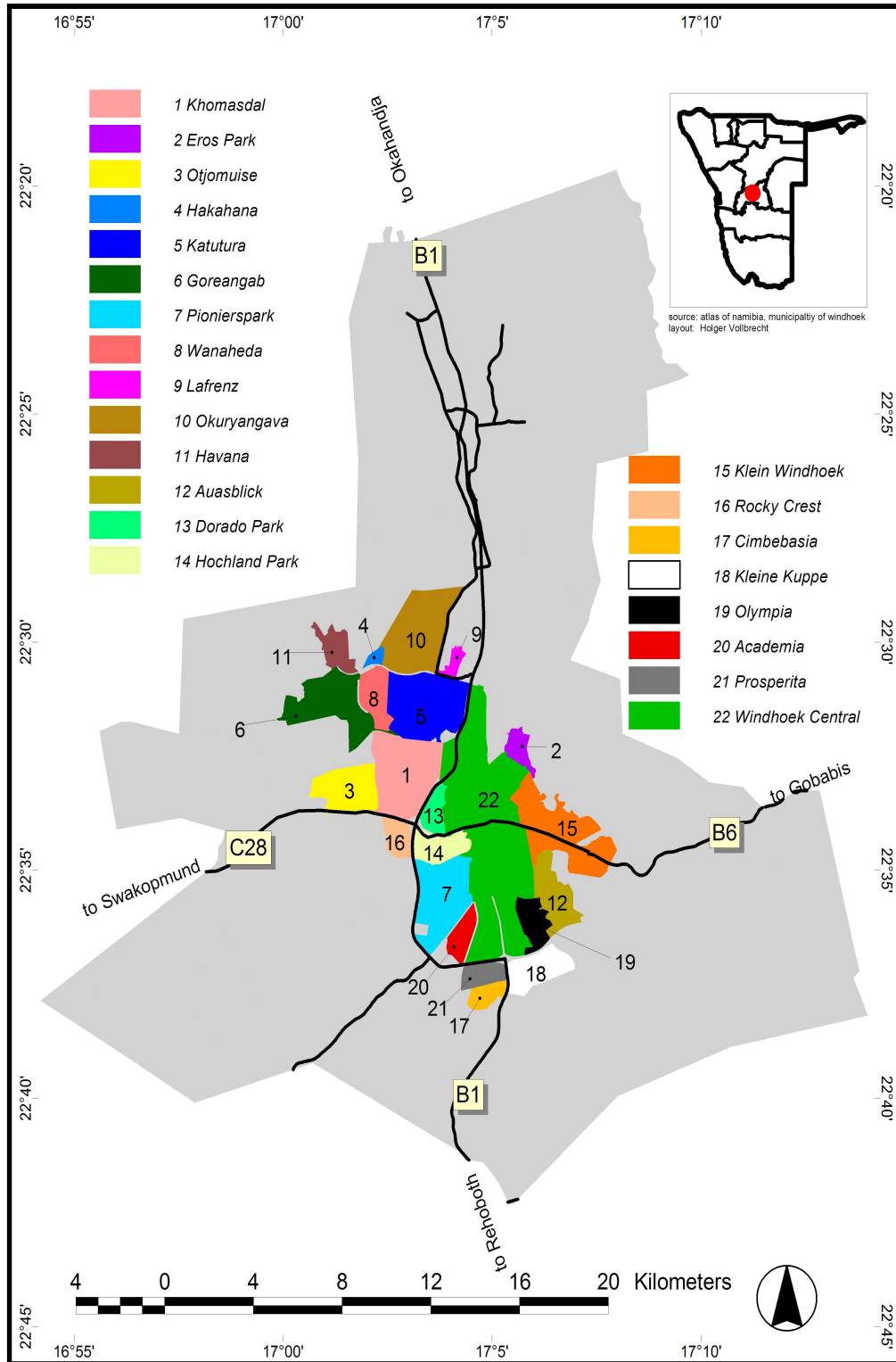


Figure 3.1: Map of the City of Windhoek, indicating the different suburbs, main road that leads outside the City. In the inserted country map, the red dot indicates the positioning of the City of Windhoek in the map of Namibia and the Khomas region. Source: Atlas of Namibia (Mendelsohn *et al.*, 2003) and City of Windhoek Municipality (2006). Layout by Holger Vollbrecht.

The City of Windhoek, excluding Brakwater has a total municipal area of 53, 176,812 ha. The Brakwater area comprises of seven (7) farms. The total developable land in the City of Windhoek is approximately 14 000 ha, where approximately 9, 092 ha are built environment (developed or proclaimed townships). The built environment is 17.1% of the total municipal area. About 3.19% of the total area is occupied by informal population (population in the informal settlements), which makes up 26.04% of the total City of Windhoek population (City of Windhoek, 2001)

3.1.3 Climate

3.1.3.1 Temperature

The highest temperatures are measured in December with an average daily maximum of 31°C and a daily minimum of 17°C (www.windhoekcc.org-22/10/06). Highest summer temperature is recorded when the cloud cover is limited. The coldest maximum temperature has an average of 20°C and a daily minimum of 6°C and they are measured in July (www.windhoekcc.org-22/10/06). The difference between summer and winter temperature are clear, but the seasons of spring and autumn are hardly distinguishable (Africon, 2004).

3.1.3.2 Rainfall

Rainfall occurs mostly in the summer months of September to March and the average rainfall in Windhoek varies between 300 mm to 400 mm per year (Stubenrauch Planning Consultants, 2004). The rainfall decreases from the Northeast to the Southwest over the

Khomas Hochland. At Bergvlug station (northwest of the Central Business District), the annual rainfall reaches 400 mm. At the Windhoek Meteorological Office the long term mean annual rainfall is 360 mm and at Mahonda (southwest of Central Business District) the annual average is 260 mm (Stubenrauch Planning Consultants, 2004). This apparent steep rainfall gradient might be affected by the local relief differences. Rainfall is highly erratic and unpredictable in time and space over the entire Khomas Hochland.

3.1.3.3 Wind

Air movement is predominantly south-easterly (www.windhoekcc.org-22/10/06). Wind also comes from an eastern, southern and northern orientation. However, it seldom comes from the northwest and southwest. Immediately after the winter months, the wind direction is predominantly westerly. This is due to the prevalence of the Southern Atlantic Anticyclonic cell resting upon the coast of Namibia. These winds are warm and dusty and are common on cloudless afternoons (Stubenrauch Planning Consultants, 2004).

3.1.4 Geology

The geology of the City of Windhoek is very complex and has been influenced by several faulting, folding, thrusting and rifting episodes. To the south of Windhoek valley, meta-sedimentary rocks such as marbles and micaceous quartzites with interbedded schists and amphibolites form the distinctive features of the Auas Mountains (Grünert, 2000). Schist outcrops contain numerous quartz veins, forming prominent ridges on higher elevations. The quartzites are subjected to brittle deformation and multiple joints, causing it to act as

important aquifer of groundwater for the City of Windhoek (Stubenrauch Planning Consultants, 2004). Closer to the Auas mountain, the quartzites are shallow and outcrops are common (Grünert, 2000). However, northwards of the mountains quartzite dips underneath the overburden schists. This implies that the vulnerability of the Windhoek aquifer to surface impacts increases towards the Auas Mountains (Africon, 2004).

3.1.5 Geo-morphology

Geo-morphologically, Windhoek forms part of Namibia's Hardveld. The Hardveld is a diverse region of rugged mountains, rolling hills, rocky outcrops and grassy plains intersected by watercourses as illustrated by Figure 3.2 (Stubenrauch Planning Consultants, 2004). All present interior rivers originate on the escarpment and Hardveld. Those from the escarpment flow westward to the Atlantic, but not all of them empty into the sea. Those that originate from the Hardveld flow in all wind directions and none of them flows directly into the sea. They form tributaries of higher order streams, well emphasized with the many streams that originate in the Khomas Hochland. Therefore, the Khomas Hochland is exposed to continued erosion and its soils are thin, skeletal and poor in fertility (Africon, 2004).

The geo-morphology of the Khomas Hochland comprises three major landform types:

- **Slope and ridges**

Slope and ridges at the foothills of the Auas Mountain form landforms at the southern boundary of the Windhoek basin. The substratum is predominantly rocks

with pockets of poorly developed soil below the rock overhangs. The topology is gentle to moderate sloping (Stubenrauch Planning Consultants, 2004).

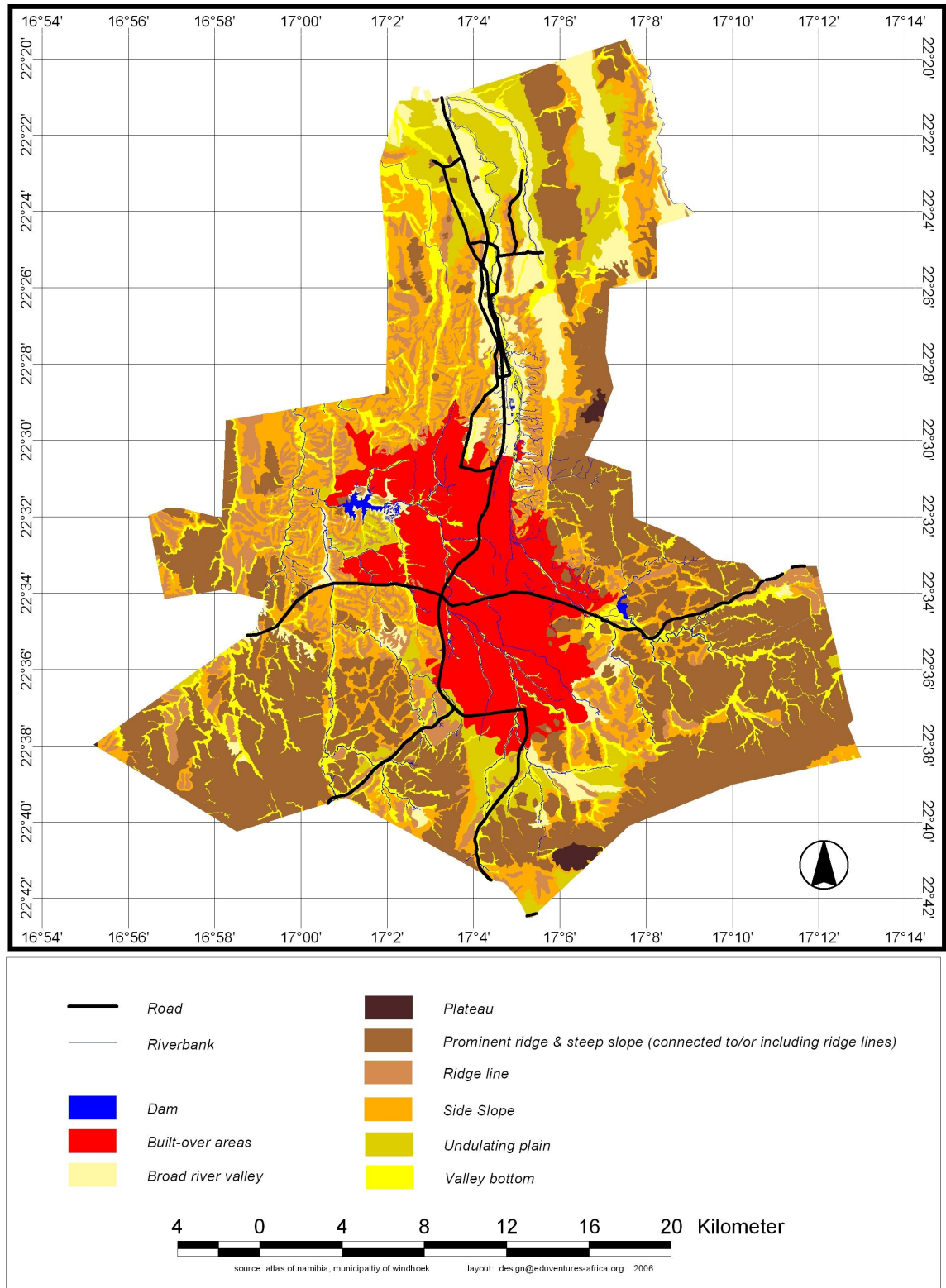


Figure 3.2: The diverse geo-morphology of the City of Windhoek. Source: Atlas of Namibia (Mendelsohn *et al.*, 2003) and City of Windhoek Municipality (2006). Layout by Holger Vollbrecht

- **Drainage lines**

Khomas Hochland is a catchment area of some of Namibia's major rivers. It forms the origin of the Gammams and Arebbusch rivers, which are the major drainage lines. Within the rivers, sandy alluvium mixed with boulder gravel forms the streambeds. These streambeds often act as important periodical aquifer where the riparian vegetation abstract water. The topography is gently sloping with locally steeper alluvial terraces (Stubenrauch Planning Consultants, 2004).

- **Denudated plains**

The isostatic movements in combination with prolonged denudation caused by the massive paleo-rivers eroded the Khomas Hochland. This resulted in denudated plains. The prolonged erosion formed jagged edges, cliffs and exposed bedrock over the entire Khomas Hochland. The Windhoek valley stream load was deposited as a thick sandy alluvium (Carr *et al.*, 1993).

3.1.6 Soil

Soil in Windhoek has poorly developed thin topsoil due to the alluvial and colluvial deposition. The soil also lacks a well defined vertical profile, has poor fertility and has low cation exchange capacities. The depositions are mainly fine sands and silts with residual quartz pebbles. River alluvium along the ephemeral river courses and valleys comprising sand, gravel and stones, forms the thickest soil (Stubenrauch Planning Consultants, 2004).

The soil stratum of the slope and ridges consists of shallow gravels and colluvial deposits, interlayered quartzite beds and micaceous schist bedrock. Often a thin layer of gravelly colluvial hillwash covers the bedrock on flatter terrains. The hillwash is uniform and is popular for road construction purposes (Africon, 2004). The sandy alluvium associated with the drainage plains varies in thickness. The vertical development is immature and the mixed consistence is directly reflecting its mode of origin. The alluvium contains high percentage of sand, especially close to the drainage lines. The high percentage of sand in the alluvium makes it popular for building and construction purposes. The alluviums in the denudated plains consist of fine grained sand, gravel and boulder gravel deposits. It may also contain isolated basin-shaped concentration of clay, where water accumulates after localized downpours (Carr *et al.*, 1993).

3.1.7 Vegetation

Windhoek lies in the centre of the Highland savanna vegetation and the vegetation is complex and varied as illustrated by Figure 3.3. The City itself is dominated by degraded land and the various categories of development altered urban vegetation linked to the land use classification, including amongst others features such as sport fields, urban gardens, parks and cemeteries, mowed grasslands, dumpsites, sewage works, informal settlements and borrow pits. The Botanical Garden is a good example of the Highland Savannah vegetation zone in which Windhoek is located (City of Windhoek, 2001).

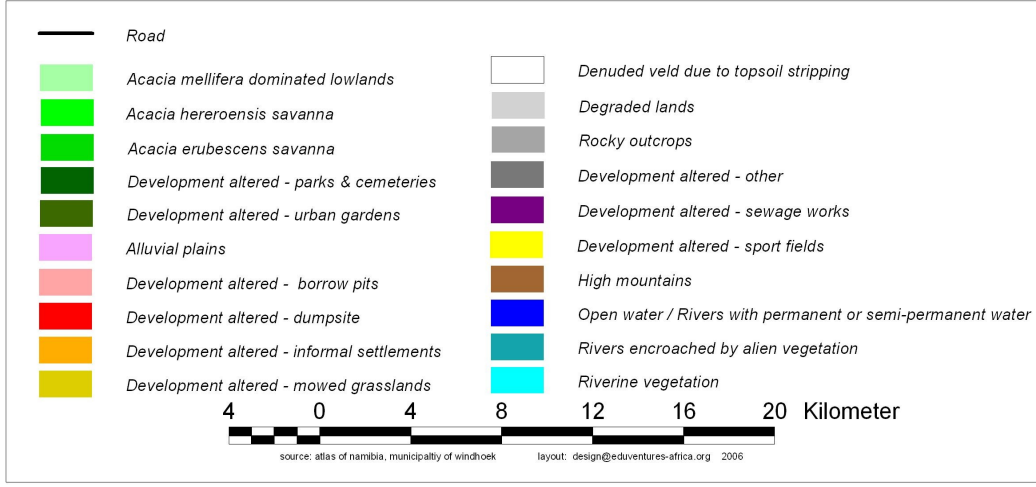
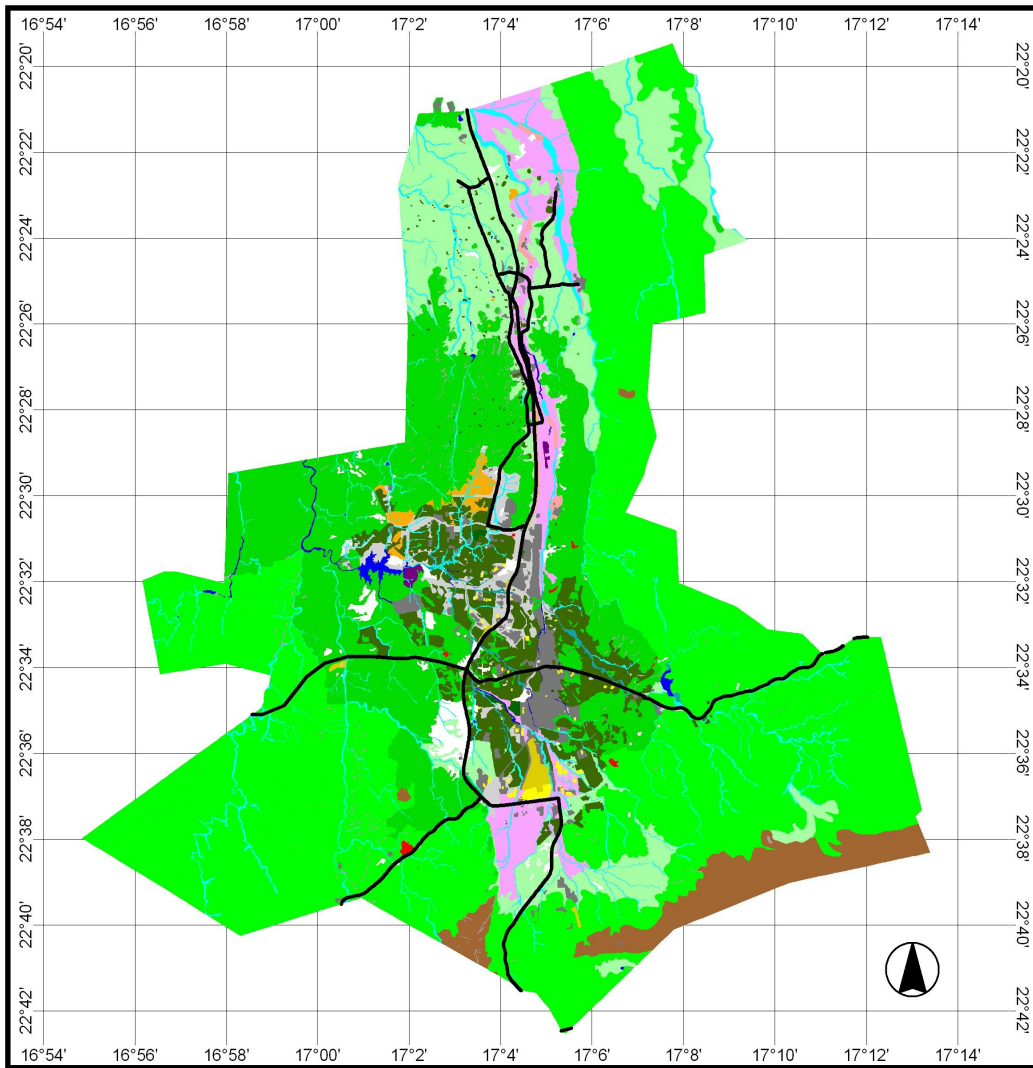


Figure 3.3: Vegetation map of the City of Windhoek. Source: Atlas of Namibia (Mendelsohn *et al.*, 2003) and City of Windhoek Municipality (2006). Layout by Holger Vollbrecht

Three vegetation types can be distinguished within the City of Windhoek:

- **Vegetation of slopes and ridges**

Moderate to steep slopes of various dipping slopes harbor tall open shrubland characterized by thicket growth forms of *Acacia hereroensis*, *A. hebeclada* and *A. reficiens* as well as *Acacia mellifera* and *Catophractes alexandrii*. *A. mellifera* and *Dichrostachys cinerea* seem to prefer lower altitudes and form monotonous thickets on the flatter slopes and ridges. Most shrubs rarely exceed 2m height. Other frequently occurring species include the perennial grasses *Cenchrus ciliaris* and *Pennisetum foermeranum* as well as the herbs *Tribulus zeyheri* and *Talinum caffrum*. Occasional trees such as *Boscia albitrunca*, *Combretum apiculatum* and *Ozoroa crassinervia* break up the shrubland. The slope and ridges support a moderate to high species diversity, including species of conservation importance such as *Aloe littoralis* and *Stapelia* species (Africon, 2004).

- **Vegetation of drainage lines**

Riverbeds harbor riparian woodlands dominated by *Ziziphus mucronata*, *Rhus lancea*, *Acacia erioloba* and *Acacia karroo* (City of Windhoek, 2001). Frequently these species reach a height of 6m and overall vegetation cover is variable. Some shrub species from the slopes occur at the edge of the riverbeds and form transition between slopes and riverbeds. Largely short-lived grasses such as *Enneapogon*

cenchroides, weedy herbs (e.g. *Bidens bipinnata* and *Tagetes minuta*) and the indigenous creeper *Citrullus lanatus* occur as ground layers of riparian vegetation.

Due to annual floods, the establishment of long-lived shrubby and diverse herbaceous vegetation on the streambed and banks are limited. Instead invasive alien species such as *Prosopis* species, *Datura innoxia*, *Datura stramonium* and *Argemone orchroleuca* easily establish on the terrain prone to inundation or where the water is within the reach of their roots (City of Windhoek, 2001).

▪ **Vegetation of denudated plains**

The denudated plains of Khomas Hochland are dominated by the *Acacia* species, but are limited in species diversity and composition. This vegetation is heavily subjected to transformations caused by human activities. Several patches of land are not properly managed and result in invading species encroachment or invasion (Africon, 2004). These vegetation are characterized by anomalies such as:

- Substitute plant communities, in particular alien species, appear soon after litho-pedological disturbance are caused by human activities;
- Since human activities do not show any link to litho-pedological variance, the transformation caused by human settlement results in plant associations that distort the transitions between natural vegetation groupings.

3.1.9 Fauna

The Khomas Hochland harbors a recorded species number of scorpions, solifuges, frogs, spiders, geckoes, skinks, agamas and snakes. Most of these organisms occur on the southern portion of the Windhoek Basin. A portion of these is also likely to occur in the vicinity of drainage lines and other reptiles mainly in rocky habitats such as slopes and ridges. Small mammals occurring in the smaller landscape, encompass several species of bats, shrews, mice, gerbils, hares, mongooses, rats, rock dassies, porcupines, ground squirrels and black backed jackal. Antelope detections include kudu, duiker and steenbok. Herds of baboons are regular within the City of Windhoek (Stubenrauch Planning Consultants, 2004).

3.2 VEGETATION SURVEY

The vegetation survey was conducted over a period of six (6) months, (starting April 2006 and ended in the last week of September 2006) in the selected sites within the City of Windhoek. Survey was done on a daily basis. During week days (Mondays to Fridays) the fieldwork started at two o'clock in the afternoon until sunset and during weekends (Saturdays and Sundays) the fieldwork started at six o'clock in the morning. This was due to the availability of the field assistant. Grids on the grided map of the City of Windhoek were used as sampling units.

3.2.1 Grid selection

A grided map, dated February 2006 and scale of 1:20033 was obtained from the City of Windhoek. The grids were numbered from 1 to 5790. The map was divided into four (4) quarters. Using Microsoft Excel, random numbers were generated for the selection of grids

in each quarter. The random numbers for the two northern and the two southern quarters were obtained as follows: RANDBETWEEN (1; 2666) and RANDBETWEEN (2667; 5790) respectively. A total of 160 grids (40 grids from each quarter) were selected for the survey. The random selection of grids was not stratified according to the geo-morphology but rather a simple random selection.

3.2.2 Geo-referencing

The 160 selected grids were geo-referenced by reading the coordinates from the map at the center of the grid. The coordinates were entered into the GPS as waypoints. The selected grids were geo-referenced in order to help locate the grids on the ground. With the help of the tourism map of City of Windhoek, the nearest route to the grids was worked out. The GPS was used to get to the exact central point of each grid on the ground.

3.2.3 Data collection

Once the central point of the grid was located, a grid was created on the ground by measuring 125 meters in all four (4) directions to demarcate a 25 0000 m² grid. The 25 0000m² grid was sub-divided into sixteen (16) 15625 m² plots to ease observation. Grids falling completely in build up areas were recorded as inaccessible and those partially in build up areas, the available open areas were considered for observations.

3.2.3.1 Distribution and abundance

In each grid, every observed *Datura innoxia* was counted and recorded. The type of human activities (construction areas and no construction areas) in each grid was recorded. Construction areas included areas where there were current or newly finished infrastructures such as roads houses and others. Also, it included sites where the area was cleared for dumping site or construction of road and building. The three geomorphological landforms (denudated plains, drainage lines and slope and ridges) and locations (open space and build up areas) where *D. innoxia* grows were observed and recorded in a data sheet. The build up areas included the residential, commercial, hospitality industry, professional, public services, industrial, transport, educational, sewage treatment, water infrastructure, and community services land use.

3.2.3.2 Reproduction status

The *D. innoxia* height (from base to tip) was measured to the nearest decimal using a measuring tape. The crown width (estimation of the proportion of leaves occupied by the perpendicular projection of the aerial parts of the plants) was also recorded for each by measuring the diameter along the densest portion of the crown. It was assumed that the crown has a circular outline.

The number of capsules (green intact capsules, green exploded capsules, dry intact capsules and dry exploded capsules) and flowers (open flowers, dry out flowers and emerging buds) were counted and recorded for each *D. innoxia* plant encountered in each

grid. The reproductive status (no inflorescence, inflorescence only, inflorescence and capsules and capsules only) of each *D. innoxia* were observed and noted.

3.2.3.3 Species composition

Apart from *D. innoxia*, all plant species found within the grid were identified and their presence recorded. Specimens of these plants were collected and identified, using keys and later confirmed with the National Botanical Research Institution (NBRI). Grasses were excluded from the assessment as it was not possible to identify them. Only the shrubs, herbs and woody vegetation were identified and recorded. The burned plants were only identified up to genus level. On each *D. innoxia* observed, other plant species within a radius of one meter and any other macro-organism associated with it were recorded.

3.3 DATA ANALYSIS

3.3.1 Distribution and abundance

Digital point polygon of the number of *D. innoxia* in each grid was produced using ArcView 3.2a. The point polygons were used to represent *D. innoxia* plants on the map. From the City of Windhoek municipality, shapefiles containing the boundary of the City of Windhoek, different suburbs, street names, land use, vegetation types, roads and drainage lines as line polygons were obtained. Maps were produced by overlaying the distribution of *D. innoxia* polygons in relation to shapefiles obtained.

Using Statistica 6.0, a goodness of fit (Kolmogorov-Smirnov) test was used to investigate whether the numbers of *D. innoxia* in the grids were normally distributed. The number of *D. innoxia* in the sampled grids were not normally distributed, $D = 3.355$, $p < 0.05$. Hence, non-parametric analysis was used. Using the Statistical Package for Social Sciences (SPSS) 15.0, the Kruskal –Wallis test was used to determine the significance in the mean rank of *D. innoxia* in the three geo-morphological landforms. The Mann-Whitney test was used to determine the significance in the mean rank of *D. innoxia* within the two identified location and type of human activities, respectively.

3.3.2 Reproductive status

Using Statistica 6.0, a goodness of fit (Kolmogorov-Smirnov) test was used to investigate whether the mean number of *D. innoxia* for the different reproductive status was normally distributed. The mean number of *D. innoxia* in the different reproductive status in the three environmental factors, namely geo-morphological landforms, location and type of human activities, were not normally distributed (Kolmogorov-Smirnov test $D = 9.53$, $p < 0.05$ for the geo-morphological landforms, $D = 10.25$, $p < 0.005$ and $D = 6.92$, $p < 0.005$ for the location and activities factors, respectively). The Friedman test was used to determine the significant differences between the reproductive status and the selected environmental factors. The Kruskal Wallis test was used for *post hoc* testing of the significant differences amongst the environmental factors. The mean number of the reproductive structures in the three geo-morphological landform, the two identified locations and activities was normally distributed ($D = 0.99$, $p > 0.05$, $D = 1.126$, $p > 0.05$ and

D= 1.045, $p>0.05$, respectively). The Two-way ANOVA was used to determine the significant difference between the mean numbers of reproductive structure in the three identified environmental factors. Tukey test was used for post hoc of the significant differences of the mean numbers of reproductive structure within the environmental factors. The height and crown width of *D. innoxia* was also normally distributed (D= 1.810, $p>0.05$) and hence the Two-way ANOVA was used to determine the significant differences between mean height and mean crown width in the three environmental factors.

To determine the relationship between the height and crown width of *D. innoxia* and the number of flowers and capsules within the City of Windhoek, the Spearman's rank correlation

3.3.3 Plant species composition

Hierarchical Cluster Analysis (HCA) using between groups linkage method and the Euclidean distance was performed on a matrix of 121 grids by 57 species. Species present/absent data (Appendix F) was used to produce a classification identifying similarities amongst grids based on species composition.

3.4 LIMITATIONS OF THE STUDY

1. Due to random selection of grids for sampling, many areas where *D. innoxia* was observed were not selected. Many grids were within build up areas and access was sometimes restricted or even denied
2. Gaining access to some grids was problematic. Entrance to few grids was via the Leopard Valley Army base and access was denied due to security reasons. Other grids were within and behind the Van Erk Powers station and access was also denied as this is a private property and a power station.

CHAPTER 4

RESULTS

From the 160 selected grids, only 121 grids were accessible and therefore the findings of this study will concentrate on those accessible grids. *D. innoxia* was observed in 50.4% of the grids (61) grids, which had a total of 900 *D. innoxia* plants.

4.1 DISTRIBUTION AND ABUNDANCE

Figure 4.1 indicates the distribution of *D. innoxia* in the City of Windhoek in relation to key features on the map such as roads, drainage lines and suburbs. *D. innoxia* was distributed all sections of the City of Windhoek. However, its occurrence was higher in the areas close to roads and drainage lines. A closer look into the areas where the largest number of *D. innoxia* was observed, which is represented on the map (Fig 4.1) by the four red circles with a dot inside, revealed that these grids (Grid 1893, Grid 2836, Grid 3774 and Grid 3183) were in areas where construction was underway and along river banks. Appendix A gives coordinates of the different grids.

Categorization was performed in order to understand the distribution of the grids according to the identified factors, which were the geo-morphological landform, location and type of human activities and this is presented in Table 4.1. The geo-morphological landforms were divided into three categories, namely the drainage lines, denudated plains and the slope and ridges. The type of human activities was divided into construction and no construction areas category. Grids classified in the construction category, were those positioned in areas where there was current or newly finished infrastructure such as

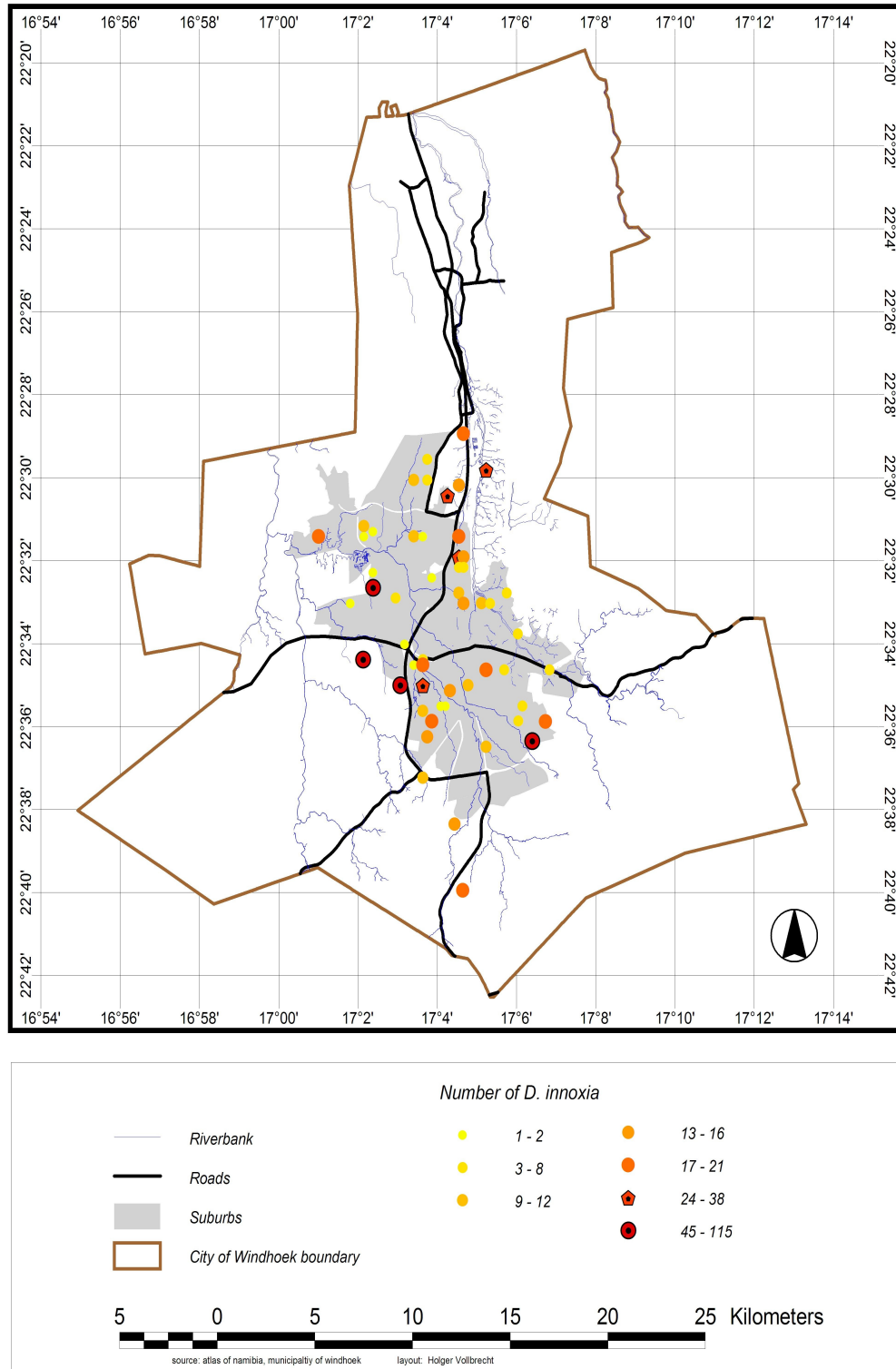


Fig 4.1: The distribution of *D. innoxia* in the City of Windhoek. Dots of different color and size represent the number of *D. innoxia* found in each grid. Adopted from: Atlas of Namibia (Mendelsohn *et al.*, 2003) and City of Windhoek Municipality (2006). Layout by Holger Vollbrecht

building of roads or houses. The location factor was divided into open areas and into built-up areas. Grids positioned in residential, commercial, hospitality industry and community services land uses were classified as built up areas.

Table 4.1: The number (N), percentage (%) and mean density of *D. innoxia* plants for each factor. The total number of grids studied and the total number of grids with *D. innoxia* in each factor is included

Factors	Categories	Total no. of Grids		No. of Grids with <i>D. innoxia</i>		Number <i>D. innoxia</i>		Mean density of <i>D. innoxia</i>
		N	%	N	%	N	%	
Geo-morphological landform	Drainage lines	18	15	13	21.3	200	22.2	11.1
	Denudated plains	82	68	36	59	556	61.8	6.8
	Slope and ridges	21	17	12	19.7	144	16	6.9
Totals		121	100	61	100	900	100	
Location	Built up Areas	66	55.5	51	83.6	734	81.5	11
	Open Space	55	45.5	10	17.4	166	18.5	3.2
Totals		121	100	61	100	900	100	
Activities	Construction	17	14	13	21.3	440	48.9	26.2
	No Construction	104	86	48	78.7	460	51.1	4.4
Totals		121	100	61	100	900	100	

In the case of the geo-morphological landform categorization, 68%, 17% and 15% of grids were found in the denudated plains, slope and ridges and drainage lines, respectively. Although having the least number of grids (15 %), the drainage lines had the highest mean rank of *D. innoxia* (Table 4.2). The denudated plains, where most disturbances occur, had close to 60% of the total number of *D. innoxia* individuals observed (Table 4.1).

Table 4.2: The mean rank of *D. innoxia* in the three identified geo-morphological landforms within the City of Windhoek.

Geo-morphological landforms	Number of grids	Mean rank of <i>D. innoxia</i>
Drainage lines	18	75.8
Denudated plains	82	57.2
Slope and Ridges	21	63.3

The Kruskal Wallis test indicated that there was no significant difference in the mean rank of *D. innoxia* in the three identified geo-morphological landforms within the City of Windhoek, ($H(2) = 4.87$, $df = 2$, $p > 0.05$ (Appendix B)).

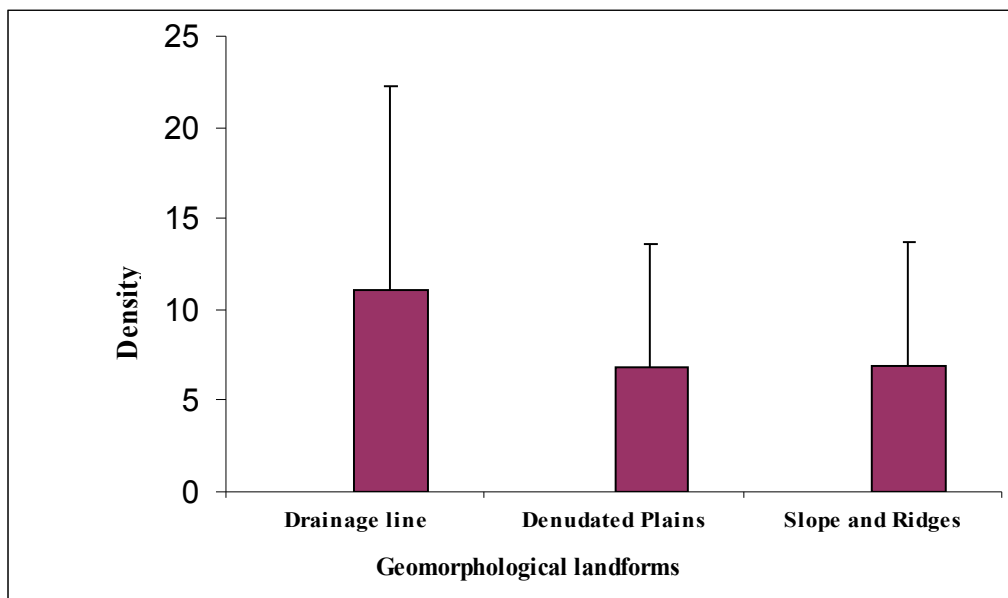


Figure 4.2: The density of *D. innoxia* per 25 000 m² in the three geomorphological landforms. The positive bars on each histogram represent the standard error of mean.

Although the denudated plains had the highest number of grids sampled and the highest number of *D. innoxia* observed (Table 4.1), there was no significant difference in the density of *D. innoxia* per unit area, ($\chi^2= 5.82$, $df= 2$, $p>0.05$), as illustrated in Figure 4.2.

The number of grids in the built-up areas and open space was 66 and 55 respectively (Table 4.1). However, 81.5% of the grids in the built-up areas had *D. innoxia*. Also, the mean rank of *D. innoxia* in the built-up areas was high compared to the open space as illustrated in Figure 4.3.

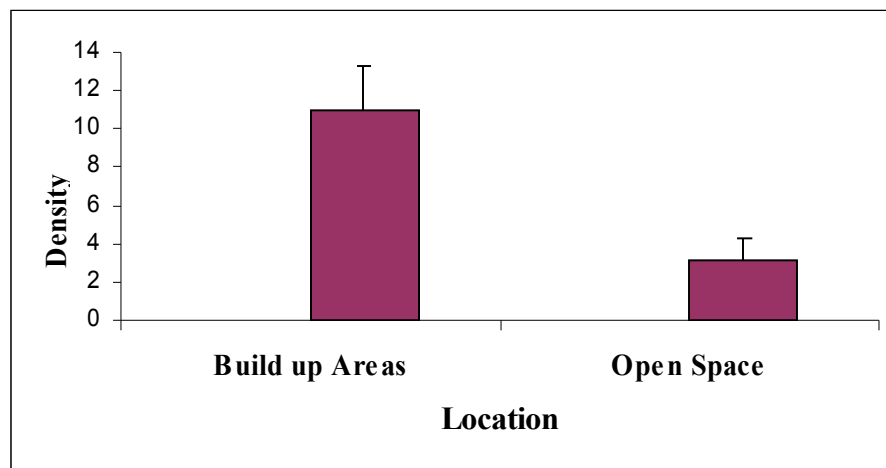


Figure 4.3: The density of *D. innoxia* per 25 000 m² in the two identified locations. The positive bars on each histogram represent the standard error of mean. The number of grids, the mean rank and median for built-up areas and open space was 66,75.5, 6.5 and 55, 43.7, 0 respectively. Few outliers were observed and this was due to the high number of *D. innoxia* observed in some grids (see appendix E and F for the outliers). The mean rank of *D. innoxia* was higher in the built-up areas (75.5)

The Mann-Whitney U test indicated that there was a significant difference in the density of *D. innoxia* between the built up areas and the open space, $U(1) = 860.5$, $p < 0.05$ (Appendix C). Figure 4.3 reveals, there was a significant higher infestation of *D. innoxia*

in the built-up areas compared to the open spaces, which had less than 20% of the observed number of *D. innoxia* (Table 4.1).

The density of *D. innoxia* in grids that were in construction areas and those in no construction areas is presented in Figure 4.4.

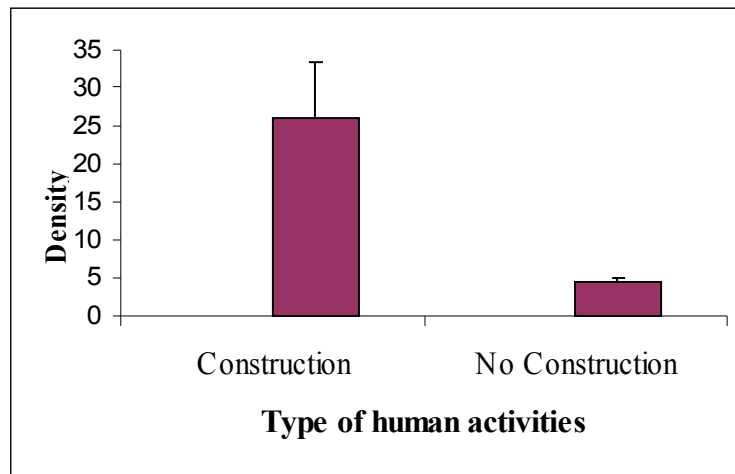


Figure 4.4: The density of *D. innoxia* per 25 000 m² in the two identified type of human activities. The positive bars on each histogram represent the standard error of mean. The number of grids, the mean rank and median for construction and the no construction was 17, 92.03, 19 and 104, 55.93, 7 respectively. Few outliers were observed and this was due to the high number of *D. innoxia* observed in some grids (see Appendix E and F for the outliers). The mean rank of *D. innoxia* was higher in the construction areas (92.03).

The Mann-Whitney U test indicated that there was a significant difference in the mean rank of *D. innoxia* between the construction sites and the sites where there was no construction, $U(1) = 356.5$, $p < 0.05$ (Appendix D). Despite having the highest number of grids with *D. innoxia* sampled (48), there was a low infestation in the areas where there was no construction. Construction sites, which only had 13 grids and a total of 440 *D.*

innoxia observed, had the highest mean of 26.2. This indicates that there was a highly significant infestation of *D. innoxia* in the construction sites (Figure 4.4).

4.2 REPRODUCTIVE STATUS

The 900 *D. innoxia* individuals observed during the study were grouped into four reproductive status, namely, (i) no inflorescence, (ii) inflorescence only, (iii) inflorescence and capsules and (iv) capsules only. Figure 4.5 shows proportion of *D. innoxia* observed during the study that was assigned in different reproductive status. About 36% of the total number of plants observed had both inflorescence and capsules (N= 322). The other status, no inflorescence (N= 190), inflorescence only (N=193) and capsule only (N= 195) comprised about 21% of the total number of individuals, recorded.

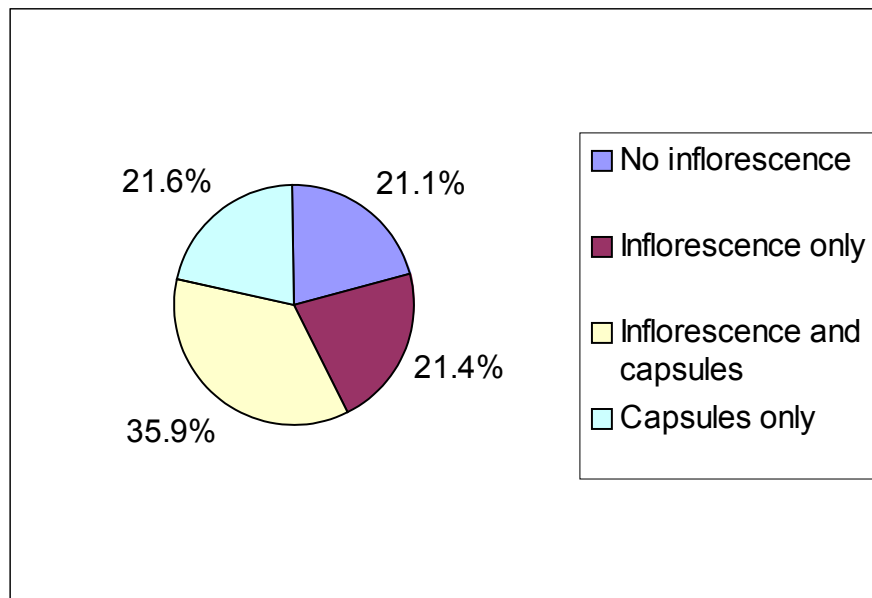


Figure 4.5: The percentage of *D. innoxia* in the four reproductive stages within the City of Windhoek, April to September. The chart is representing all the individual *D. innoxia* observed (N= 900).

There was a high percentage of individuals with both inflorescence and capsules in all the environmental factors as indicated in Table 4.3. As expected, there were a high percentage of individuals with no inflorescence in the construction areas compared to the no construction areas. Fewer individuals with capsules only were observed in all the environmental factors, except the drainage lines which had the highest percentage (35.5%) of individuals with capsules only.

Table 4.3: The number and percentage of total individuals of *D. innoxia* in the four reproductive stages within the environmental factors. The number subscripted in brackets indicates the total number of individuals in the different categories (N).

Factors	Categories	No inflorescence		Inflorescence only		Inflorescence and capsules		Capsules only	
		N	%	N	%	N	%	N	%
Geomorphological landform	Drainage lines ₍₂₀₀₎	28	14	36	18	75	37.5	61	30.5
	Denudated plains ₍₅₅₆₎	125	22.5	128	23	202	36.3	101	18.2
	Slope and ridges ₍₁₄₄₎	37	25.7	29	20.2	46	31.9	32	22.2
Location	Built-up areas ₍₇₃₄₎	150	20.4	152	20.7	278	37.9	154	21
	Open spaces ₍₁₆₆₎	40	24.1	40	24.1	45	27.1	41	24.7
Activities	Construction S ₍₄₄₀₎	109	24.8	107	24.3	155	35.2	69	15.7
	No construction ₍₄₆₀₎	81	17.6	91	19.8	172	37.4	116	25.2

4.2.1 Reproductive status and structures in the three geo-morphological landforms

4.2.1.1 Reproductive structures

Within the three identified geo-morphological landform of the City of Windhoek, a two-way ANOVA indicated that there was no significant difference in the mean number of flowers ($F= 4.4$, $df= 2$, $p>0.05$), emerging buds ($F= 2.2$, $df= 2$, $p>0.05$) and the dry exploded capsules ($F= 1.1$, $df= 2$, $p>0.05$). However, there is a significant difference in the mean number of the green intact capsules ($F= 8.5$, $df= 2$, $p<0.05$), green exploded capsules ($F= 12.8$, $df= 2$, $p<0.05$) and dry intact capsules ($F= 12.5$, $df= 2$, $p<0.05$) (Appendix G). The Turkey test indicated that the drainage line had more green intact capsules than the denudated plains. However, there was no significant difference ($F=0.4$, $df= 2$, $p>0.05$) between the mean number of green intact capsules within the drainage lines and the slope and ridges, and between the denudated plains and the slope and ridges. There was a significant difference ($F=0.2$, $df= 2$, $p<0.05$) in the mean number of green exploded capsules in the drainage lines and the denudated plains. *D. innoxia* plants in the drainage lines had significantly more green exploded capsules than those in the denudated plains. *D. innoxia* plants growing in the drainage lines had significantly more dry intact capsules than the *D. innoxia* plants in the denudated plains and slope and ridges. There was a significant difference ($F= 0.7$, $df=2$, $p<0.05$) in the mean numbers of *D. innoxia* plants with dry intact capsules in the three geo-morphological landforms. However, there was no significant difference ($F= 0.7$, $df= 2$, $p>0.05$) between the mean numbers of dry intact capsules in the denudated plains and the slope and ridges (Figure 4.6).

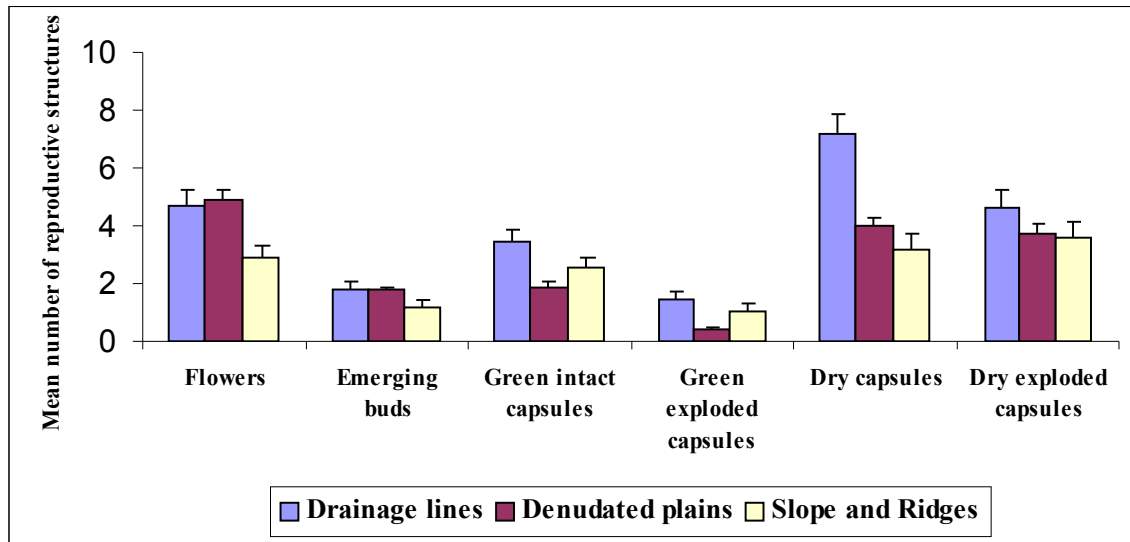


Figure 4.6: The reproductive structures of *D. innoxia* in the three geomorphological landforms. The reproductive stages are represented by the mean number of flowers, emerging buds, green intact and exploded capsules, as well as the dry and exploded capsules. The bars on each histogram represent the standard error of the mean.

4.2.1.2 Reproductive status

Within the three geo-morphological landforms, the mean rank of the four reproductive status, namely (i) no inflorescence, (ii) inflorescence only, (iii) inflorescence and capsules and (iv) capsules only were compared (Figure 4.7). The Friedman test indicated that there was no significant difference in the mean rank of *D. innoxia* individuals within the four different reproductive status, $\chi^2_F(3) = 7, p > 0.05$. There was no significant difference in the mean rank of *D. innoxia* individuals with no inflorescence ($\chi^2 = 0, df = 2, p > 0.05$), inflorescence only ($\chi^2 = 6.9, df = 2, p > 0.05$) and the inflorescence and capsules ($\chi^2 = 2.5, df = 2, p > 0.05$) within the three geomorphological landforms, as indicated by the Kruskal Wallis test (Appendix H). However, there was a significant difference in the mean rank of *D. innoxia* individuals with capsules only ($\chi^2 = 21.699, df = 2, p < 0.001$) within the

three geomorphological landforms. There were more individuals with capsules only in the drainage lines compare to the denudated plains and slope and ridges (Figure 4.7).

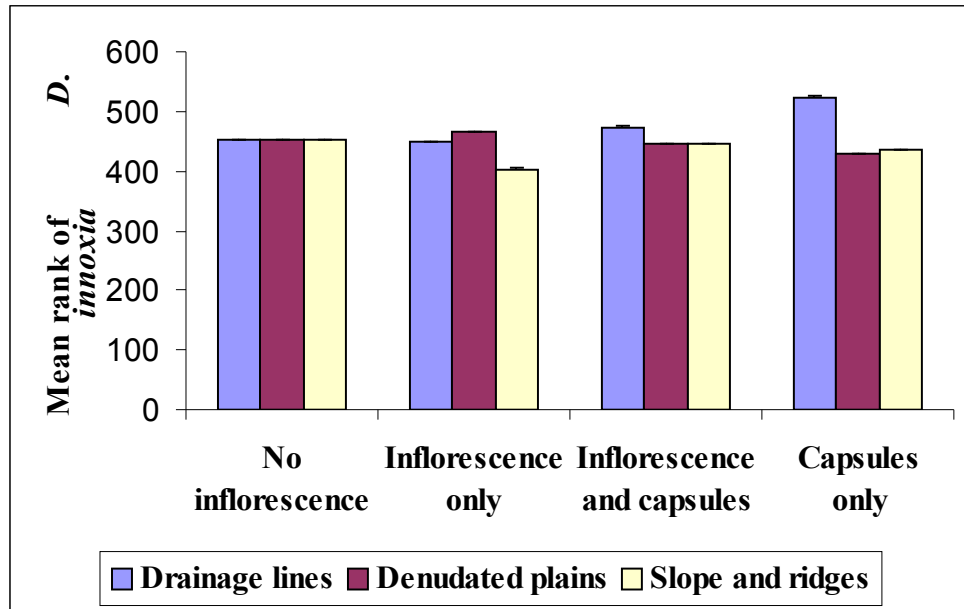


Figure 4.7: The mean rank of *D. innoxia* reproductive status in the geomorphological landforms. The reproductive stages were represented by no inflorescence, inflorescence only (inclusive of flowers and emerging buds), inflorescence and capsules and capsules only. The bars on each histogram represent the standard error of mean.

4.2.2 Reproductive status and structures in the open and build-up areas

4.2.2.1 Reproductive structures

Within the two identified location within the City of Windhoek, a two-way ANOVA indicated that there was no significant difference ($F= 3.9$, $df=1$, $p>0.05$) in the mean number of all the reproductive structure in both the build-up areas and the open spaces (Appendix I and Figure 4.8).

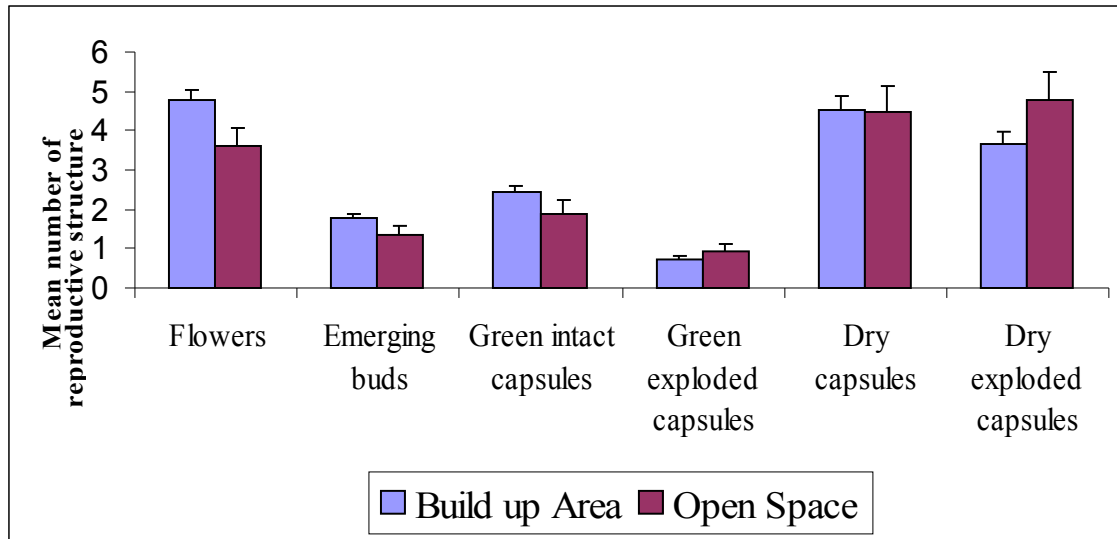


Figure 4.8: The reproductive structures of *D. innoxia* in the two locations, namely the built up area and the open space. The reproductive structures are represented by the mean number of flowers, emerging buds, green intact and exploded capsules, as well as the dry and exploded capsules. The bars on each histogram represent the standard error of the mean

4.2.2.2 Reproductive status

The mean rank of the four reproductive status, namely (i) no inflorescence, (ii) inflorescence only, (iii) inflorescence and capsules and (iv) capsules only in the open and built-up areas were compared (Figure 4.9). Friedman test indicated that there was a significant difference in the mean rank of *D. innoxia* individuals within the four different reproductive structures, $\chi^2_F(2) = 5$, $p < 0.05$. There was no significant difference in the mean rank of *D. innoxia* individuals with no inflorescence and capsules only within the two identified locations within the City of Windhoek, as indicated by the Mann-Whitney U-test ($U(1) = 63.5$, $p > 0.05$ and $U(1) = 62.2$, $p > 0.05$, respectively) (Appendix J). However, there was a significant difference in the mean rank of *D. innoxia* plants with inflorescence only and inflorescence and capsules, ($U(1) = 57.0$, $p < 0.001$ and $U(1) = 56.6$,

$p < 0.01$, respectively) growing in the built-up areas and in open spaces (Appendix H). There were significantly more individuals with inflorescence only and inflorescence and capsules in the build up areas compare to the open spaces (Figure 4.9).

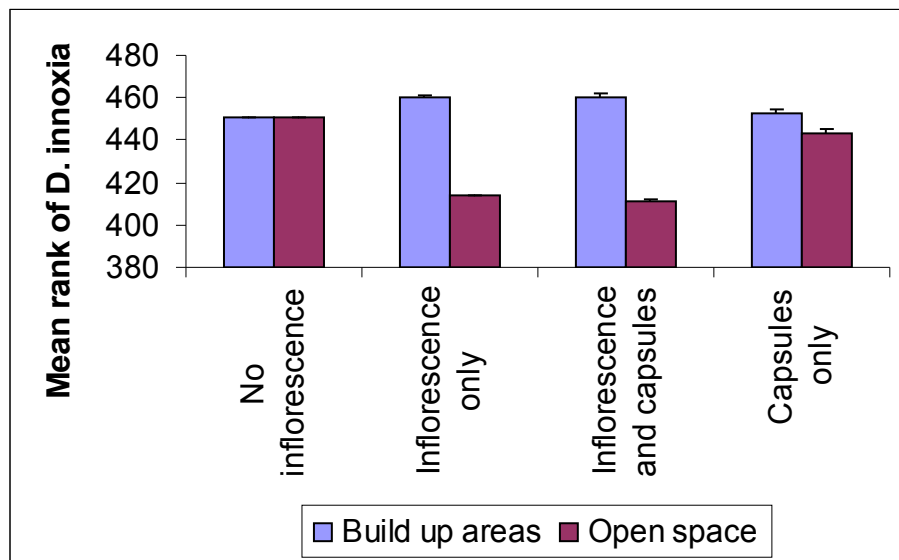


Figure 4.9: The mean rank of *D. innoxia* in the two identified locations within the City of Windhoek. The reproductive status was represented by no inflorescence, inflorescence only (inclusive of flowers and emerging buds), inflorescence and capsules and capsules only. The bars on each histogram represent the standard error of the mean.

4.2.3 Reproductive status and structures in the construction and no construction areas

4.2.3.1 Reproductive structures

The mean number of reproductive structures in the two identified type of human activities with the City of Windhoek were compared (Figure 4.10). A two-way ANOVA indicated that there was no significant difference ($F=1.4$, $df= 1$, $p > 0.05$) in the mean number of all the reproductive structure in both construction and no construction sites (Appendix K and Figure 4.10).

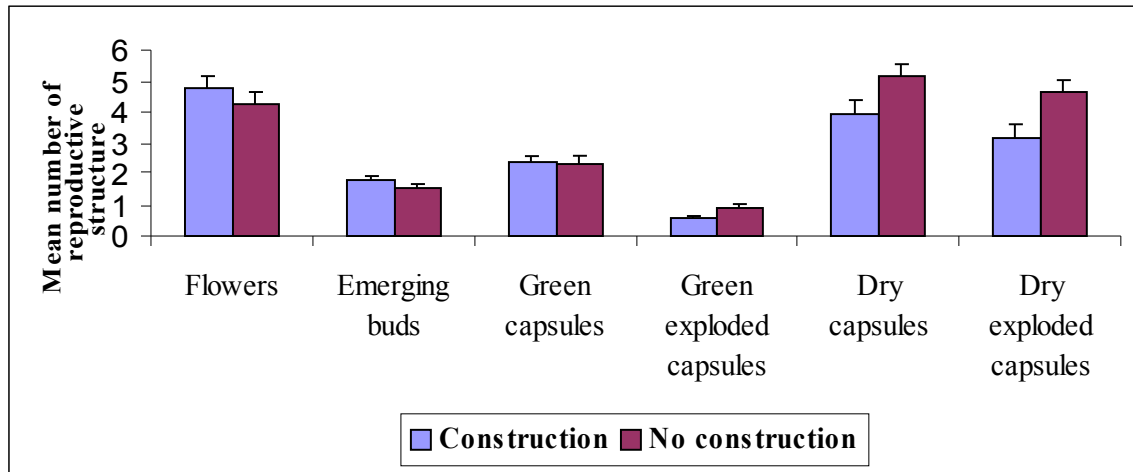


Figure 4.10: The reproductive structures of *D. innoxia* in the two identified type of human activities, namely construction and no construction. The reproductive structures are represented by the mean number of flowers, emerging buds, green intact and exploded capsules, as well as the dry and exploded capsules. The bars on each histogram represent the standard error of the mean.

4.2.3.2 REPRODUCTIVE STATUS

The mean rank of the four reproductive status, namely (i) no inflorescence, (ii) inflorescence only, (iii) inflorescence and capsules and (iv) capsules only in the construction and no construction site were compared (Figure 4.11). Friedman test indicated that there was a significant difference in the total individuals of *D. innoxia* within the four different reproductive status, $\chi^2_F(2) = 5$, $p < 0.05$. The Mann-Whitney U-test, indicated that there is no significant difference between the individuals with no inflorescence ($U(1) = 101475$, $p > 0.05$), inflorescence only ($U(1) = 96604.5$, $p > 0.05$) and inflorescence and capsules ($U(1) = 98072.5$, $p < 0.05$). However, there was a significant difference in the individuals with capsules only within the construction areas and the no

construction areas ($U(1) = 88098.5$, $p < 0.001$) (Appendix L). There were significantly more individuals with capsules only within the no construction areas compare to the construction areas (Figure 4.11).

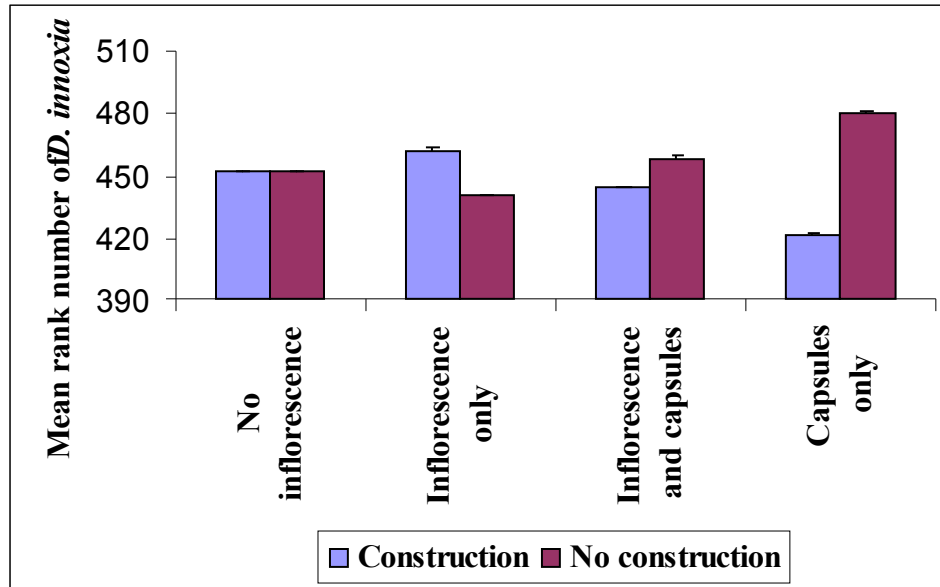


Figure 4.11: The mean rank of *D. innoxia* in the two identified type of human activities within the City of Windhoek. The reproductive status was represented by no inflorescence, inflorescence only (inclusive of flowers and emerging buds), inflorescence and capsules and capsules only. The bars on each histogram represent the standard error of the mean.

4.2.4 Height and crown width

There was no specific height or crown width for *D. innoxia* to produce flowers or capsules. Plants bore flowers and capsules at different heights and crown widths. The shortest *D. innoxia* that was observed bearing a flower was 6 cm high. At this height, the plant had no leaves and the crown width was the diameter of the capsule. Only one plant with both a flower and a capsule was observed with a height and crown width of 12 cm and 23 cm respectively. This plant was observed in the denudated plains, during the

month of July (winter period). The tallest *D. innoxia* plant with the widest crown, bearing flowers and capsules was 182cm high, with a crown width of 229cm.

4.2.4.1 Height and crown width of *D. innoxia* in the three geomorphological landforms

The difference in the mean height of *D. innoxia* plants of the four reproductive status within the geomorphological landform were determined (Figure 4.12). A two-way ANOVA indicated that there were significant differences ($F= 176.3$, $df= 199$, $p<0.05$) in the mean height of *D. innoxia* in the three geo-morphological landforms (Appendix M). *D. innoxia* growing in the drainage lines were significantly taller than those plants growing in the denudated plains and slope and ridges. Figure 4.12 shows the mean height of *D. innoxia* in the four reproductive status, within the three geo-morphological landforms.

There was no significant difference ($F= 77.1$, $df=199$, $p>0.05$) in the mean height of *D. innoxia* individuals with no inflorescence and those individuals with inflorescence only. However, there was a significant difference ($F=109.3$, $df= 199$, $p<0.05$) in the mean height of *D. innoxia* individuals with inflorescence, inflorescence and capsules and those with capsules only. The individuals with both the inflorescence and capsules had a higher mean height in all the geo-morphological landforms.

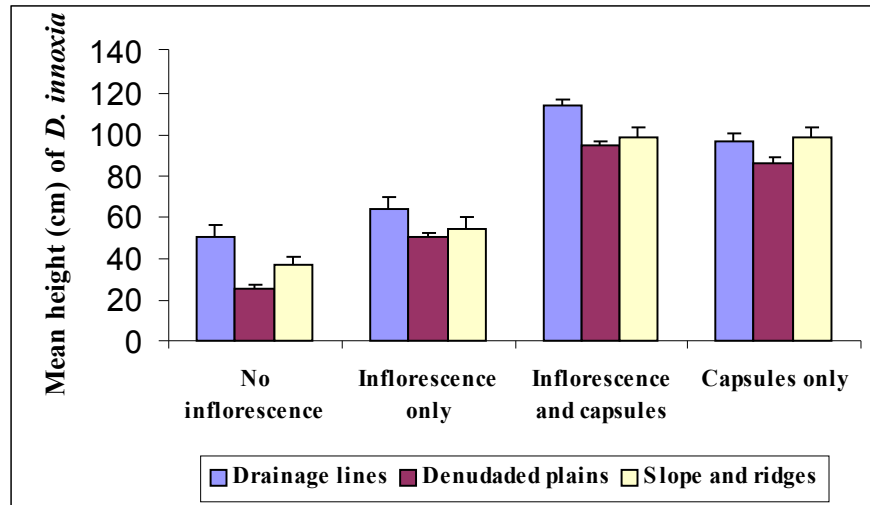


Figure 4.12: The mean height (cm) of *D. innoxia* of the four reproductive status within the three geo-morphological landforms. The reproductive stages are represented by no inflorescence, inflorescence only (inclusive of flowers and emerging buds), inflorescence and capsules and capsules only. The bars on each histogram represent the standard error of mean.

The difference in the mean crown width of *D. innoxia* plants of the four reproductive status within the geomorphological landform were determined (Figure 4.13). There was a significant difference ($F= 29.6$, $df=199$, $p<0.05$) in the mean crown width of *D. innoxia* for all the reproductive stages within the drainage lines, denudated plains and the slope and ridges, as indicated by the two-way ANOVA (Appendix N). Figure 4.13 indicated that *D. innoxia* plants growing in the drainage lines had wider crown compare to those growing in denudated plains and the slope and ridges. Also, there was no significant difference ($F=149.3$, $df=199$, $p>0.05$) in the mean crown width of *D. innoxia* individuals with both inflorescence and capsules and those with capsules only in the drainage lines and the slope and ridges. However, there was a significant difference in the mean crown ($F=27.2$, $df=199$, $p<0.05$) width of individuals with both inflorescence and capsules and those with capsules only in the denudated plains.

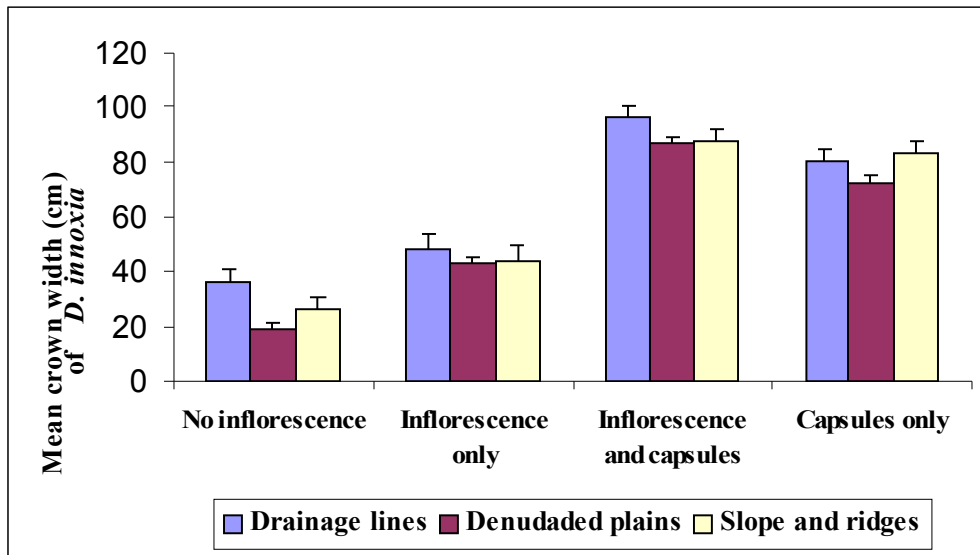


Figure 4.13: The mean crown width (cm) of *D. innoxia* of the four reproductive status within the three geo-morphological landforms. The reproductive stages are represented by no inflorescence, inflorescence only (inclusive of flowers and emerging buds), inflorescence and capsules and capsules only. The bars on each histogram represent the standard error of mean.

4.2.4.2 Height and crown width of *D. innoxia* in the open spaces and built-up areas

The difference in the mean height of *D. innoxia* plants of the four reproductive status within the built-up and open spaces were determined (Figure 4.14). A two-way ANOVA test indicates that there are significant differences in the mean height of *D. innoxia* in build-up areas and open spaces (Appendix M). There is a significant difference ($F=212.8$, $df=174$, $p<0.05$) between the mean height of *D. innoxia* individuals with no inflorescence and those with inflorescence only. Figure 4.14 gives the mean height of *D. innoxia* in the four reproductive stages, within the two identified location. The Turkey test indicated that *D. innoxia* individuals in the open space had a higher mean height of individuals with no inflorescence and those with inflorescence compare to the build-up

areas. However, there was no significant difference ($F= 32.9$, $df= 174$, $p>0.05$) in the mean height of *D. innoxia* individuals with both inflorescence and capsules and those with capsules only.

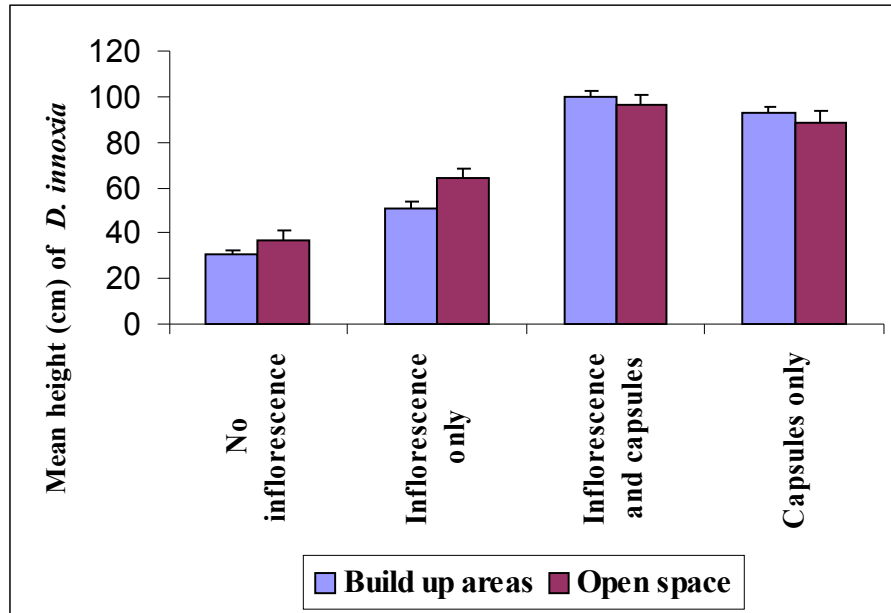


Figure 4.14: The mean height (cm) of *D. innoxia* of the four reproductive status within the two identified locations. The reproductive stages are represented by no inflorescence, inflorescence only (inclusive of flowers and emerging buds), inflorescence and capsules and capsules only. The bars on each histogram represent the standard error of mean

The difference in the mean crown width of *D. innoxia* plants of the four reproductive status within the built-up and open spaces were determined (Figure 4.15). A two-way ANOVA test indicated that there was significant difference ($F=36.8$, $df= 174$, $p<0.05$) in the mean crown width of *D. innoxia* of the four different reproductive status in the open space and in the built-up areas (Appendix N). Figure 4.15 gives the mean crown width of *D. innoxia* in the four reproductive status, in the open space and in the built-up areas.

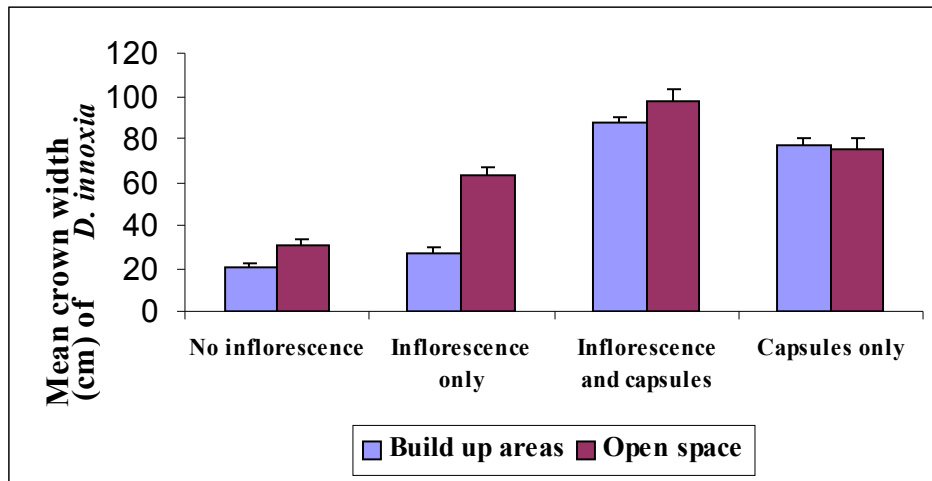


Figure 4.15: The mean crown width (cm) of *D. innoxia* of the four reproductive status within the two identified location. The reproductive status is represented by no inflorescence, inflorescence only (inclusive of flowers and emerging buds), inflorescence and capsules and capsules only. The bars on each histogram represent the standard error of mean.

There was a significant difference ($F= 178.2$, $df= 174$, $p<0.05$) between the mean crown widths of *D. innoxia* individuals with no inflorescence, those with inflorescence only and those both inflorescence and capsules. In the open spaces, *D. innoxia* plants with no inflorescence, those with inflorescence only and those with both inflorescence and capsules had a wider mean crown width compare to the *D. innoxia* plants in the built-up areas. However, there was no significant difference ($F= 66.5$, $df= 174$, $p>0.05$) in the mean crown width of *D. innoxia* plants with capsules only growing in the open spaces and built-up areas.

4.2.4.3 Height and crown width of *D. innoxia* in the construction and no construction sites

Figure 4.16 gives the mean height of *D. innoxia* in the four reproductive status in the sites where there was construction and no construction activities. The two way ANOVA test indicated that there are significant differences ($F=85.2$, $df=499$, $p>0.05$) in the mean height of *D. innoxia* plant in site where there are no construction activities and those in site where there is construction activities (Appendix M). The Turkey post hoc test indicated that the *D. innoxia* plants in the site where there are no construction activities are taller than the plants in the construction site within the four reproductive status. However, there was no significant difference ($F=157.3$, $df=499$, $p>0.05$) in the mean height of *D. innoxia* individuals with both inflorescence and capsules and those with capsules only.

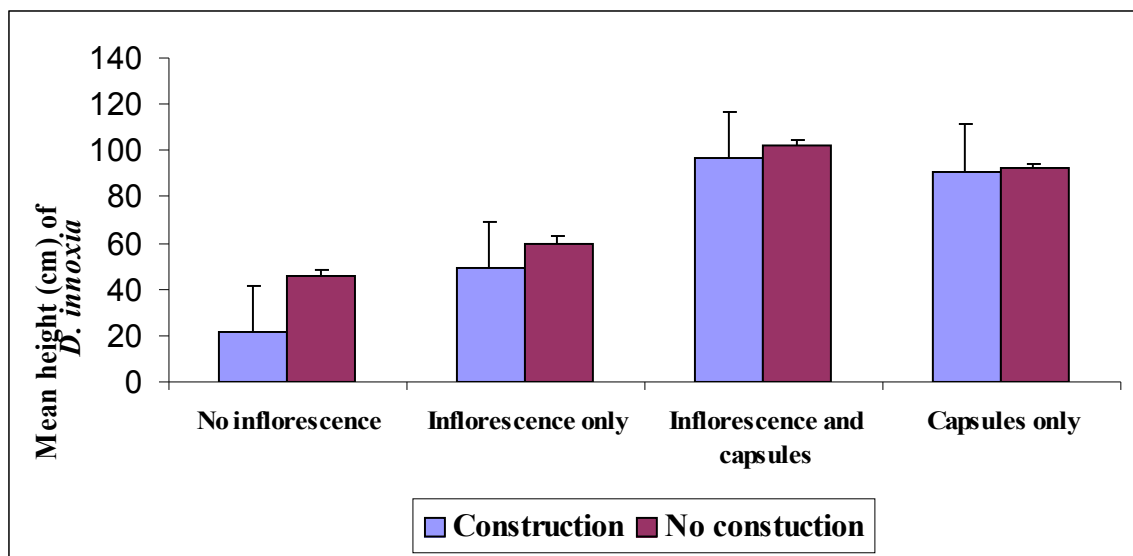


Figure 4.16: The mean height (cm) of *D. innoxia* of the four reproductive status within the two identified type of human activities. The reproductive stages are represented by no inflorescence, inflorescence only (inclusive of flowers and emerging buds), inflorescence

and capsules and capsules only. The bars on each histogram represent the standard error of mean

Figure 4.17 gives the mean crown width of *D. innoxia* in the four reproductive status, in the construction and no construction sites. A two-way ANOVA test indicated that there was a significant difference ($F=79.2$, $df=449$, $p<0.05$) in the mean crown width of *D. innoxia* plants growing in the construction and no construction sites (Appendix N). *D. innoxia* plants with no inflorescence, those with inflorescence only and those with both the inflorescence and capsules and growing in the no construction site had wider crown width compare to the plants growing in the construction sites. However, there was no significant difference ($F= 63.4$, $df= 449$, $p>0.05$) in the mean crown width of *D. innoxia* plants with capsules only in the construction and no construction sites.

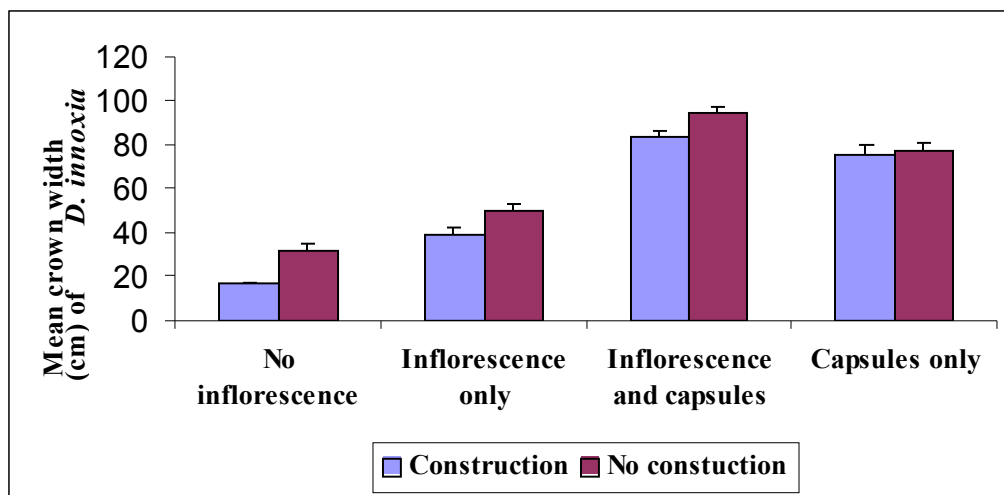


Figure 4.17: The mean crown width (cm) of *D. innoxia* of the four reproductive status within the two identified type of human activities. The reproductive status were represented by no inflorescence, inflorescence only (inclusive of flowers and emerging buds), inflorescence and capsules and capsules only. The bars on each histogram represent the standard error of mean.

4.2.5 Relationship between the height and crown with and the number of flowers and capsules

4.2.5.1 Relationship between the height and number of flowers and capsules of *D. innoxia*

The Spearman's rank correlation co-efficient was used to described the strength of association between the height and the total number of flowers in the City of Windhoek (Figure 4.18) and revealed that on average there was a weak ($r = 0.41$), positive association between the height of *D. innoxia* and the total number of flowers. However, little (17%) variations in the number of flowers were explained by the height of *D. innoxia*. Although the association was weak, the p-value indicated that the association was significant ($p < 0.01$).

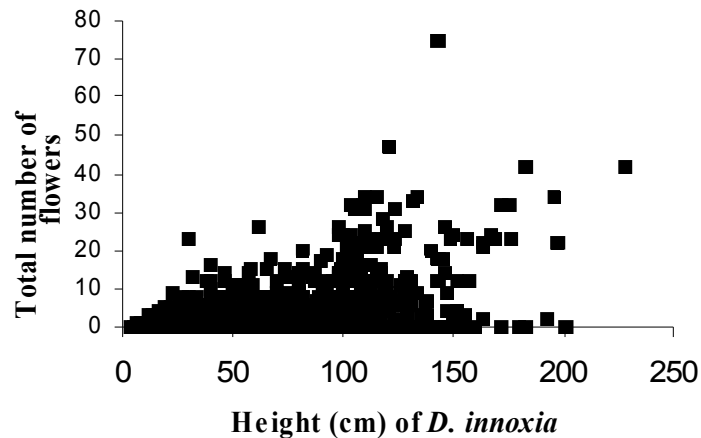


Figure 4.18: Relationship between the height (cm) of *D. innoxia* and the total number of flowers on each plant recorded during the study in the City of Windhoek. $N= 900$, $r = 0.41$, $r^2 = 0.1681$, $p < 0.01$.

The strength of association between the height and the total number of emerging buds in the City of Windhoek (Figure 4.19) was described using the Spearman's rank correlation co-efficient. The correlation co-efficient revealed that on average there was a weak ($r = 0.4$), positive association between the height of *D. innoxia* and the total number of emerging buds. However, only 16% of the variations in the total number of emerging buds were explained by the height of *D. innoxia*. Although the association was weak, the p-value indicated that the association was significant ($p < 0.01$).

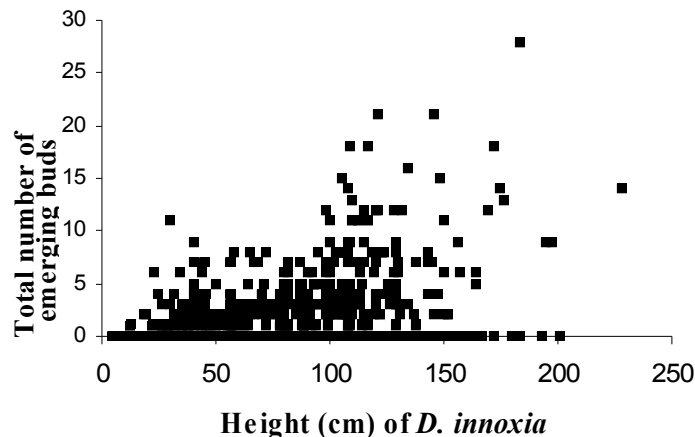


Figure 4.19: Relationship between the height (cm) of *D. innoxia* and the total number of emerging buds on each plant recorded in the study the City of Windhoek. N= 900, $r = 0.4$, $r^2 = 0.1584$, $p < 0.01$.

The strength of association between the height and the total number of green intact capsules in the City of Windhoek (Figure 4.20) was described using the Spearman's rank correlation co-efficient. The correlation co-efficient revealed that on average there was a weak ($r = 0.5$), positive association between the height of *D. innoxia* and the total number of green intact capsules. However, only 22% of the variations in the total number of green intact capsules were explained by the height of *D. innoxia*. Although the association was weak, the p-value indicated that the association was significant ($p < 0.01$).

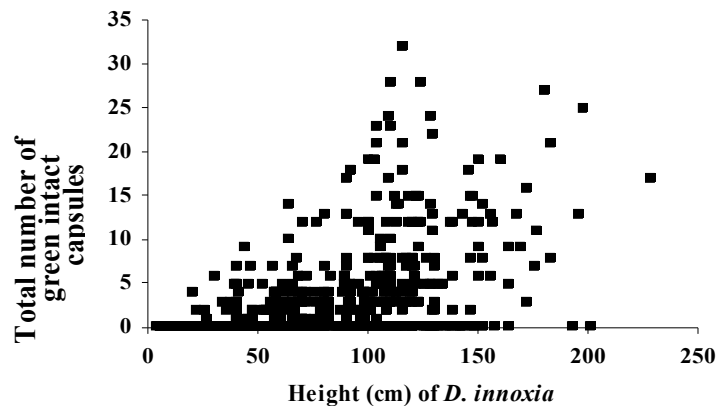


Figure 4.20: Relationship between the height (cm) of *D. innoxia* and the total number of green intact capsules on each plant recorded during the study in the City of Windhoek. N= 900, $r = 0.5$, $r^2 = 0.2162$, $p < 0.01$

The Spearman's rank correlation co-efficient was used to describe the strength of association between the height and the number of total green exploded capsules in the City of Windhoek (Figure 4.21) and revealed that on average there was a very weak ($r = 0.3$), positive association between the height of *D. innoxia* and the total number of green exploded capsules. However, little (11%) variations in the total number of green exploded capsules were explained by the height of *D. innoxia*. Although the association was weak, the p-value indicated that the association was significant ($p < 0.01$).

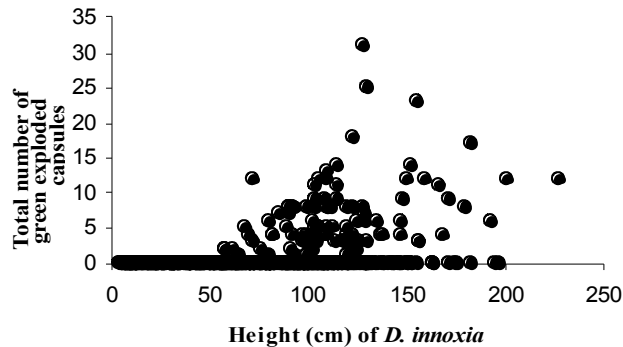


Figure 4.21: Relationship between the height (cm) of *D. innoxia* and the total number of green exploded capsules on each plant recorded during the study in the City of Windhoek. $N = 900$, $r = 0.3$, $r^2 = 0.11$, $p < 0.01$

The strength of association between the height and the total number of dry intact capsules in the City of Windhoek (Figure 4.22) was described using the Spearman's rank correlation co-efficient. The correlation co-efficient revealed that on average there was a weak ($r = 0.5$), positive association between the height of *D. innoxia* and the total number of dry intact capsules. However, 22% of the variations in the number of dry intact capsules were explained by the height of *D. innoxia*. Although the association was weak, the p-value indicated that the association was significant ($p < 0.01$).

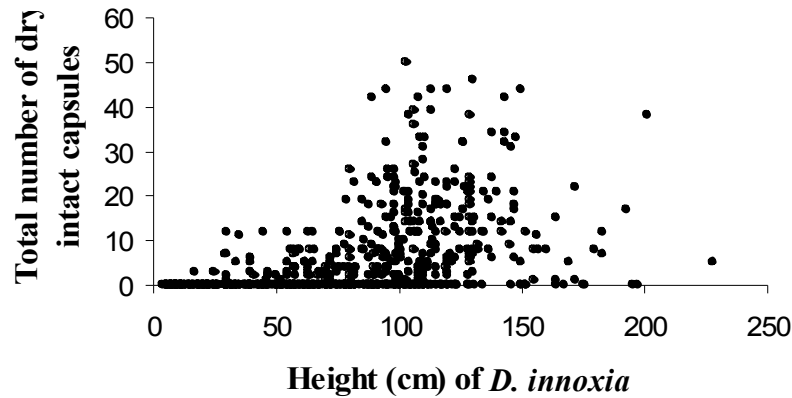


Figure 4.22: Relationship between the height (cm) of *D. innoxia* and the total number of dry intact capsules on each plant recorded during the study in the City of Windhoek. N= 900, $r = 0.5$, $r^2 = 0.22$, $p < 0.01$

The Spearman's rank correlation co-efficient was used to describe the strength of association between the height and the total number of dry exploded capsules in the City of Windhoek (Figure 4.23) and revealed that on average there was a weak ($r = 0.41$), positive association between the height of *D. innoxia* and the total number of dry exploded capsules. However, little (16%) variations in the total number of dry exploded capsules were explained by the height of *D. innoxia*. Although the association was weak, the p-value indicated that the association was significant ($p < 0.01$).

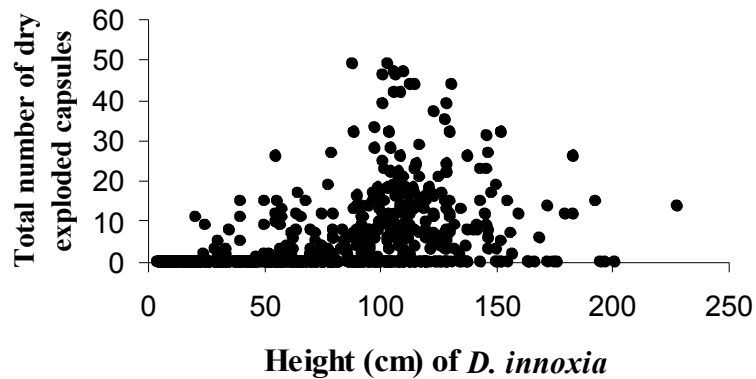


Figure 4.23: Relationship between the height (cm) of *D. innoxia* and the total number of dry exploded capsules on each plant recorded during the study in the City of Windhoek. $N=900$, $r=0.4$, $r^2=0.16$, $p<0.01$

4.2.5.2 Relationship between the crown width and number of flowers and capsules of *D. innoxia*

The Spearman's rank correlation co-efficient was used to describe the strength of association between the crown width and the total number of flowers in the City of Windhoek (Figure 4.24) and revealed that on average there was a weak ($r=0.44$), positive association between the crown width of *D. innoxia* and the total number of flowers. However, little (19%) variations in the total number of flowers were explained by the crown width of *D. innoxia*. Although the association was weak, the p-value indicated that the association was significant ($p<0.01$).

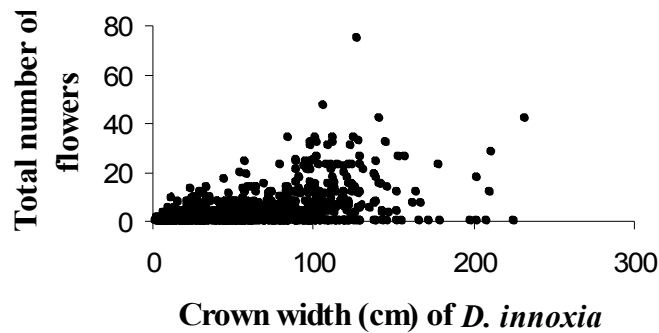


Figure 4.24: Relationship between the crown width (cm) of *D. innoxia* and the total number of flowers on each plant recorded during the study in the City of Windhoek. N= 900, $r = 0.44$, $r^2 = 0.19$, $p < 0.01$.

The strength of association between the crown width and the total number of emerging buds in the City of Windhoek (Figure 4.25) was described using the Spearman's rank correlation co-efficient. The correlation co-efficient revealed that on average there was a weak ($r = 0.4$), positive association between the height of *D. innoxia* and the total number of emerging buds. However, 16% of the variations in the number of dry intact capsules were explained by the crown width of *D. innoxia*. Although the association was weak, the p-value indicated that the association was significant ($p < 0.01$).

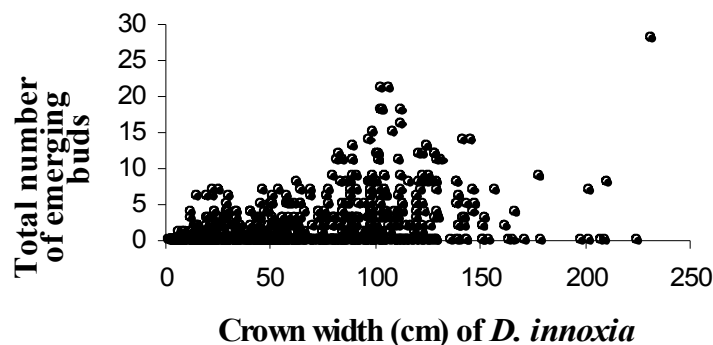


Figure 4.25: Relationship between the crown width (cm) of *D. innoxia* and the total number of emerging buds on each plant recorded during the study in the City of Windhoek. N= 900, $r = 0.4$, $r^2 = 0.16$, $p < 0.01$

The strength of association between the crown width and the total number of green intact capsules in the City of Windhoek (Figure 4.26) was described using the Spearman's rank correlation co-efficient. The correlation co-efficient revealed that on average there was a weak ($r = 0.42$), positive association between the crown width of *D. innoxia* and the total number of green intact capsules. However, 18% of the variations in the number of green intact capsules were explained by the crown width of *D. innoxia*. Although the association was weak, the p-value indicated that the association was significant ($p < 0.01$).

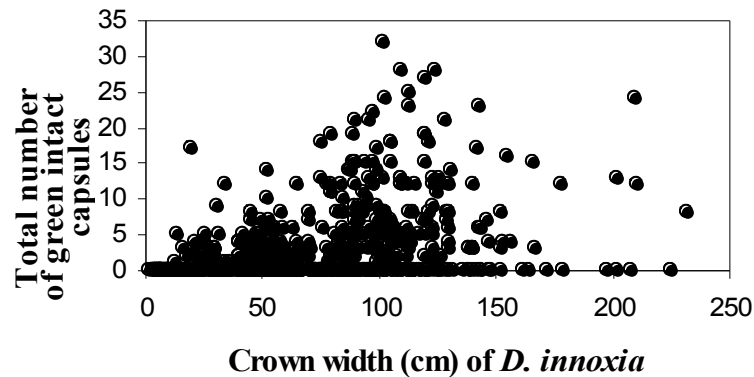


Figure 4.26: Relationship between the crown width (cm) of *D. innoxia* and the total number of green intact capsules on each plant recorded during the study in the City of Windhoek. $N = 900$, $r = 0.42$, $r^2 = 0.18$, $p < 0.01$

The strength of association between the crown width and the total number of green exploded capsules in the City of Windhoek (Figure 4.27) was described using the Spearman's rank correlation co-efficient. The correlation co-efficient revealed that on average there was a very weak ($r = 0.3$), positive association between the crown width of *D. innoxia* and the total number of green exploded capsules. However, only 9% of the variations in the number of green intact capsules were explained by the crown width of

D. innoxia. Although the association was weak, the p-value indicated that the association was significant ($p < 0.01$).

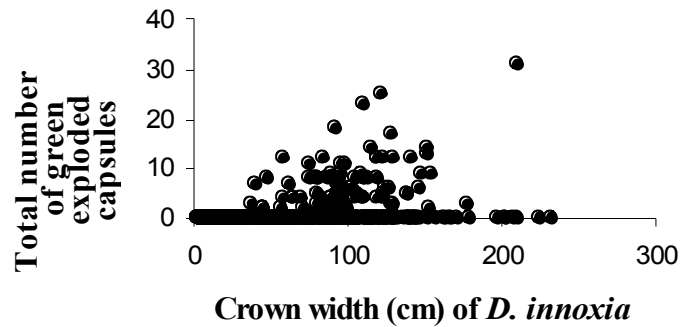


Figure 4.27: Relationship between the crown width (cm) of *D. innoxia* and the total number of green exploded capsules on each plant recorded during the study in the City of Windhoek. $N = 900$, $r = 0.3$, $r^2 = 0.09$, $p < 0.01$

The strength of association between the crown width and the total number of dry intact capsules in the City of Windhoek (Figure 4.28) was described using the Spearman's rank correlation co-efficient. The correlation co-efficient revealed that on average there was a weak ($r = 0.52$), positive association between the crown width of *D. innoxia* and the total number of dry intact capsules. However, 27% of the variations in the number of dry intact capsules were explained by the crown width of *D. innoxia*. Although the association was weak, the p-value indicated that the association was significant ($p < 0.01$).

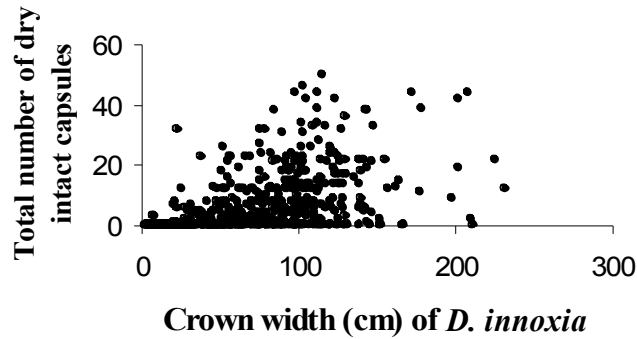


Figure 4.28: Relationship between the crown width (cm) of *D. innoxia* and the total number of dry intact capsules on each plant recorded during the study in the City of Windhoek. $N=900$, $r = 0.52$, $r^2 = 0.27$, $p < 0.01$

The strength of association between the crown width and the total number of dry exploded capsules in the City of Windhoek (Figure 4.29) was described using the Spearman's rank correlation co-efficient. The correlation co-efficient revealed that on average there was a weak ($r = 0.5$), positive association between the height of *D. innoxia* and the total number of dry exploded capsules. However, 25% of the variations in the number of dry exploded capsules were explained by the crown width of *D. innoxia*. Although the association was weak, the p-value indicated that the association was significant ($p < 0.01$).

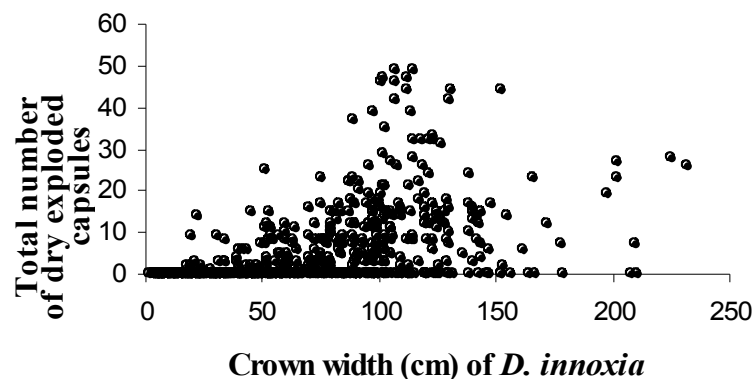


Figure 4.29: Relationship between the crown width (cm) of *D. innoxia* and the total number of dry exploded capsules on each plant recorded during the study in the City of Windhoek. $N= 900$, $r = 0.5$, $r^2 = 0.25$, $p < 0.01$.

4.3.1 SPECIES COMPOSITION

The Hierarchical Cluster Analysis (HCA) separated the vegetation into nine main clusters (Figure 4.30). Grid with similar species composition was clustered together. Amongst the clusters, the degree of dissimilarity was high. The least similar clustering was more than 90% similarity. *Acacia mellifera*, *Dichrostachys cinerea*, *Boscia albitrunca* and *Senecio windhoekensis* overlapped in all the nine clusters, and were also the dominant woody and herbaceous vegetation in all the nine clusters. The nine clusters are described below.

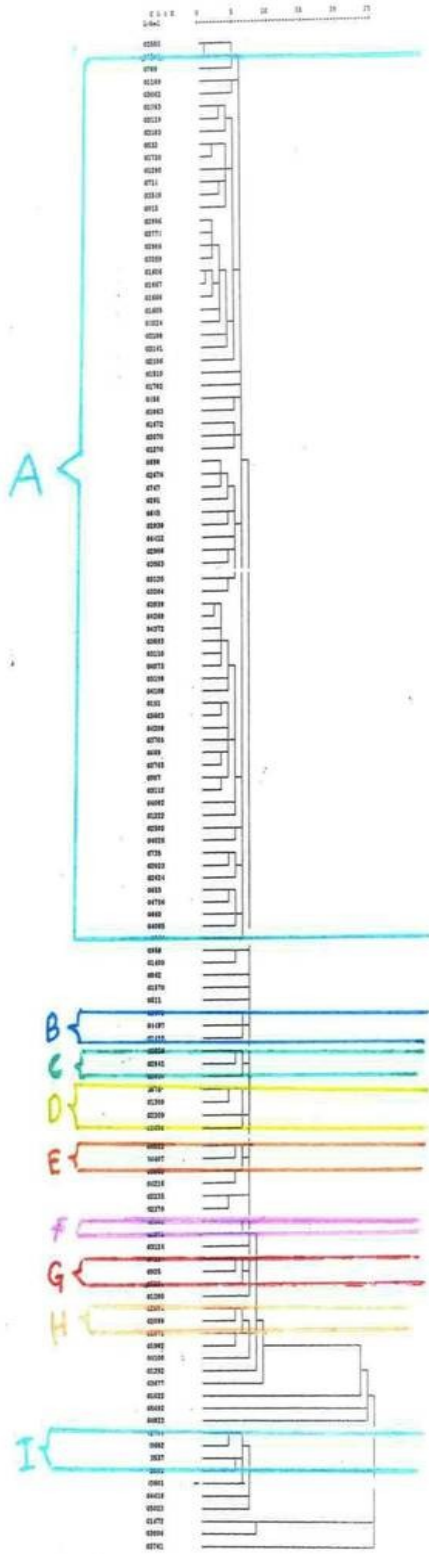


Figure 4.30: The Hierarchical Cluster dendrogram showing a classification of grids into nine clusters based on species presence/absence data

Cluster A:

This was the largest and most compact cluster. Most plant species observed were present within this cluster, with the exception of the *Pinus* sp., *Dombeya rotundifolia* and *D. stramonium*. *Grewia flavescens*, *Montinia caryophyllacea* and the *Amaranthus* sp. were the herbaceous plants only observed in this cluster. Other common species included *Acacia hebeclada*, *Catophractes alexandri*, *Ehretia alba* and *Sonchus asper*. There was a high dominance of invasive alien species, including *Datura innoxia*, with *Argemone orchroleuca* being the most dominant invasive alien species. Most grids within this cluster were located in the denudated plains and outside the construction areas.

Cluster B:

The herbaceous vegetation rather than the woody vegetation dominated this cluster. Common species included *Ehretia alba*, *Grewia bicolor*, *Gnidia polycephala*, *Bidens* sp. and *C. alexandri*. Few invasive alien species are found in this cluster. *D. stramonium* and *Arundo donax* were the only invasive species.

Cluster C:

This cluster had the least number of plant species; only 40% of the total observed species (Appendix G) were within this cluster. The herbaceous vegetation mostly dominated this cluster. The dominant herbaceous species included *Sonchus asper*, *Tagetes minuta*, *Rumex crispus* and *Tithonia rotundifolia*. The dominant woody vegetation included *A. hebeclada*, *Rhus lancea* and *Ziziphus mucronata*. Also, there was a dominance of

invasive alien species, mostly *Prosopis*, *D. innoxia*, *D. stramonium* and *A. orchroleuca*. Most grids within this cluster were in the drainage lines.

Cluster D:

Herbaceous vegetation and few of the trees dominated this cluster. The trees present included *C. alexandri* and *E. alba*. There was a dominance of *Solsola kali* and *Solanum delagoense*, which is peculiar to this cluster. Other dominant herbaceous vegetation included *S. asper*, *T. minuta* and *R. crispus*. Invasive alien species were also dominant in this cluster, with *Nicotiana glauca* dominating.

Cluster E:

There were no invasive alien species within this cluster. *Leucas pechuelii* and *Tarchonanthus camphoratus* were the dominant vegetation in this cluster. Other common species included *A. ataxacanth*, *R. lancea* and *Z. mucronata*.

Cluster F:

Faidherbia albida was only observed in this cluster. Other common species included *A. hebeclada*, *A. hereroensis* and *Leucas pechuelii*. No invasive alien species were found within this cluster.

Cluster G

This cluster was characterized by the domination of *Clonia* sp. and *Schinus molle* (which is an alien plant but not invasive). More of the herbaceous vegetation is present in this

cluster and few of the trees are present. The dominating invasive alien species are *D. innoxia*, *N. glauca* and *A. orchroleuca*.

Cluster H:

This cluster is characterized by the presence of the *Pinus* sp. and domination by *Sida cordifolia* and *Combretum apicalatum*. Other common species include *Euclea undulate*, *Ricinus communis*, *Lycium oxycarpum* and *S. asper*. Invasive alien species such as *D. innoxia*, *T. rotundifolia* and *R. communis*, although present, were not dominant. *A. orchroleuca* was absent.

Cluster I:

This cluster is characterized by the presence of *Opuntia ficus-indica* and the dominance by *Ondetia linearis*. Other common species included *A. hebeclada*, *T. minuta*, *C. alexandri* and *E. alba*. The alien invasive species were present but more recessive.

4.3.2 Plants and macro- organism associated with *D. innoxia*

Within a radius of one meter (from the observed *D. innoxia* to the other plant species), the following plant species were observed and Plate 4.1 gives an illustrative example of the association:

- *Argemone ochroleuca*
- *Boscia albitrunca*
- *Datura stramonium*
- *Nicotiana glauca*

- *Ondetia linearis*
- *Rumex crispus*
- *Salsola kali*
- *Senecio windhoekensis*
- *Sonchus asper*
- *Stipagrostis uniplumis*



Plate 4.1: Plant species associated with *D. innoxia*. The plants are growing next to a overflowing drain. The white in the foreground is powder used to dry the running water and the plant species are *Senecio windhoekensis*, *Rumex crispus* and some grasses, mostly *Stipagrostis uniplumis*.

On some *D. innoxia* individuals, the following organisms were found either on the flowers and capsules or under the plant:

- *Harmonia* sp. (Ladybird)
- *Monomorium* sp. (Ants)
- *Reticulitermes* sp. (Termites)
- *Apis mellifera* (Honey bee)
- Aphids (mostly on the open capsules)
- Small mammals (rodents)

The ladybird and the honeybee were observed on the sepals of the flowers. The ants were observed moving the seeds of *D. innoxia* from one location to another, storing the seed under *Sonchus asper*. Plate 4.2 shows the visitation by honeybee on the flower of *D. innoxia*.



Plate 4.2: A honeybee found on the anthers of *D. innoxia* flower

4.3.3 Other invasive alien plants

Although the focus of the study was based on the distribution of *D. innoxia*, there was several other invasive alien species observed during the study. They were:

- *Argemone ochroleuca*
- *Arundo donax*
- *Datura stramonium*
- *Lantana camara*
- *Leucaena leucocephala*
- *Melia azedarach*
- *Nicotiana glauca*
- *Opuntia ficus-indica*
- *Prosopis* spp.
- *Ricinus communis*
- *Tithonia rotundifolia*

A. ochroleuca was observed in almost every grid apart from those occurring in the open space and where there were no human activities. There was serious infestation by *Prosopis* spp. in Brakwater, on the road to Okahandja, where *Prosopis* spp. has transformed that area as it is the most abundant plant species found there. A high number (63) of *Datura stramonium* individuals in Grid 2836, were found close to the drainage line.

CHAPTER 5: DISCUSSION

5.1 DISTRIBUTION AND ABUNDANCE

The present study revealed that *D. innoxia* within the City of Windhoek is not limited to any surroundings, although there was a high occurrence in areas close to the roads, human activities and drainage lines (Fig 4.1). According to Bethune *et al.*, (2004) and Boyer & Boyer (1989), the distribution of *D. innoxia* is not limited to any habitats or surroundings. However, it is mainly distributed along watercourses.

The occurrence of *D. innoxia* is not influenced by different locations but rather by the different types of land uses (Table 4.1). The difference in the number of *D. innoxia* and the type of activities can be attributed to disturbance. The construction areas and the build up areas had high number of *D. innoxia* compared to area where there was no construction and the open spaces (Figure 4.3 & 4.4 and Appendices C&D). This suggests that *D. innoxia* occurs mostly in disturbed areas.

Disturbance creates gaps and provides opportunities for new invaders (Huston, 1994) and with accelerating construction activities within the City of Windhoek; this encourages an increase of *D. innoxia* within the City of Windhoek. The intensity and scale of disturbance determine whether regeneration will begin for the surviving species or whether new migrants will invade (Huston, 1994; Beeby, 1993). From most of the grids where a high number of *D. innoxia* was observed, it was evident that intensive use of heavy machinery for construction, clearing of land (intensive disturbance) allowed

migrants (opportunistic plants) to invade. Seeds are carried in the soil by the earth-moving equipments and they facilitate invasion (Chapman *et al.*, 2001). According to Parsons and Cuthbertson (1992), *D. innoxia* can be dispersed as root cut pieces and this can facilitate further invasions. Grid 3183 on the Western Bypass in Rocky Crest had intensive disturbance and the plant species found there were predominantly opportunistic invasive alien species, namely *A. orchroleuca*, *D. innoxia* and *N. glauca*. In Grid 4416, also on the Western Bypass in Pionerspark, there was less disturbance (digging of a hole) with only *D. innoxia*. In this grid the surviving plant species could regenerate. Regeneration by surviving plant species eliminated the opportunistic plants (Huston, 1994) and that is why there were no other invasive alien plants apart from *D. innoxia*.

The high infestation of *D. innoxia* in the construction areas and built-up areas reveals the association of *D. innoxia* with disturbance (Figure 4.3 & 4.4). According to Chapman *et al.* (2001), development of new infrastructure provides a mechanism for the transport and dispersal of propagules along new routes. Also, building of infrastructure provides new foci of disturbances during construction. Boyer and Boyer (1987) suggested that the distribution of *D. innoxia* is mainly along the riverbeds and disturbed areas, and the high infestation of *D. innoxia* in the drainage lines followed by the denudated plains within the City of Windhoek supports the statement (Figure 4.1 & 4.2).

This study revealed that as a weedy plant, *D. innoxia* is a pioneer plant that invaded newly disturbed areas (Figure 4.1 & Appendix A). Pioneer plants can be either alien or indigenous plants that are adapted to colonize denuded and disturbed areas. *D. innoxia* is

a perennial plant that persists for a while. However, it completes its life cycle rapidly and produces large numbers of seeds in the short time available before other plant species arrive (Beeby, 1993). However, the plants do not have a strong competitive ability and are therefore gradually replaced by plants higher up in the natural plant succession (Bromilow, 1995). Despite their nuisance value, pioneer plants are actually valuable components of an ecosystem in that they change a harsh environment into one more suited to plant life, and then gradually disappear (Rosenzweig, 1996). As long as the area remains disturbed the pioneer plants will thrive there. If an area overrun by pioneer plants is left alone and not disturbed any further, these pioneer plants will eventually be replaced by palatable grasses or by other indigenous plants, depending on the climatic region (Rosenzweig, 1996 & Dowdeswell, 1984).

The suggestion that *D. innoxia* is a pioneer plant is supported by the observation in the City of Windhoek that it rapidly colonized disturbed areas. For instance, a lot of *D. innoxia* individuals with no inflorescence were observed at the construction of the bridge and road (connecting Rocky Crest with the City) on the Western Bypass. Pioneer species are plants with adaptations such as long roots, rapid germination rate, root nodes containing nitrogen fixing bacteria and leaves that reduce transpiration. *D. innoxia* have long roots, produces large number of seeds with rapid seed germination (Jansen, 2001). Apart from being suggested as a pioneer plant, *D. innoxia* also has additional ability to encroach upon undisturbed, pristine areas (Henderson, 2001). On Sam Nuujoma Avenue on the way to Daan Viljoen, one plant of *D. innoxia* was observed. This plant was

observed on a hill with no apparent human activities. This indicates the ability of *D. innoxia* ability to encroach undisturbed areas.

Pathways and vectors that assist with the dispersal of *D. innoxia* are important links to invasion (McNeely *et al.*, 2001). Human activities, such as construction and the use of equipments, movement of soil from one areas to another, are mostly vectors that transport *D. innoxia* across barriers. The seeds of *D. innoxia* are released from the capsules onto the ground and the rest are dispersed by the wind (Jansen, 2001). According to Loutit and Tarr (1985), the dispersal of *D. innoxia* is mainly by waterborne seeds with 87% germination success. Other means of dispersal is by the fruit spines getting caught in the hair of animals, which then carry the fruit far from the mother plant (Loutit and Tarr, 1985; Parsons and Cuthbertson, 1992). Within the drainage lines, once the line flows or gets flooded, the seeds are dispersed to new locations (Plate 2 & 3 in Appendix section). The denudated plains are the areas where more human activities are taking place and the movement of *D. innoxia* to new locations can be attributed to human activities.

The study also revealed that *D. innoxia* is most likely to be found along riverbanks, disturbed areas and around human settlement as indicated (Figure 4.1 –4.4 & Plate 1 – 3 in Appendix section). The occurrence of *D. innoxia* is influenced by the different type of human activities and the location as it was growing in all sections within the City of Windhoek (Figure 4.1 - Figure 4.4 & Appendix A).

5.2 REPRODUCTIVE STATUS

During the survey period (April to September 2006), *D. innoxia* was producing flowers and leaves throughout. The actual size and the number of the new flowers and leaves being produced were only reduced during the winter period (personal observations). *D. innoxia* has complete, perfect flower and it is monoecious (Campbell, 1996). *D. innoxia* is a day-neutral plant, it flowers when it reaches a certain degree of maturity and has a continuous floral development and it flowers without stopping once it starts (Jansen, 2001). The life cycle of *D. innoxia* is similar to the one of cotton (Parsons and Cuthbertson, 1992). With continuous floral development, capsules are also continuously produced. This mechanism of *D. innoxia* may have evolved as a strategy to produce more seeds. This study revealed that *D. innoxia* has a continual floral and capsules development as most plants observed during the study had both the inflorescence and capsules (Figure 4.5).

The construction areas had a high number of plants with no inflorescence compared to the no construction areas (Figure 4.11). However the number of plants with both the inflorescence and capsules was also high in the construction areas (Table 4.3). Also the drainage lines had a high number of *D. innoxia*. This gives a great concern about the future abundance and distribution of *D. innoxia*. The City of Windhoek is developing rapidly and *D. innoxia* might be a nuisance. The whole plant of *D. innoxia*, including the seeds are poisonous and can cause skin irritation (Henderson, 2001 and Jansen, 1998). Being an invasive alien plant, *D. innoxia* usually grows vigorously and disperses rapidly. Instead of being outcompeted by better-adapted plants, the invasive plants actively

displace the indigenous vegetation and often transform the plant community (Jansen, 1998 and 2001; Henderson, 2001). In Brakwater, Grid 645, where was a high infestation by *Prosopis* species. The area appeared transformed as only few *Acacia erioloba* and *A. mellifera* was observed compared to areas with no *Prosopis* infestation (personal observations).

The most important factor that enables alien plants to become invaders is the absence of their natural enemies (Munthali, 2004). Other characteristics that could enhance the invasiveness of *D. innoxia* are strong vegetative growth, prolific seed production, long-lived seeds, a high seed germination rate, effective seed dispersal mechanisms and rapid maturation to a seed-producing stage (Avery *et al.*, 1950). Also, the seeds of *D. innoxia* contain tropane alkaloids (scopolamine and hyoseyamine), which enhance the germination as well as shoot/root elongation (Parsons and Cuthbertson, 1992).

Since *D. innoxia* is poisonous and causes irritation of the skin, a large infestation such as the one in Plate 2 & 3 (in the Appendix section) may cause health problems to the inhabitants of the City of Windhoek. Practically, it is difficult to eradicate *D. innoxia* due to its large seed reserve in the soil and seeds can remain viable for many years (Klein and Bredenkamp, 1998). New areas can be infested with seeds from neighboring areas and by the different land uses. However, according to Parsons and Cuthbertson, (1992), control of the spread of *D. innoxia* can be controlled by cleaning all the equipments used in infested areas. In crop production, rotational cropping, from soybeans to cotton can be practiced (Parsons and Cuthbertson, 1992). Within the City of Windhoek, it is difficult to

eradicate *D. innoxia* as development is continuing and disturbances are associated with development. The prevention of the spread of *D. innoxia* is also difficult as the cleaning of earth-moving equipment used during constructions is difficult. Seeds may remain dormant for a long period and invasion may occur long after constructions are done.

The study also revealed that there was a very weak relationship between the height and crown width of *D. innoxia* and the flowers and capsules it bears (Figure 4.18 – Figure 4.29). Since there were positive relationships, although weak to modest, it was expected that with the increase in height and crown width of *D. innoxia* plants, there would be increase in the total number of flowers and capsules. The variations of the number of flowers or capsules were not influenced by the height or crown width of *D. innoxia* (Figure 4.18-Figure 29). Variations that might have influenced the number of flowers and capsules are the environmental conditions. These environmental conditions can be the availability of moisture and temperature. In bad environmental condition, plants revert on saving energy and might dry out, shed all the productive structure (Klein and Bredenkamp, 1998).

On the contrary, the study done by Nghoshi (2005) indicated that there was a positive correlation between the crown width and the number of capsules. The study done by Nghoshi was done in the Gammams river (within a certain section of the drainage lines in the City of Windhoek) and only in the month of April. Many rivers and tributaries join the Gammams river and it is the only river that enters the Goreangab Dam (Nghoshi, 2005). This study was done over a period of six months (April to September) and covered

all section of the drainage lines within the City of Windhoek. Depending on the environmental condition, *D. innoxia* flower at any height as a strategy to produce more seeds (Klein and Bredenkamp, 1998). In wild populations, when the environmental conditions are unfavorable (e.g. insufficient moisture and unfavorable temperatures), *D. innoxia* tend to mature or flower at any height. The shortest height *D. innoxia* bear flowers was at a height of 6cm (personal observation).

According to Nghoshi, 2005, taller plants have larger crown size and have more capsules, which was not always the case in this study. Due to environmental conditions (e.g. cold temperatures), some plants might have dried out and subsequently shed some structures, such as leaves, branches and reproductive structures. Also, the difference in the results of the two studies can be attributed to the difference in the sample size. The total number of *D. innoxia* plants observed during this study was 900 where as Nghosi sampled a total less than 900 *D. innoxia* plants. According to Dytham (1999), with large sample size value of the coefficient of determination to show that there is some relationship between two variables is very low.

There was a high percentage of the mature (bearing both inflorescence and capsules) plant compared to the plants with inflorescence only (Fig 4. 5), which means more seeds were produced to allow the establishment of *D. innoxia*. Since the dispersal of *D. innoxia* is also waterborne (Loutit and Tarr, 1985), *D. innoxia* have the ability to colonize vast areas (Plate 2 & 3 in the Appendix section).

The seeds of *D. innoxia* are mature when the four valves open and the capsules become hard, dry and brown (Plate 1.1). The mature capsules shed most of their seeds directly on to the ground and the rest are shed by wind (Jansen, 1998). In many cases, *D. innoxia* occurs in clumps in areas far from watercourses as these seeds germinate close to the mother plant.

Although a perennial plant, *D. innoxia* produces a high number of seeds (average up to 650 seeds per capsule) (Loutit and Tarr, 1985 & personal observation) in a short time (can have capsules at a height of 6 cm). To have more seeds produced, under unfavorable conditions the plant can flower when few weeks old (Klein and Bredenkamp, 1998).

The study revealed that *D. innoxia* is a perennial plant with a continuous floral development and there was significant difference in the reproductive status of *D. innoxia* within the geo-morphological landforms (drainage line, denudated plains and slope and ridges), type of activities (constructions vs no construction) and the location (build up areas and open spaces) (Figure 4.7, 4.9 & 4.11 & Table 4.3). More plants with inflorescence and capsules were observed, producing a lot of seeds for secured reproduction (Klein and Bredenkamp, 1998). Since *D. innoxia* is an invasive alien plant, it produces flowers and capsules at any height and crown size, which is a strategy used by many invasive species to ensure reproduction, the study accept that there was a weak relationship between the height and crown width and the number of flowers and the number of capsules.

5.3 SPECIES COMPOSITION

Windhoek lies at the centre of the Highland savanna vegetation which is characterized by a variety of *Acacia* trees such as *A. hereroensis*, *A. hebeclada* and *A. reficiens* *A. mellifera* and shrubs *C. alexandrii* (City of Windhoek, 2004). Plate 4.1 showed that *D. innoxia* co-exist with other plant species such as *S. windhoekensis*, which is overlapping in all clusters. Some grids were within partially build up areas, areas cleared for construction and as dumping sites, burned areas, within informal settlement and within areas with little to no human activities. These different land uses had an influence on the species composition within most grids apart from the assumed presence of *D. innoxia* (personal observation). As vast areas of lands were cleared and most plant species removed, thus influencing species composition in some grids. The degree of disturbance is an important factor determining the species composition in ecosystems (Huston, 1994). Disturbance creates space for the invasion of new species and prevents the domination of the community by a small number of competitive species (Beeby, 1993; Huston, 1994). Also, whether an alien species might become invasive depends on the ecological role the plant may play (Mooney *et al.*, 2005). However, the invasion by *D. innoxia* did not prevent the domination of *S. windhoekensis*, which was present in all the grids and *D. innoxia* played a role of a pioneer plant. Grids situated in the open areas where there was little or no disturbance, had close to 90% dissimilarities to the rest of the grids, which had a certain degree of disturbance (Figure 4.30, cluster E).

The other organisms associated with *D. innoxia* were mainly insects and small mammals. These organisms might play important role in pollination and dispersal. Honeybee and the ladybird beetle were observed entering the flower of *D. innoxia*, most likely searching for nectar (Plate 4.2). The flowers of *D. innoxia* are hermaphroditic and these insects help with pollination (Jansen, 2001). Ants were observed moving seeds from *D. innoxia* to *Laggera decurrens*, which was growing almost 3m from *D. innoxia*. Ants store the seeds as food reserve but in the meantime they assist with seed dispersal. Since small mammals might feed on seeds, their association with *D. innoxia* can also be linked to dispersal. The visitation by the honey bees was to collect nectar and in the process acting as pollinators.

Generally and in most case, the relationship between the animals and plants is mutual. Animals eat plants as food. In return animals carry pollen and seeds as plants need to reproduce (Campbell, 1996). Whether the same concept is valid with *D. innoxia*, further studies are needed. The structure of *D. innoxia* flowers and the visitation by the honeybee and the ladybird beetle indicated that the flower is not pollinator specific. Literature indicated that the type of *D. innoxia* flower does not have any exclusive relationship with any pollinator (Loutit and Tarr, 1985; Parsons and Cuthbertson, 1992). *D. innoxia* flowers have adaptive feature such as the funnel shape and white flowers to attract pollinators (Avery *et al.*, 1950). Being an alien plant species in a foreign environment and without natural enemies, specific pollinators will not be the best survival strategy for *D. innoxia*. Also, as an invasive alien plant within the City of Windhoek, *D. innoxia* does

not have natural enemies and cannot afford to be pollinator specific. The association between the aphids on the open capsules and seeds is not understood.

D. innoxia was found growing in close association with *A. orchroleuca*. While *D. innoxia* only occurred in more than half of the sampled grids, *A. orchroleuca* occurred in almost all grids. The high abundance of *A. orchroleuca* indicated that it might be a vigorous invader than *D. innoxia*.

Interestingly, *D. stramonium* was not as abundant as *D. innoxia* and the two species hardly occurred in the same area. The only grid where the two species occurred was in Grid 2836 in Hochland Park. This grid was behind newly build flats where it was disturbed with dirty running water. *D. innoxia* is a cosmopolitan weed and occurs anywhere where there are human activities or disturbances. In South Africa, *D. innoxia* is sometimes grown as an ornamental plant and is not treated as a general weed. On the contrary, *D. stramonium* is a problematic plant that competes with summer grain for nutrients, moisture and light due to the broad leaves (Klein and Bredenkamp, 1998). Unlike *D. innoxia*, *D. stramonium* occurred where there was a high level of moisture. Unlike *D. stramonium*, *D. innoxia* does not have a strong affinity for moisture; rather it is associated with disturbance (Klein and Bredenkamp, 1998).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The study has shown that *D. innoxia* is widely distributed along riverbanks, disturbed areas and around human settlement. There was no significant difference in the number of *D. innoxia* in the three geo-morphological landforms, namely drainage lines, denudated plains and slopes and ridges, in the City of Windhoek. However, there was a significant difference in the number of *D. innoxia* with respect to type of human activities and the different locations. The occurrence of *D. innoxia* is not influenced by the three geomorphological landforms. Although a higher mean rank of *D. innoxia* was recorded in the drainage lines, *D. innoxia* was growing in all surroundings in the City of Windhoek. Results seem to suggest that the occurrence of *D. innoxia* is influenced by the different activities. The high infestation in the construction site and in the built-up areas suggest that the distribution of *D. innoxia* is associated with disturbances.

There was significant difference in the reproductive status of *D. innoxia* within the three geo-morphological landform, type of activities and the different locations in the City of Windhoek. *D. innoxia* is a perennial weed and has a continuous floral development and therefore there were more *D. innoxia* plants with inflorescence and capsules than the plants with inflorescence or capsules only. Plants with inflorescence were more observed in more recent construction sites compared to older construction sites.

The City of Windhoek, being situated in the highland savanna vegetation, all the dominant species characterizing the highland savanna were present. Variation within the

vegetation composition was attributed to the different land uses within the City of Windhoek and not to the presence of *D. innoxia*.

In conclusion, *D. innoxia* is a cosmopolitan opportunistic weed that is abundant in construction sites, drainage lines and around human settlements. The distribution of *D. innoxia* is associated with disturbance. Possible source of infestation by *D. innoxia* are within the human settlements, drainage lines and around construction areas.

Within the City of Windhoek, it is difficult to eradicate *D. innoxia* as development is continuing and disturbances are associated with development. The cleaning of earth-moving equipment used during constructions might be difficult; however the cleaning will help with elevating the spread of *D. innoxia*.

For proper management and control of any invasive alien species, detailed studies on the dispersal, competitiveness, and phenology are needed. Competition by *D. innoxia* with indigenous plants might be seen as minimal, but they take over areas that would be occupied by herbaceous vegetation of the riverbanks. This in turn might impact on pollinators, herbivores and other species that might not be able to utilise the invasive species. Also, since *D. innoxia* is poisonous and can cause irritation to the skin, its effect on human health within the City of Windhoek should be studied.

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Useful websites

1. <http://www.biodiv.org/programmes/cross-cutting/alien/>
2. <http://www.iucn.org/themes/ssc/news/invasives.htm>
3. <http://www.gisp.org/>
4. www.windhoekcc.org

List of appendixes

Appendix A: Distribution of *D. innoxia* in the City of Windhoek

Number	Plot number	Y	X	# of <i>D. innoxia</i>	Suburb	General comment/Physical condition
1	151	-22.48439	16.9948	0	Big Bend	Out skirt of WHK, the end
2	291	-22.48022	17.07814	18	Brakwater	Open space, Prosopis infestation
3	456	-22.48855	17.00522	0	Big Bend	Out skirt of WHK, the end
4	511	-22.49064	17.01564	0	Kambila	Out skirt of WHK, the end
5	532	-22.49064	17.06147	8	Babilon	within tomato tree, rocky area and slope. Within informal settlement
6	645	-22.49481	17.08856	24	Brakwater	Open space, Prosopis infestation
7	653	-22.49689	16.99897	0	Big Bend	Out skirt of WHK, the end
8	660	-22.49689	17.01356	0	Kambila	Out skirt of WHK, the end, Damping site
9	669	-22.49689	17.03231	0	Kambila	Out skirt of WHK, the end
10	698	-22.49698	17.09272	0	Brakwater	Open space,
11	714	-22.49897	17.02189	23	Kambila	within tomato tree, rocky area and slope. Within informal settlement
12	729	-22.49897	17.05522	12	Babilon	within tomato tree, rocky area and slope. Within informal settlement
13	732	-22.49897	17.06147	5	Babilon	within tomato tree, rocky area and slope. Within informal settlement
14	735	-22.49897	17.06772	0	Babilon	burned, no settlement
15	747	-22.48231	17.09064	0	Brakwater	Open space to Okahandja
16	789	-22.50106	17.07605	16	Lafrenz Industrial	Open space
17	862	-22.50522	17.01772	12	Hakahana	within grasses/refuse
18	876	-22.50522	17.07083	25	Lafrenz Industrial	Human activities
19	907	-22.50731	17.00731	0	Goreangab Ext 3	Open space
20	915	-22.50731	17.02397	5	Hakahana	within tomato tree, rocky area and slope. Within informal settlement
21	925	-22.50731	17.04689	0	Ombili	All sorrouded by Jesus Centre

22	931	-22.50731	17.05939	0	Okuryangava	within houses
23	958	-22.50938	17.00939	0	Goreangab Ext 3	Open space, end of Windoek
24	1022	-22.51147	17.03647	0	Wanahenda	Too large and steep rocks. Partly burned
25	1045	-22.51147	17.08647	0	NamPower van Erk	No Access
26	1072	-22.51356	17.03647	0	Wanahenda	Fall within houses
27	1126	-22.51564	17.04481	0	Soweto	Fall within houses
28	1169	-22.51769	17.03231	11	Wanahenda	Occur within refuse/grasses. Riverbed between house
29	1176	-22.51772	17.04897	0	Soweto	Fall within houses
30	1222	-22.51981	17.03647	1	Wanahenda	Rocky sand
31	1270	-22.52189	17.01147	21	Goreangab Ext 3	Occur in clumps and within refuse/grasses. Area burned and used as toilet. Plot within informal settlement and there is dirty water running.
32	1280	-22.52189	17.03231	1	Wanahenda	Occur within refuse/grasses. Riverbed across road.
33	1290	-22.52189	17.05522	12	Katutura	Within refuse/grasses, gravel, rocky soil and close to houses
34	1292	-22.52189	17.05939	2	Katutura	Rocky sand
35	1300	-22.52189	17.07605	19	Northen Industrial	refuse/grasses, soil turned over
36	1303	-22.52198	17.08022	0	NamPower van Erk	No Access
37	1364	-22.52398	17.08133	0	NamPower van Erk	No Access
38	1400	-22.52606	17.02606	0	Goreangab Ext 3	Before Goreangab recreation entrance
39	1410	-22.52606	17.04897	0	Soweto	Fall within houses, river & school
40	1472	-22.52814	17.0505	0	Katutura	Fall within houses, river & school
41	1510	-22.53022	17.00314	0	Goreangab Ext 3	Goreangab dam at sewage
42	1518	-22.53022	17.01981	0	Goreangab Ext 3	Inside Goreangab dam
43	1520	-22.53022	17.02497	0	Goreangab Ext 3	Inside Goreangab dam
44	1533	-22.53022	17.08647	0	Katutura	Fall within houses
45	1570	-22.53022	17.00105	0	Goreangab Ext 3	Open space
46	1595	-22.53022	17.05522	0	Katutura	Fall within houses

47	1605	-22.53022	17.07605	38	Northern Industrial	Road construction
48	1606	-22.53022	17.07814	16	Northern Industrial	Road construction & buildings
49	1666	-22.53439	17.07605	8	Northern Industrial	Mostly buildings, human activities
50	1667	-22.53439	17.07814	7	Northern Industrial	Mostly buildings, human activities
51	1672	-22.53439	17.08647	0	Eros	Open space
52	1675	-22.53439	17.09272	0	Eros	Fall within houses
53	1720	-22.53647	17.03647	2	Khomasdal	within refuse/grasses, plot within houses
54	1782	-22.53855	17.06355	1	Khomasdal	within grasses
55	1802	-22.53855	17.10314	0	Eros	Open space
56	1863	-22.54064	17.10314	0	Eros	Open space
57	1893	-22.54272	17.03647	45	Khomasdal	on building refuse behind newly build flats and houses. Area burned
58	1971	-22.5448	17.07605	12	Windhoek North	River between houses
59	1979	-22.5448	17.09064	0	Eros	Fall within houses
60	1982	-22.5448	17.098	4	Eros	River between houses
61	2023	-22.54689	17.04689	3	Khomasdal	within refuse
62	2035	-22.54689	17.07814	0	Windhoek North	Rhino Park
63	2041	-22.54689	17.09272	0	Eros	Fall within houses
64	2070	-22.54897	17.02606	2	Otjomuise	Within thick grasses covered with refuse
65	2083	-22.54897	17.05522	0	Khomasdal	Fall within houses
66	2094	-22.54897	17.07814	13	Windhoek North	River/houses/open space
67	2099	-22.54897	17.08647	9	Eros	Fall within houses
68	2106	-22.54897	17.09064	6	Eros	Building & river
69	2160	-22.53439	17.08647	0	Eros	Fall within houses
70	2235	-22.55314	17.11564	0	Ludwigsdorf	Open space
71	2302	-22.55522	17.11147	0	Ludwigsdorf	Open space
72	2375	-22.55731	17.11564	0	Ludwigsdorf	Open space
73	2379	-22.55731	17.12189	0	Ludwigsdorf	Open space
74	2422	-22.55939	17.07814	0	Windhoek West	Fall within houses
75	2497	-22.56147	17.07605	0	Windhoek Central	Fall within houses
76	2502	-22.56147	17.08842	0	Windhoek Central	Open space

77	2509	-22.56147	17.10314	8	Ludwigsdorf	Building & river
78	2513	-22.56147	17.11147	0	Ludwigsdorf	Fall within houses
79	2564	-22.56356	17.07397	0	Windhoek Central	Fall within houses
80	2571	-22.56356	17.08647	0	Windhoek Central	Parliament Garden
81	2583	-22.56356	17.11147	0	Ludwigsdorf	Fall within houses
82	2624	-22.56564	17.05105	1	Khomasdalen	little human activities. Up hill
83	2635	-22.56564	17.07605	0	Windhoek Central	Fall within houses
84	2676	-22.56772	17.01147	0	Sam nujoma Drive	On the way to Daan Viljoen
85	2764	-22.56981	17.05105	0	Rocky Crest	Area just cleared for construction. Rocky Crest
86	2765	-22.56981	17.05314	0	Rocky Crest	Rocky Crest towards DV road
87	2836	-22.57189	17.03188	63	Hoclandpark	Behind newly build flats. Disturbed with running water
88	2838	-22.57189	17.05939	8	Hoclandpark	Hochland park new areas
89	2841	-22.57189	17.06564	0	Hoclandpark	Open space
90	2906	-22.57397	17.05522	2	Hoclandpark	Next to house renovated
91	2908	-22.57397	17.05939	17	Hoclandpark	Next to Uejaa's house
92	2910	-22.57397	17.06355	0	Pioneerspark	Compeletly within houses
93	2913	-22.56772	17.09064	0	Windhoek Central	Within Parliament
94	2929	-22.56772	17.12397	0	Ludwigsdorf	Fall within houses
95	2938	-22.57397	17.12814	0	Avis	Open space, end of Windoek
96	2996	-22.57606	17.09689	8	Windhoek Central	Next to road & houses
97	3006	-22.57606	17.11772	8	Avis	Open space, end of Windoek
98	3062	-22.57606	17.08856	21	Windhoek Central	Soil turned over.
99	3110	-22.58022	17.04272	0	Rocky Crest	End of Rocky Crest
100	3112	-22.58022	17.04689	0	Rocky Crest	End of Rocky Crest
101	3119	-22.58022	17.06147	8	Pioneerspark	Next to houses
102	3120	-22.58022	17.06355	3	Pioneerspark	Next to houses
103	3124	-22.58022	17.07397	0	Pioneerspark	Cemetry
104	3141	-22.58022	17.10731	8	Pioneerspark	Open space, human activities
105	3183	-22.58231	17.04897	115	Rocky Crest	Soil turned over. Beginning of Rocky

						Crest at the new road construction
106	3188	-22.58231	17.05939	27	Pioneerspark	within grasses and refuse
107	3198	-22.58231	17.08022	12	Hoclandpark	Open space next to houses
108	3205	-22.58231	17.09481	0	Olympia	Within buildings
109	3219	-22.58231	17.12397	0	Olympia	within houses
110	3259	-22.58439	17.06147	0	Pioneerspark	90% within houses
111	3264	-22.58439	17.07189	16	Hoclandpark	within grass/refuge
112	3397	-22.58856	17.0573	0	Pioneerspark	Compeletly within houses
113	3502	-22.59064	17.06772	1	Pioneerspark	Houses
114	3503	-22.59064	17.0698	1	Pioneerspark	Houses
115	3537	-22.59272	17.05933	0	Pioneerspark	Next to Pailinium
116	3540	-22.59272	17.06564	0	Pioneerspark	At church and all tress are planted and maintained
117	3561	-22.59064	17.10522	6	Auasblick	Construction
118	3583	-22.59272	17.05939	11	Avis	Within river
119	3603	-22.59486	17.04675	0	Pioneerspark	At Baines
120	3623	-22.59486	17.09064	0	Suiderhof	Within army base
121	3677	-22.59689	17.0573	0	Pioneerspark	Open space
122	3681	-22.59689	17.06355	19	Pioneerspark	Uphill, back of newly constructed houses
123	3682	-22.59689	17.06564	0	Pioneerspark	At Bains, rest within houses
124	3698	-22.59689	17.11564	19	Olympia	Soil turn over
125	3705	-22.59689	17.11563	8	Olympia	within grass/refuge
126	3746	-22.59897	17.05939	0	Olympia	Open space
127	3774	-22.60497	17.10978	46	Olympia	Area cleared for dumping side
128	3881	-22.60314	17.06147	16	Olympia	Soil turn over
129	3882	-22.60314	17.06355	0	Olympia	Fall within houses
130	3893	-22.60314	17.06147	0	Olympia	Open space
131	3939	-22.60328	17.04272	0	Pioneerspark	Open space
132	3941	-22.60522	17.04689	0	Pioneerspark	Open space
133	4023	-22.6073	17.0573	0	Pioneerspark	Open space
134	4024	-22.6073	17.08856	9	Pioneerspark	Between the 2 sport stadium

135	4026	-22.6073	17.06355	0	Pioneerspark	Behind Unam's new hostels
136	4073	-22.60939	17.04272	0	Pioneerspark	Open space
137	4082	-22.60939	17.04494	2	Pioneerspark	Next to houses
138	4083	-22.60939	17.06355	0	Pioneerspark	Hindrick Isaaks, within houses
130	4085	-22.60939	17.07605	0	Eros Airport	Eros Airport
140	4100	-22.60939	17.1062	0	Eros Airport	Eros Airport
141	4108	-22.60939	17.12397	0	Academia	Open space
142	4208	-22.61355	17.04481	0	Pioneerspark	Open space
143	4216	-22.61355	17.06147	0	Pioneerspark	Unam entrance
144	4269	-22.61564	17.1323	0	Pioneerspark	Open space
145	4372	-22.60105	17.1323	0	Kleine Kuppe	Open space
146	4407	-22.6198	17.04064	0	Pioneerspark	Open space
147	4412	-22.6198	17.04897	0	Pioneerspark	Open space
148	4416	-22.6198	17.05939	11	Pioneerspark	Unam to Country Club
149	4497	-22.62189	17.07814	0	Prosperita	Open space, human activities
150	4756	-22.63022	17.07387	0	Prosperita	Open space, burned & cleared for road
151	4823	-22.58231	17.08022	0	Cimbambacia	Open space, river
152	5023	-22.63856	17.07397	14	Cimbambacia	Open space, river
153	5435	-22.65106	17.09897	0	Leopard Valley	Army base, no access
154	5442	-22.65106	17.11147	0	Leopard Valley	Army base, no access
155	5450	-22.65106	17.11147	0	Leopard Valley	Army base, no access
156	5692	-22.65939	17.07605	0	Side of Heroes Arcre	Open space to Rehoboth
157	5761	-22.66542	17.07783	31	Heroes Arcre	Construction
158	5712	-22.65939	17.11564	0	Leopard Valley	Army base, no access
159	5763	-22.66147	17.08231	0	Leopard Valley	Army base, no access
160	5775	-22.66147	17.10731	0	Leopard Valley	Army base, no access

Appendix B: Test statistic of the Kruskal-Wallis test, indicating the significance of the confident level in the difference with the identified geo-morphological landforms

	Number of <i>D. innoxia</i>
Chi-Square	4.865
df	2
Asymp. Sig.	.088
Sig.	.087(a)
Lower Bound	.080
Upper Bound	.094

Appendix C: Test statistic of the Mann Whitney U test, indicating the significance of the confident level in the difference, number of grids and the mean rank of *D. innoxia* with the identified locations

Location	Number of grids	Median	Mean rank of <i>D. innoxia</i>
Built-up areas	66	6.5	75.46
Open spaces	55	0	43.65
		Number of <i>D. innoxia</i>	
Mann-Whitney U test		860.5	
Wilcoxon W		2400.5	
Z		-5.3	
Asymp. Sig		0.00	

Appendix D: Test statistic of the Mann Whitney U test, indicating the significance of the confident level in the difference, number of grids and the mean rank of *D. innoxia* with the identified activities

Location	Number of grids	Median	Mean rank of <i>D. innoxia</i>
Built-up areas	17	19	92.03
Open spaces	104	7	55.93
		Number of <i>D. innoxia</i>	
Mann-Whitney U test		356.5	
Wilcoxon W		5816.5	
Z		-4.2	
Asymp. Sig		0.00	

Appendix E: The number of *D. innoxia* in the grids according to the identified environmental factors

No.	Grid no.	Number of <i>D. innoxia</i>	Geo-morphological landform	Location	Activities
1	151	0	Denudated Plains	Open Space	No Construction
2	291	18	Slope and Ridges	Open Space	No Construction
3	456	0	Slope and Ridges	Open Space	No Construction
4	511	0	Slope and Ridges	Build up Areas	No Construction
5	532	8	Slope and Ridges	Open Space	No Construction
6	645	24	Drainage line	Open Space	No Construction
7	653	0	Denudated Plains	Open Space	No Construction
8	660	0	Denudated Plains	Open Space	No Construction
9	669	0	Denudated Plains	Open Space	No Construction
10	698	0	Slope and Ridges	Open Space	No Construction
11	714	23	Slope and Ridges	Build up Areas	No Construction
12	729	12	Drainage line	Build up Areas	No Construction
13	732	5	Slope and Ridges	Build up Areas	No Construction
14	735	0	Slope and Ridges	Open Space	No Construction
15	747	0	Denudated Plains	Open Space	No Construction
16	789	16	Slope and Ridges	Open Space	No Construction
17	862	12	Denudated Plains	Build up Areas	No Construction
18	876	25	Denudated Plains	Build up Areas	No Construction
19	907	0	Denudated Plains	Open Space	No Construction
20	915	5	Denudated Plains	Build up Areas	No Construction
21	925	0	Denudated Plains	Build up Areas	No Construction
22	958	0	Denudated Plains	Open Space	No Construction
23	1022	0	Denudated Plains	Build up Areas	No Construction
24	1169	11	Slope and Ridges	Build up Areas	No Construction
25	1222	1	Denudated Plains	Build up Areas	No Construction
26	1270	21	Drainage line	Open Space	No Construction
27	1280	1	Drainage line	Build up Areas	No Construction
28	1290	12	Denudated Plains	Build up Areas	No Construction
29	1292	2	Denudated Plains	Build up Areas	No Construction
30	1300	19	Denudated Plains	Build up Areas	Construction
31	1400	0	Denudated Plains	Open Space	No Construction
32	1410	0	Drainage line	Build up Areas	No Construction
33	1472	0	Drainage line	Build up Areas	No Construction
34	1510	0	Drainage line	Open Space	No Construction
35	1570	0	Denudated Plains	Build up Areas	No Construction
36	1605	38	Denudated Plains	Build up Areas	Construction
37	1606	16	Denudated Plains	Build up Areas	Construction
38	1666	8	Denudated Plains	Build up Areas	No Construction
39	1667	7	Denudated Plains	Build up Areas	No Construction
40	1672	0	Denudated Plains	Open Space	No Construction
41	1720	2	Denudated Plains	Build up Areas	No Construction
42	1782	1	Denudated Plains	Build up Areas	No Construction
43	1802	0	Denudated Plains	Open Space	No Construction

44	1863	0	Denudated Plains	Open Space	No Construction
45	1893	45	Denudated Plains	Build up Areas	Construction
46	1971	12	Slope and Ridges	Build up Areas	No Construction
47	1982	4	Drainage line	Build up Areas	No Construction
48	2023	3	Denudated Plains	Build up Areas	No Construction
49	2070	2	Denudated Plains	Build up Areas	No Construction
50	2094	13	Slope and Ridges	Build up Areas	No Construction
51	2099	9	Denudated Plains	Build up Areas	No Construction
52	2106	6	Drainage line	Build up Areas	No Construction
53	2235	0	Denudated Plains	Open Space	No Construction
54	2302	0	Denudated Plains	Open Space	No Construction
55	2375	0	Denudated Plains	Open Space	No Construction
56	2379	0	Denudated Plains	Open Space	No Construction
57	2502	0	Denudated Plains	Open Space	No Construction
58	2509	8	Drainage line	Build up Areas	No Construction
59	2624	1	Slope and Ridges	Open Space	No Construction
60	2676	0	Slope and Ridges	Open Space	No Construction
61	2764	0	Denudated Plains	Build up Areas	Construction
62	2765	0	Denudated Plains	Open Space	No Construction
63	2836	63	Drainage line	Build up Areas	Construction
64	2838	8	Denudated Plains	Build up Areas	Construction
65	2841	0	Denudated Plains	Open Space	No Construction
66	2906	2	Denudated Plains	Build up Areas	Construction
67	2908	17	Drainage line	Build up Areas	No Construction
68	2938	0	Drainage line	Open Space	No Construction
69	2996	8	Denudated Plains	Build up Areas	No Construction
70	3006	8	Drainage line	Open Space	No Construction
71	3062	21	Denudated Plains	Build up Areas	Construction
72	3110	0	Slope and Ridges	Open Space	No Construction
73	3112	0	Slope and Ridges	Open Space	No Construction
74	3119	8	Denudated Plains	Build up Areas	No Construction
75	3120	3	Denudated Plains	Build up Areas	No Construction
76	3124	0	Denudated Plains	Build up Areas	No Construction
77	3141	8	Denudated Plains	Open Space	No Construction
78	3183	115	Denudated Plains	Build up Areas	Construction
79	3188	27	Denudated Plains	Build up Areas	No Construction
80	3198	12	Denudated Plains	Build up Areas	No Construction
81	3259	0	Denudated Plains	Build up Areas	No Construction
82	3264	16	Denudated Plains	Build up Areas	No Construction
83	3502	1	Denudated Plains	Build up Areas	No Construction
84	3503	1	Denudated Plains	Build up Areas	No Construction
85	3537	0	Denudated Plains	Build up Areas	No Construction
86	3540	0	Denudated Plains	Build up Areas	No Construction
87	3561	6	Slope and Ridges	Build up Areas	Construction
88	3583	11	Drainage line	Build up Areas	No Construction
89	3603	0	Denudated Plains	Build up Areas	No Construction
90	3677	0	Slope and Ridges	Build up Areas	Construction
91	3681	19	Denudated Plains	Build up Areas	No Construction

92	3682	0	Denudated Plains	Build up Areas	No Construction
93	3698	19	Denudated Plains	Build up Areas	Construction
94	3705	8	Denudated Plains	Build up Areas	No Construction
95	3746	0	Denudated Plains	Open Space	No Construction
96	3774	46	Denudated Plains	Open Space	Construction
97	3881	16	Denudated Plains	Build up Areas	Construction
98	3893	0	Denudated Plains	Open Space	No Construction
99	3939	0	Denudated Plains	Open Space	No Construction
100	3941	0	Slope and Ridges	Open Space	No Construction
101	4023	0	Denudated Plains	Open Space	No Construction
102	4024	9	Denudated Plains	Build up Areas	No Construction
103	4026	0	Denudated Plains	Open Space	No Construction
104	4073	0	Denudated Plains	Open Space	No Construction
105	4082	2	Denudated Plains	Build up Areas	No Construction
106	4085	0	Denudated Plains	Open Space	No Construction
107	4100	0	Denudated Plains	Open Space	No Construction
108	4108	0	Denudated Plains	Open Space	No Construction
109	4208	0	Denudated Plains	Open Space	No Construction
110	4216	0	Denudated Plains	Build up Areas	No Construction
111	4269	0	Denudated Plains	Open Space	No Construction
112	4372	0	Denudated Plains	Open Space	No Construction
113	4407	0	Denudated Plains	Open Space	No Construction
114	4412	0	Denudated Plains	Open Space	No Construction
115	4416	11	Drainage line	Open Space	No Construction
116	4497	0	Denudated Plains	Open Space	No Construction
117	4756	0	Denudated Plains	Open Space	Construction
118	4823	0	Drainage line	Build up Areas	No Construction
119	5023	14	Drainage line	Open Space	No Construction
120	5692	0	Slope and Ridges	Open Space	No Construction
121	5761	31	Slope and Ridges	Build up Areas	Construction

Appendix F: Extreme Values contributing to the significant difference between the built up areas and the open space, comparing the number of *D. innoxia*

	Activities			Case Number	Value
Number of <i>D. innoxia</i>	Construction	Highest	1	78	115
			2	63	63
			3	96	46
			4	45	45
			5	36	38
		Lowest	1	117	0
			2	90	0
			3	61	0
			4	66	2
			5	87	6
	No Construction	Highest	1	79	27
			2	18	25
			3	6	24
			4	11	23
			5	26	21
		Lowest	1	120	0
			2	118	0
			3	116	0
			4	114	0
			5	113	0(a)

Appendix G: ANOVA results, indicating the significant differences between the reproductive structures within the three identified geo-morphological landforms.

		Sum of Squares	df	Mean Square	F	Sig.
No. of flowers	Between Groups	472.273	2	236.136	4.427	.012
	Within Groups	47895.732	898	53.336		
	Total	48368.004	900			
No. of emerging capsules	Between Groups	44.783	2	22.392	2.160	.116
	Within Groups	9307.328	898	10.365		
	Total	9352.111	900			
No. of green capsules	Between Groups	364.247	2	182.124	8.529	.000
	Within Groups	19176.166	898	21.354		
	Total	19540.413	900			
No. of green exploded capsules	Between Groups	179.559	2	89.779	12.773	.000
	Within Groups	6311.904	898	7.029		
	Total	6491.463	900			
No. of dry capsules	Between Groups	1759.767	2	879.883	12.466	.000
	Within Groups	63384.582	898	70.584		
	Total	65144.349	900			
No. of dry exploded capsules	Between Groups	140.427	2	70.213	1.072	.343
	Within Groups	58819.251	898	65.500		
	Total	58959.678	900			

Appendix H: Test statistic of the Kruskal-Wallis test, indicating the significance of the confidence level in the difference of individual with capsules only within the identified geo-morphological landforms.

Variable	Inflorescence	Inflorescence only	Inflorescence and Capsules	Capsules only
Chi-Square	0.000	6.857	2.520	21.699
df	2	2	2	2
Asymp. Sig.	1.000	0.032	0.284	0.000
N	900	900	900	900

Appendix I: ANOVA results, indicating the significant differences between the reproductive structures within the two identified locations within the City of Windhoek.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	188.435	1	188.435	3.516	.061
Within Groups	48179.570	899	53.592		
Total	48368.004	900			
Between Groups	29.715	1	29.715	2.866	.091
Within Groups	9322.396	899	10.370		
Total	9352.111	900			
Between Groups	41.283	1	41.283	1.903	.168
Within Groups	19499.130	899	21.690		
Total	19540.413	900			
Between Groups	5.246	1	5.246	.727	.394
Within Groups	6486.217	899	7.215		
Total	6491.463	900			
Between Groups	1.027	1	1.027	.014	.905
Within Groups	65143.321	899	72.462		
Total	65144.349	900			
Between Groups	173.952	1	173.952	2.660	.103
Within Groups	58785.727	899	65.390		
Total	58959.678	900			

Appendix J: Test statistic of the Mann-Whitney U test, indicating the significance of the confidence level in the difference of individual with inflorescence only and inflorescence and capsules only within the identified locations with the City of Windhoek.

Variable	No Inflorescence	Inflorescence only	Inflorescence and Capsules	Capsules only
Mann-Whitney U	63525.000	57020.000	56593.500	62205.000
Wilcoxon W	78925.000	72420.000	71993.500	77605.000
Z	.000	-2.193	-2.564	-.445
Asymp. Sig. (2-tailed)	1.000	0.028	0.010	0.656
N	900	900	900	900

Appendix K: ANOVA results, indicating the significant differences between the reproductive structures within the two identified locations within the City of Windhoek.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	58.987	1	58.987	1.098	.295
Within Groups	48309.017	899	53.736		
Total	48368.004	900			
Between Groups	14.849	1	14.849	1.430	.232
Within Groups	9337.262	899	10.386		
Total	9352.111	900			
Between Groups	.829	1	.829	.038	.845
Within Groups	19539.584	899	21.735		
Total	19540.413	900			
Between Groups	25.397	1	25.397	3.531	.061
Within Groups	6466.066	899	7.193		
Total	6491.463	900			
Between Groups	336.311	1	336.311	4.665	.031
Within Groups	64808.038	899	72.089		
Total	65144.349	900			
Between Groups	444.874	1	444.874	6.835	.009
Within Groups	58514.804	899	65.089		
Total	58959.678	900			

Appendix L: Test statistic of the Mann-Whitney U test, indicating the significance of the confidence level in the difference of individual with inflorescence only and inflorescence and capsules only within the identified activities with the City of Windhoek.

Variable	No Inflorescence	Inflorescence only	Inflorescence and Capsules	Capsules only
Mann-Whitney U	101475.000	96604.500	98072.500	88098.500
Wilcoxon W	203401.000	198530.500	199547.500	189573.500
Z	.000	-1.299	-.996	-3.566
Asymp. Sig. (2-tailed)	1.000	.194	.319	.000

Appendix M: ANOVA results, indicating the significant differences of the height of *D. innoxia* between the reproductive structures within the identified environmental factors in the City of Windhoek.

Factor	Grouping		Sum of Squares	df	Mean Square	F	Sig.
Geo-morphological landforms	Drainage lines	Between Groups	110262.631	3	36754.210	36.939	.000
		Within Groups	195021.189	196	995.006		
		Total	305283.820	199			
	Denudated Plains	Between Groups	436601.032	3	145533.677	162.881	.000
		Within Groups	493211.664	552	893.499		
		Total	929812.696	555			
	Slope and Ridges	Between Groups	108237.264	3	36079.088	43.779	.000
		Within Groups	116200.226	141	824.115		
		Total	224437.490	144			
Location	Build-up Areas	Between Groups	602086.252	3	200695.417	212.802	.000
		Within Groups	680924.201	722	943.108		
		Total	1283010.453	725			
	Open spaces	Between Groups	93981.808	3	31327.269	32.791	.000
		Within Groups	163367.129	171	955.363		
		Total	257348.937	174			
Activities	Construction areas	Between Groups	444162.178	3	148054.059	157.344	.000
		Within Groups	419666.080	446	940.955		
		Total	863828.258	449			
	No construction areas	Between Groups	228135.851	3	76045.284	85.214	.000
		Within Groups	398904.286	447	892.403		
		Total	627040.137	450			

Appendix N: ANOVA results, indicating the significant differences of the crown width of *D. innoxia* between the reproductive structures within the identified environmental factors in the City of Windhoek.

Factor	Grouping		Sum of Squares	df	Mean Square	F	Sig.
Geo-morphological landforms	Drainage lines	Between Groups	105896.992	3	35298.997	29.587	.000
		Within Groups	233836.163	196	1193.042		
		Total	339733.155	199			
	Denudated Plains	Between Groups	406725.914	3	135575.305	149.441	.000
		Within Groups	500783.532	552	907.217		
		Total	907509.446	555			
	Slope and Ridges	Between Groups	101605.938	3	33868.646	27.198	.000
		Within Groups	175579.414	141	1245.244		
		Total	277185.352	144			
Location	Build-up Areas	Between Groups	549134.529	3	183044.843	178.252	.000
		Within Groups	741413.186	722	1026.888		
		Total	1290547.715	725			
	Open spaces	Between Groups	103207.964	3	34402.655	36.835	.000
		Within Groups	159707.545	171	933.962		
		Total	262915.509	174			
Activities	Construction areas	Between Groups	350764.796	3	116921.599	125.386	.000
		Within Groups	415891.704	446	932.493		
		Total	766656.500	449			
	No construction areas	Between Groups	258304.848	3	86101.616	79.121	.000
		Within Groups	486440.384	447	1088.234		
		Total	744745.233	450			

Appendix O: List of all plants observed during the study

- *Acacia ataxacanth*
- *Acacia erioloba*
- *Acacia hebeclada*
- *Acacia hereroensis*
- *Acacia mellifera*
- *Albizia anthelmintia*
- *Aloe littoralis*

- *Amaranthus* sp
- *Aptosimum spinescens*
- *Argemone ochroleuca*
- *Arundo donax*
- *Bidens* sp
- *Boscia albitrunca*
- *Catophractes alexandri*
- *Clonia* sp
- *Combretum apiculatum*
- *Datura innoxia*
- *Datura stramonium*
- *Dichrostachys cinerea*
- *Dombeya rotundifolia*
- *Ehretia alba*
- *Ehretia namibensis*
- *Euclea undulata*
- *Faidherbia albida*
- *Gnidia polycephala*
- *Gomphorarpus* sp.
- *Grawia flavescens*
- *Grewia bicolor*
- *Laggera decurrens*
- *Lantana camara*
- *Leucaena leucocephala*
- *Leucas pechuelii*
- *Lycium oxycarpum*
- *Lycium* sp
- *Melia azedarach*
- *Montinia caryophyllacea*
- *Nicotiana glauca*
- *Ondetia linearis*
- *Opuntia ficus-indica*
- *Pines* sp
- *Prosopis* sp
- *Rhus lancea*
- *Ricinus communis*
- *Rumex crispus*
- *Salsola kali*
- *Schinus molle*
- *Senecio windhoekensis*
- *Sida cordifolia*
- *Solanum delagoense*
- *Solanum nigrum*
- *Sonchus asper*

- *Sonchus oleraceus*
- *Tagetes minuta*
- *Tarchonanthus camphorates*
- *Tithonia rotundifolia*
- *Ziziphus mucronata*



Plate 1: *D. innoxia* in area where there is soil turn over



Plate 2: *D. innoxia* growing on the sides of a riverbank. The only other plant species is another invasive alien *A. orchroleuca*.



Plate 3: *D. innoxia* growing in on the edge of a drainage line, which is situated within human settlement.

