IMPACTS OF EXOTIC INVASIVE PLANTS ON THE COMPOSITION AND STRUCTURE OF RIPARIAN WOODY VEGETATION IN THE LOWER ORANGE RIVER- TSAU//KHAEB (SPERRGEBIET) NATIONAL PARK, NAMIBIA

by

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Abstract

The adverse impacts of exotic invasive plants in protected areas, agricultural areas and riparian zones are a global concern. With particular focus on riparian zones, the invasive alien plant species displaces indigenous riverine vegetation, alters species composition and plant community structure. In totality, alien invasive species affects ecological functioning of natural systems as well as disturbs the ecosystem and habitat integrity. This study therefore investigates the impact of exotic invading plant species on the structure and composition of the resident woody vegetation communities within the riparian zones of the lower Orange River part of Tsau//Khaeb (Sperrgebiet) National Park, Namibia. A comparative methodological study approach was adopted and a 20 m x 50 sampling plots were used for intensity density and biomass assessment between the invaded and uninvaded sites. Differences in canopy cover stem, width and vegetation height between the invaded and un-invaded sites were determined by using a t-test for the equality of means which was performed at the 5% significance level. The results proved that there was a significant difference in the mean height, mean canopy cover and mean stem width of the vegetation ($p = 0.00$). The most common exotic invader recorded are *Datura inoxia, Eucalyptus camaldulensis, Nicotiana glauca, Prosopis spp* and *Ricinus communis*. It is concluded that invasive alien plants exerts adverse impacts on the characteristics of riparian vegetation communities of the Lower Orange River in the Tsau//Khaeb (Sperrgebiet) National Park. Thus, there is a need for an active management and control interventions of alien invasive plant species within the riparian zones of the Orange River in the Tsau//Khaeb (Sperrgebiet) National Park.

Keywords: riparian zone, indigenous plants, alien invasive plants, lower Orange River, Tsau//Khaeb (Sperrgebiet) National Park.

DECLARATION

I, Kosmas Shilongo, 2011107188 declare that this dissertation is my own work, that has not been submitted for any other degree, at University of Free States, or any other University or any higher education institution, and that all resources that I have used or quoted are indicated in the text and acknowledged in the list of references

Signed…………………………………..

Date……………………………………..

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CHAPTER 1: INTRODUCTION

1.1 Background

Various species (fauna and flora) were introduced by humans from their natural localities to the new environments. Some of the introductions were purposeful while others were fortuitous (Turpie, 2009: 43). Several introduced species particularly plants escaped from their introduced environment and become neutralized in the region of introduction while posing impacts to the new environments and to the detriment of resident species (Stohlgren *et al.,* 1999a: 43; Sagoff, 2005: 172; Ehrenfeld, 2008: 1161). A few of the areas currently affected by alien invasion are riparian ecosystems within protected areas. Magee *et al.* (2010: 759) emphasized that exotic invading plants cause massive stress to ecosystems and are also signs of reduction in the integrity of ecosystems. The management of invasive alien (exotic) plants in protected areas, agricultural areas and riparian zones are some of the increasing challenges being faced by the protected areas and wildlife managers worldwide (de Wit *et al.,* 2001: 167; Heyda *et al.,* 2009: 398; Magee *et al.*, 2010: 761).

The impacts of invasive alien plants species in ecosystems is a growing concern globally (Beater *et al.,* 2008:496; Hladyz *et al.,* 2011: 444; Le Maitre *et al.*, 2000: 397). Thus focusing on riparian zones as important ecosystems, the invasive alien plants are a serious ecological concern (Stohlgren *et al.,* 1999b: 25; Richardson *et al.,* 2004: 44; Holmes *et al.,* 2008:539). In addition, the invasive alien plants are a threat to river ecosystems and have adverse impacts when not controlled. In fact, the management of many riparian zones in the world, particularly in Southern Africa is challenged due to increasing densities of invading exotic vegetation (Holmes *et al.,* 2005: 553; van Wilgen *et al.,* 2007: 711). Invasive plant species also known as non-native or exotic species are a threat to the integrity of the riparian ecosystems as they can result in ecological threats such as local extinction of resident species, alteration and degradation of riparian ecosystems which results in modification of natural habitats, land degradation as well as loss of agricultural productivity (Nel *et al.*, 2004: 53).

Exotic invading species also impact on ecosystem processes such as nutrient recycling (Ehrenfeld, 2003: 503). In addition, Holmes *et al.* (2008: 531) also emphasized that riparian zones are highly vulnerable to alien plant infestations. Many researchers such as Naiman and Decamps (1997: 621), Holmes *et al.* (2005: 553), Osawa *et al.* (2010: 95) and Stohlgren *et al.* (1999b: 114) have all defined riparian zones as boundaries between the stream and the terrestrial environments that provide various ecosystems services such as habitats, stabilization of riverbanks, filtration of sediments and nutrients.

In spite of these significant ecosystem services, these zones are relentlessly degraded by invasive alien plants particularly woody species (Holmes *et al.*, 2005: 553). Riparian ecosystems have high species diversity due to periodic flood events that devastate vegetation cover and create new ground for plant re-colonization thus creating diverse habitats (Stohlgren *et al.,* 1997:1064; Washitani & Miyawaki & 2004: 89). Despite the necessity to address the impact of alien invasive plants, challenges are usually experienced mainly because some protected areas lack adequate manpower to deal with invasive plant species management, for example, eradication of aggressive invaders.

Given their high importance, riparian ecosystems are increasingly becoming a priority for many conservation projects and efforts. However, little is known about the vulnerability of riparian zones to plant species invasions. For this reason, there is a growing anxiety about the impacts of invasive alien plants; hence there is a need of increasing efforts to manage invading (exotic) plant species (Le Maitre *et al.,* 2000: 397).

This study concentrated on the lower part of the Orange River that falls within the Tsau//Khaeb (Sperrgebiet) National Park. The Tsau//Khaeb (Sperrgebiet) National Park was proclaimed a protected area in 2008 (Ministry of Environment and Tourism, 2009: 34). The Lower Orange River is part of the Orange – Senqu River basin, one of the largest river basins in Southern Africa (Orange-Senqu Strategic Action Programme, 2012: 2).

The main aim of conservation authorities in protected areas and adjacent conservation areas is to conserve biotic diversity thus the existence of exotic invasive species in ecosystems is in conflict with the conservation objectives and needs to be tackled (Shapaka *et al.,* 2008: 19).

Although alien plants infestation is regarded as modest in Namibia, the Orange River is more under threat since it flows through the hyper-arid part of Southern Africa from its source in Lesotho through neighbouring South Africa collecting invasive alien plants propagules (O'Keeffe *et al.,* 1994: 39; Joubert, 2009: 397) and deposit them towards the rich- nutrient area towards the Orange River mouth. In general, the riverine vegetation of the lower Orange River is described by O' Keeffee *et al.* (1994: 39) and (Joubert, 2009: 398) as dense, almost impenetrable woody thicket dominated by the willow *Salix mucronata, Acacia karroo*, *Euclea pseudebenus, Rhus lancea* and *Rhus pendulina* that make up the canopy within the riparian zones of the Orange River.

Furthermore, invading exotic species such as *Prosopis* spp, *Nicotiana glauca, Ricinus communis* and *Datur*a spp are slowly colonizing habitats (Burke & Mannheimer, 2004: 29). Hence, it is practically evident that the density of invasive plants particularly the *Prosopis* spp in the lower Orange River and other parts of the river is flourishing. *Prosopis* spp is regarded as one of the worst invaders (Le Maitre *et al.,* 2000: 402). The main purpose of the Tsau/Khaeb (Sperrgebiet) National Park is to protect, manage and enhance conservation and socio-economic values along with placing the primary importance on the universally significant biodiversity of an area (Ministry of Environment and Tourism, 2009: 5).

The management plan of the Sperrgebiet National Park emphasizes the eradicate alien invasive species (fauna and flora) from the protected area (Ministry of Environment and Tourism, 2009: 30). Hence invasive alien plants present in the lower Orange River is clearly in conflict with the mission of the Tsau//Khaeb (Sperrgebiet) National Park. Additionally, alien invasive plants are rarely regarded as a serious problem in Namibia, although the problem of invading exotic plants were first emphasized in this arid country for the first time in 1984

(Shapaka *et al.,* 2008: 19; Henschel & Parr, 2010: 6). The adverse impacts of invasive alien plants in Namibia is generally considered to be comparatively modest, however, the relative slow increase of exotic plants in Namibia's arid environment poses an impact on ecosystem functioning well (Joubert, 2009: 387).

Consequently, there is a need for research to acknowledge the significant value of invasive exotic plants including those that have detrimental effects on biodiversity (Richardson & van Wilgen, 2004:48). This study therefore aimed at assessing the impacts of invading alien plants on the structure and composition of the resident riparian vegetation in the lower Orange River. A comparative study between the invaded and uninvaded plots are used to determine the potential impacts of invading alien plants as they provide valuable information for nature conservation and the management of the landscape (Heyda *et al.,* 2009: 364).

The study was carried out between Sendelingdrift and Hohenfels in the Tsau//Khaeb (Sperrgebiet) National Park, Namibia. The study established that invasive alien plant species contribute to the decrease in species diversity, richness and composition as well as structure of the native woody vegetation within the riparian communities. *Eucalyptus camaldulensis, Datura inoxia, Nicotiana glauca, Ricinus communis* and *Prosopis* spp were five of the invasive alien plants species recorded during this study.

1.2 Problem statement

The riparian ecosystem within the lower Orange River, like those in many parts worldwide is under threat from exotic invading plant species. Invasive alien plant species such as *Prosopis* spp, *Eucalyptus camaldulensis*, *Nicotiana glauca, Ricinus communis* and *Datura inoxia* have invaded the Hohenfels area within the lower Orange River, Tsau//Khaeb (Sperrgebiet) National Park. If the invasion is allowed to increase, it may lead to extinction of resident species and eventually alteration of habitats in this part of the park.

Stohlgren *et al.,* (1999a: 43) considered that protected areas are important area in terms of assessment of potential impacts of alien invasion due to their unspoiled ecosystems. The foremost purpose of the Tsau/Khaeb (Sperrgebiet) National Park is to safeguard, manage, maintain unique biodiversity of succulent karoo and enhance conservation and socio-economic values and to place primary importance on the universally significant biodiversity of an area (Ministry of Environment and Tourism, 2009: 5). Moreover, the Management Plan of the Sperrgebiet National Park emphasized on the eradication of alien invasive species (fauna and flora) from the protected area (Ministry of Environment and Tourism, 2009: 30). Like any other riparian zones, the lower Orange River riparian ecosystem has dynamic hydrology and opportunities for plant recruitments following flood events (Richardson *et al.,* 2005; 553). Thus it is also susceptible to biological invasions, particularly the invading alien woody vegetation. Therefore it is highly important to maintain the ecological integrity of the Orange River system in order to preserve the overall biodiversity of the Tsau//Khaeb (Sperrgebiet) National Park.

1.3 Research question

This study attempted to answer the following question:

What are the impacts of invasive alien plants on the structure and compositions of the indigenous riparian vegetation in the lower Orange River within the Tsau//Khaeb (Sperrgebiet) National Park?

1.4 Research aims and objectives

The main aim of the study was to assess the impacts of invasion on the vegetation composition and structure in the riparian zones of the lower Orange River, Tsau//Khaeb (Sperrgebiet) National Park- Namibia. It is hypothesized that alien plants invasion will gradually alter composition and structure of resident vegetation in the area. Hence, based on the above aim and hypothesis, the purpose of the study is summarized as follows:

To compare the vegetation composition and structure through a comparative study between alien invaded and uninvaded plots in order to determine the effect of invasion on indigenous riparian vegetation along the lower Orange River.

1.5 Relevance of this study to environmental management

Environmental management, according to Nel and Kotze (2009: 7) entails the involvement of environmental managers and agents of governments in planning, monitoring, and implementing of mechanisms for identifying threats to ensure that components of environments are utilized in a sustainable manner. In light of this definition, there is a strong link between the present study and environmental management as the researcher attempted to identify the potential impacts that invasive alien plants have on the environment specifically on ecological components. In addition, vegetation communities form part of the fundamental units of the life supporting systems and they are also regarded as the essential units of natural resources management (Strohbach, 2001: 93).

On a global scale, invading alien vegetation is among the principal environmental concerns that contribute to the loss of biological diversity, ecosystem deprivation and negatively impact on the delivering of ecosystem services worldwide as well as threatening sustainable utilization of ecosystem-derived benefits (van Wilgen *et al.*, 2001:146 - 147). It is also shown in the study of Heyda and Pysek (2006: 147) that transformation of vegetation communities through invasion of exotic plant species cause vital implications to riverine habitats for wildlife and may increase the risk of catastrophic perturbations. Exotic plant invasions also contribute substantial losses to animal and plant agricultural production (Prieur-Richard & Lavorel, 2000: 1).

This study attempts to link research findings to practical issues in terms of management of invasive plant species within the Tsau//Khaeb (Sperrgebiet) National Park. Furthermore, the study will contribute to the better understanding of the ecological impacts of invasive species and its importance in terms of prioritizing management efforts in the spheres of conservation within the Tsau//Khaeb (Sperrgebiet) National Park. The research will also help to set priorities for the control and eradication of exotic invading plants and allow the management of the Tsau//Khaeb (Sperrgebiet) National Park to predict the threat of future infestations.

Although this study did not look at potential socio-economic impacts such as invasive alien plants, it recommends further research on environmental impacts in order to develop an understanding of environmental effects of exotic invading plants as this will be used to quantify the economic impacts. However, the standard system to quantify the economic effects needs to be established because it does not currently exist (van Wilgen *et al.,* 2001: 150).

Furthermore, ensuring sound invasive alien vegetation management also requires effective environmental management, which can be made possible through the implementation of eradication mechanisms. In fact, all invasive alien plants controls are aimed at contributing towards biodiversity protection and enhancement of ecosystem services provision. Many species, particularly plants have been transferred intentionally for various purposes such as ornamental, shade, fuel production or unintentionally from their areas of origin and then become invasive in new territories. The reasons why some introduced species have proliferated are still not known (Turpie, 2009: 42).

Damage to ecosystems by invasive alien plants and the economic implications of this damage are also unknown due to high cost of exotic invasive species control. In addition, there is a lack of appreciation on the economic value of biological diversity and the impacts of biodiversity degradation. Miller and Spoolman (2009: 216) highlighted that the degradation of ecosystems is a very serious universal environmental concerns due to the significant economic and ecological services they provide. Ecosystem services are highly considerable to human-well-being (Richardson & van Wilgen, 2004: 48).

There is also a link between impact of invasive species and environmental change. In addition, owing to its potential to change ecosystems and habitats to the detriment of endemic biota, invading exotic species have huge significant socio-economic and environmental impacts such as decrease in agricultural productivity, reduced densities, species diversities of invertebrates (both aquatic and terrestrial), augmented soil erosion and sedimentation of river banks and catchment areas (Department of Environment Affairs and Tourism, 2008: 75). Although this study focused on the potential impacts of invasive alien plants in riparian vegetation, the findings will also be useful in the assessments of economic aspects and consequences of infestations. As well, in terms of eradication and ecological restoration, clearing of invasive alien plants, do create jobs and empower unemployed people.

CHAPTER 2: LITERARTURE REVIEW

2.1 Exotic plant invasion and riparian ecosystems

In essence, exotic plant invasion is the attacking, assaulting, encroaching and infringement of resident vegetation communities by alien plant species (Shea & Chesson, 2002: 171; Heyda & Pysek, 2006:144; Chatanga, 2007: 1). In terms of invasion ecology with particular reference to alien plants, species invasions refers to plant species that were relocated from their natural localities through anthropogenic means and become neutralized in new environment (van Wilgen *et al.,* 2001: 146, Washitani & Wiyawaki 2004: 90, Curtis & Mannheimer, 2005: 632; Foxcroft & Richardson, 2003:386).

According to Gregory *et al.,* (1991: 542) and Macfarlane (2013: 33), the invasion of ecosystems by certain exotic biota is well-documented as a key environmental problem and a threat to biological diversity. The severity of this threat is amplified by increasing level of human movement and transportation of goods (Prieur- Richard *et al.,* 2000: 2; de Wit *et al.,* 2001: 167; Turpie, 2009: 43; Curtis & Mannheimer, 2005: 633). Moreover, vulnerability of riparian ecosystem to alien invasion can also be aggravated by human-induced disturbances (Holmes *et al.,* 2005: 556). To effectively manage this threat, the impact of these species on ecosystems have to be fully investigated and understood as well as considering that introduction of invasive alien species has to be prevented in regions and protected areas.

In addition, Curtis and Mannheimer (2005: 632) indicated that alien plant species may be regarded invasive when it escapes from its point of introduction, and cause detrimental impacts to its new environment. It is suggested in various global reviews that worst the invaders negatively change ecosystems by using excessively resources such as water, light and nutrients. In addition, they also alter habitats and change disturbance regimes, such as flood, particularly in the riparian zones (Richardson & van Wilgen, 2004: 48). Also, exotic invading plant species do not only cause displacement and extinction of native species, but species such as *Eucalyptus* spp, *Prosopis* spp and *Pinus* spp do consume large volumes of valuable water (Curtis

& Mannheimer, 2005: 632; Marais & Wannenburgh, 2008:1; Holmes *et al.,* 2005: 553). Riparian zones are defined by Gregory *et al.* (1991: 540), Naiman & Dacamps (1997: 621) and Osawa *et al.* (2010: 95) as the ecotone, zone or boundary that includes a variety of environmental factors, ecological processes and vegetation communities between the aquatic and terrestrial ecosystems. The term riparian is derived from a Latin word *riparius*, which means "depending on the bank of the river" (Naiman & Decamps, 1997: 622). These interfaces consist of assortment of landforms, plant communities and habitats within a larger landscape. According to Sabo *et al.* (2005: 56) riparian zones are ecosystems of important conservation concern in the world that provide essential ecosystems services such as habitat provision to a variety of species, filtration of agricultural pollutants, and acts as buffer zones against flood and erosion (Table 1). This provision of these ecosystems can be negatively affected if the riparian zones are transformed by invading alien plants.

Table1. List and description of some of the ecosystem services provided by un-disturbed riparian vegetation derived from Chatanga (2007), Gordon (1998) and Heyda *et al.* (2009).

Ecosystem services	Description
Protecting water quality	riparian vegetation traps sediments, remove contaminants and encourage percolation
Providing habitats to many organisms	heterrogenous shurbs and trees provide food and shelter to many riparian and aquatic biota
Riverbank stabilization	Diverse riparian communities moderates soil moisture in riverbanks and streams and roots provide strength to soil profiles, enhancing the stability of the riverbank, and prevent erosion
Flood Attenuation	Riparian vegetation support follodplain storage due to back water effects and consequently decreased flood peaks
Detrital input	Leaves and twigs from resident riparian plants aerial cover are significant source of energy and habitats

In view of ecological services, riparian zones and rivers are incorporated in conservation areas with the aim to protect habitat, richness and diversity of species of the presented region (Sabo *et al.,* 2005:56). This is due to the reason that riparian zones throughout the world are infested with an increasing density and abundance of alien plants (Le Maitre *et al.,* 2000: 397; Beater *et al.,* 2008: 496; Henchel & Parr, 2010: 5; Orange-Senqu Strategic Action Programme, 2012: 7). According to Macfarlane (2013: 41), managers of conservation areas are concerned because of potential adverse impacts of exotic plants on resident plant species diversity and natural processes such as nutrient recycling.

Exotic plant invasions do alter the composition and structure of plant communities within the riparian ecosystems to the detriment of biodiversity conservation within the riparian zones worldwide (Le Maitre *et al.,* 2000: 397; Holmes *et al.,* 2005: 553; Heyda & Pysek, 2006: 144; van Wilgen *et al.,* 2007: 711), this constitutes implications in terms of management of wildlife and tourism specifically in protected areas. Hence, there is a significant urgent need for empirical investigations to determine the susceptibility of particular habitats to invasive alien plant infestation.

In support of the need of empirical research regarding invasive alien plant's impact on vegetation, Richardson *et al.* (2004: 44) emphasized that any alterations in plant communities will exert change in ecosystem functioning. Nonetheless, more recent researches has started to emerge on the impact of clearing invasive exotic plants in riparian ecosystems as well restoration of riparian zones degraded by invasive alien plants. Moreover, studies maintain that in order to allow timely response and possible eradication, it is important that new incursions of invasive species are detected as early as possible (Foxcroft, 2009: 4). Magee *et al.* (2009:759) testifies that non-native plant species have been associated with augmented threat of local extinction of rare indigenous vegetation. Conversely, Gordon (1998: 975) states that ecologists, environmentalists and landowners have started giving the impacts and features of non-native plant species an amplifying attention.

In light of this, Sagoff (2005: 230) argues that many ecologists are confused as they cannot explain which effects linked to alien species are detrimental and why. Thus, there is a need to increase knowledge and understanding on the proliferation and impacts of invasive alien plants.

A study by Hejda *et al.* (2009: 401) revealed that the impacts of infestations on vegetation structure depend on the identity of the invader such as invader height and canopy cover. Hence, canopy cover and height of woody vegetation are important variables in this study. Although systematic studies of the impact of exotic species on ecosystems have recently begun, these studies have increased knowledge and understanding of the scientists, but not for conservation managers (Richardson & van Wilgen, 2004:50). This has resulted in failure to implement the published journals for effective conservation actions. Therefore, there is a need of stakeholder's involvement in terms of implementing conservation efforts and make informed decisions (Cosquer *et al.,* 2012: 56)

According to van Wilgen *et al.* (2001: 147) many studies on plant invasions focused more on the ecology and management of invasive alien plants and failed to include the economic aspects and consequences of infestation. Thus, more studies are required to investigate the economic impacts and consequences of plant invasions. Furthermore, a study conducted by Beater *et al.* (2008: 502) in Savanna and Grassland Biomes revealed that an increase in alien canopy cover has led to significant decrease in native aerial woody species cover as well as ground cover vegetation.

In a study conducted on the lower Kuiseb River by Henschel and Parr (2010: 11), they found a high intensity of invasive exotic plants within the riparian zones. All these empirical evidence are explicit indications that riparian vegetation are vulnerable to invasive alien infestations. Moreover, exotic plants infestations pose a significant threat to biodiversity by replacing indigenous vegetation (Stohlgren *et al.,* 1999b: 25; Washitani & Miyawaki, 2004: 89; Chatanga, 2007:2). However they also have some good uses, thus they were introduced (Henschel & Parr, 2010: 5).

The alterations to the vegetation will persuade local extinctions of native species, as well as habitat transformation (Richardson & Wilgen, 2004: 45), thus will also have effects on ecosystem processes and functions. Generally as emphasized by Shapaka *et al*. (2008:20) and Joubert (2009: 386), Namibia through its Ministry of Environment and Tourism need to revive its commitment in terms of exotic alien control and research. Studies conducted have also documented the change in density and composition of resident vegetation. Richardson and van Wilgen (2004: 48) indicated that communities dominated by indigenous *Acacia* species are being altered by exotic *Prosopis* spp in arid savannas. Alien invasive plants particularly trees, cause a significant universal alterations, usually encouraging change in indigenous species composition and ecosystem structure (Magee *et al.,* 2010: 759).

Hejda *et al.* (2009: 394) compared impact invasive plants on species richness, diversity and composition between two plots (invaded and un-invaded plots) in the riparian zones. The investigation revealed that a low number of exotic plants in invaded plots do not induce alteration in vegetation structure and composition. A number of studies have recognized a variety of impacts of a given exotic plants species on vegetation communities, surface water resources and delivery of ecosystem goods and services (Le Maitre *et al.,* 397; Richardson & van Wilgen, 2004:48; Heyda *et al.,* 2009:397; Henschel & Parr, 2010: 5; Hladyz *et al.,* 2011:452).

The study of Hejda and Pysek (2006: 143) also revealed that the invasive exotic plant *Impatiens glandulifera* has modest impacts on the characteristic of riparian communities. Joubert (2009: 399) narrated that although impacts of invasive alien plant in Namibia exerts negligible pressure on ecosystem the impacts on populations, communities and ecosystem processes in Namibia are not directly quantified. Richardson *et al.* (2007: 130) accentuates that certain plant species transform vegetation composition and may increase fire frequency that may lead to demise of native riparian vegetation. Most of the studies on impacts of invasive alien plants on riparian zones have been carried out in South Africa, but little work has been conducted in Namibia (Shapaka *et al.,* 2008: 20; Joubert, 2009: 339).

According to Bethune *et al.* (2004: 23), the problem of alien plants was first highlighted in Namibia in 1984. Curtis & Mannheimer (2005: 632) had also stated that various exotic plant species that are problematic in South Africa occur also in Namibia, however at a limited scale. In South Africa, most empirical investigations on the impact of invasive alien plant on vegetation communities were conducted in the Fynbos biome (Richardson & van Wilgen, 2004: 48). Most of this work focuses on evaluating the effectiveness of invasive alien plant clearing and on the impacts of invasive alien plants on surface water yield (Holmes *et al.,* 2008)

It is well documented that invasive exotic species specifically trees usually consume more water in relation to indigenous plants and also adversely modify ecosystem structure and functions, and affect the delivery of ecosystem services (Richardson & Wilgen, 2004: 45; Holmes *et al.,* 2008: 532). In addition, riparian zones are increasingly becoming a major focus in the management and restoration at a landscape level in order to improve water quality and conserve wildlife populations (Froxcroft & Richardson, 2003: 386; Holmes *et al.,* 2005: 553). However, the restoration of resident vegetation and the eradication of aggressive invaders are not ecologically and economically easy (Fleishman *et al.,* 2003: 484). Interestingly, Holmes *et al.* (2005: 554) had also linked the current anthropogenic-induced climate change to alien invasion, by indicating that climate change may increase vulnerability of riparian communities to alien infestation.

It is predicted that floods and droughts events may be augmented as a result of climate change (Holmes *et al.,* 2005: 554). The problem of invasive alien plants in Namibia is considered comparatively not intense and therefore the relative slow growth of invasive alien plants is not regarded a conservation priority in Namibia (Bethune *et al.*, 2004: 12). However as indicated by Joubert (2009: 397) and the Orange-Senqu Strategic Action Programme (2012: 7) that the Orange River is more under threat of the exotic plant invasion (specifically a number of woody plants). Hence, there is a significant need for empirical investigations on this part of the river.

Namibia, with its low population density has few researchers committed to environmental research with particular reference to plant invasions (Bethune *et al.,* 2004: 17; Shapaka *et al.,* 2008: 20, Joubert, 2009:387) and not on the significant impacts. Curtis and Mannheimer (2005: 632) felt that species such as *Eucalyptus camaldulensis* are not a threat to Namibia. However, there is no study that measured the impacts of these species particularly in watercourses and riverbanks in Namibia particularly the Orange River. Studies conducted in Namibia largely focused on the distribution of invasive alien plants (e.g. Burke & Mannheimer, 2004: 79; Shapaka *et al.,* 2008:19, Henschel & Parr, 2010: 5).

The neighboring country, South Africa has a remarkable Working for Water Programme that was initiated in 1995 to primarily control the proliferation of invasive alien plants in order to maintain and restore natural ecosystems (Le Maitre *et al.,* 2000: 397; Marais & Wannenburgh, 2008: 11). Beater *et al.* (2008: 495) evaluated the effectiveness of Working for Water alien clearing projects and established that clearing decrease dramatically the canopy cover of invading species. With particular reference to protected areas management, the Kruger National Park has also developed and improved the management system known as strategic adaptive management which acknowledges the Potential of Thresholds Concern (TPC) in terms of invasive alien species (Froxcroft, 2001: 5; Foxcroft, 2009: 1).

Namibia needs to draw from the wealth of experience in South Africa and elsewhere in the world to fight against alien plants invasions (Joubert, 2009: 398) specifically from the Working for Water Programme and the Kruger management system above-stated. In terms of eradication and ecological restoration, clearing of invasive alien plants, do create jobs and empower unemployed people (Marais & Wannenburgh, 2008: 1), however, it is an expensive exercise that can go wrong if not well planned. In the evaluation of Working for Water clearing projects, Beater *et al.* (2008: 496) and Magee *et al.* (2010: 759) estimated that the cost of clearing of invasive alien species amounts approximately to R 1.6 billion per year.

Although the Constitution of the Republic of Namibia (Ministry of Information and Broadcasting, 2007: 42) have emphasized that ecosystems, important ecological processes and biodiversity of Namibia should be maintained, there is a gap in terms of legislation, as there is no enacted legislative tool specifically referring to invasive alien plants in Namibia (Joubert, 2009: 401). Therefore, it is valuable to introduce new legislation that clearly deals with invasive alien plants, particularly now that the impacts of climate change may increase the density of exotic species in arid and semi-arid environments.

2.2 Origin and brief description of recorded alien plant species

2.2.1 Eucalyptus camaldulensis

Eucalyptus camaldulensis commonly known as Australian wattle or gum tree is one of the 300 species of *Eucalyptus* that were introduced to Southern Africa from Australia for the purpose of timber, firewood production and ornamental purposes (Palgrave, 2002: 839). It is a tall tree that reach over 8 meter high and invades river banks, perennial and dry channels. The leaves are dull green, with reddish petiole and about 12-20 cm long (Figure 1). According to Curtis and Mannheimer (2005: 633), *Eucalyptus* spp is not a problem tree in Namibia though it impact seriously on water courses; however Palgrave (2002: 839) indicated that it invades riverbanks in South Africa.

In addition, Curtis and Mannheimer (2005: 633) indicated that *Eucalyptus* spp in Namibia was planted several years ago on farms and gardens but they are not neutralized.

2.2.2 Prosopis spp

In Namibia, there are three species that represent genus *Prosopis* namely *Prosopis glandulosa*, *P. chilensis* and *P. velutina,* and they can hybridize, making taxonomic identification difficult (Joubert, 2009: 385). Due to taxonomic confusion of genus *Prosopis* caused by hybridization, for the purpose of this study, all *Prosopis* was just referred to as *Prosopis* spp. The species is a shrub, a multi-stemmed tree or a large canopy spreading tree with a height between 15-20 m (Figure 1). *Prosopis* spp was introduced in Southern Africa from southwestern of USA mainly for fodder, shade and wood production (Palgrave, 2002: 305; Curtis & Mannheimer, 2005: 634). However, the species escaped out of its introduced area, and it now aggressively invading arid areas in Namiba and considerable areas in South Africa. All the three species of *Prosopis* are declared major invaders in South African biomes (Palgrave, 2002: 305; Nel *et al.,* 2004:56).

(a)  (b) 

Figure 1. *Prosopis* spp, (a) and *Eucalyptus camaldulensis* (b) one of the exotic invaders in invaded sites (picture: K. Shilongo, August 2013)

2.2.3 *Ricinus communis*

Ricinus communis also known as Caster-oil bush belongs to the family of Euphorbiaceae (Joubert, 2009: 391) and was introduced from tropical Africa for ornamental purposes. It is a shrub or a small tree up to 3.5 m tall that favours disturbed area, dumpsites, roadsides and river banks.

Its leaves are deadly noxious and the seed contains a deleterious and highly toxic coat (Curtis & Mannheimer, 2005: 638).

2.2.4 *Nicotiana glauca*

According to Curtis and Mannheimer (2005: 642), *Nicotiana glauca* which was introduced from Argentina (for ornamental purposes) is not considered a major threat in Namibia, however this alien plant is worth for empirical investigation to assess its impacts on indigenous species. It is also declared as a weed in South Africa.

2.2.5 *Datura* spp

Datura spp is represented by three species in Namibia, namely *Datura felox, Datura inoxia* and *Datura stramonium*. It originates in North and Central America and it is now invading areas along watercourses, around dams and riverbanks. The species are also not considered a problem in Namibia as reported by Curtis and Mannheimer (2005: 643).

2.3 Characteristics of invading exotic plant species

Exotic plants such *Eucalyptus camaldulensis* have vigorous growth, high canopy and are much taller than native species (Palgrave, 2002: 839) and they utilize groundwater and other resources such as nutrients and light at the expense of native species (Naiman & Decamps, 1997:627). Also they may easily invade areas of low species diversity than areas of high diversity (Stohlgren *et al.,* 1998: 113). Invading species such as *Nicotiana glauca, Datura inoxia* and *Ricinus communis* have short infantile period, constant reproduction and speedy population growth (Rejmanek & Richardson, 1996: 1685).

Flood events encourage high species richness, thus responsible for promoting vulnerability of riparian zones to invasion thereby creating a mosaic of micro-habitats through decreasing strength of competition (Gregory - Hood & Naiman, 2000: 105; Osawa & Mitsuhashi, 2010: 95).

CHAPTER 3: STUDY AREA

3.1 Location

Namibia is a big country, covering an area of about 823,680 km^2 (Mendelssohn *et al.,* 2009: 8). The government through the Ministry of Environment and Tourism run 21 protected areas, covering an area of 135906.29 km^2 (Directorate of Parks and Wildlife Management, 2010: 16). Tsau//Khaeb (Sperrgebiet) National Park is situated in the south-western corner of Namibia, numbered 17 in Figure 2.

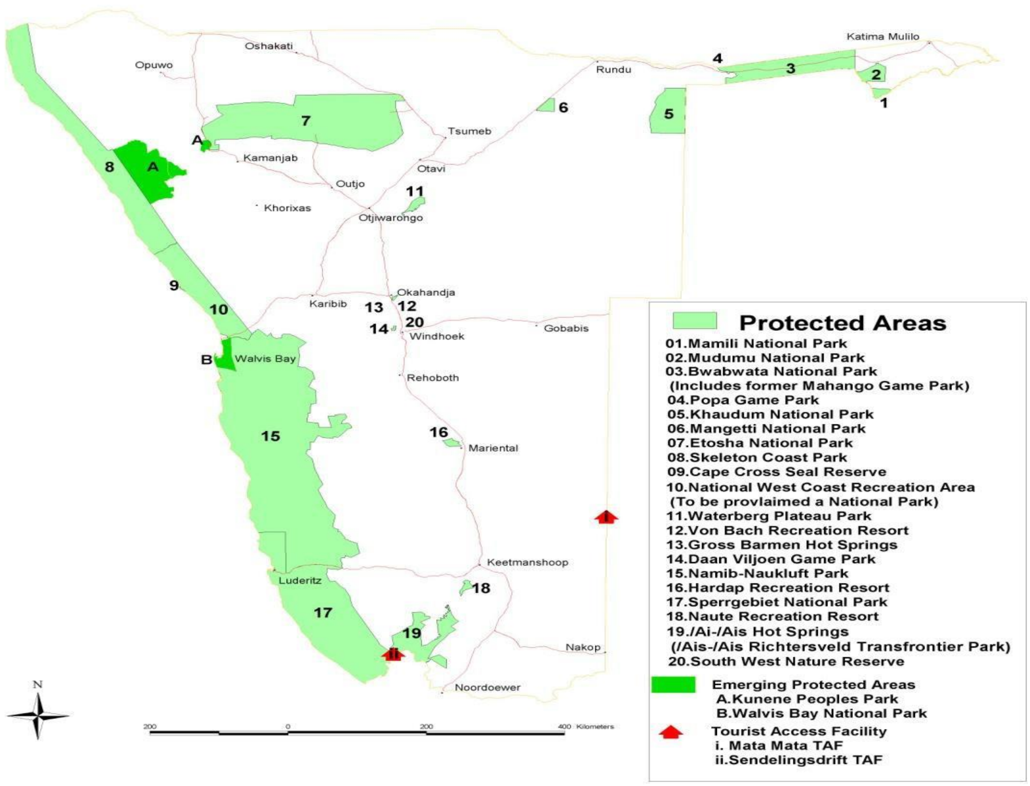

Figure 2: Location of the Tsau//Khaeb (Sperrgebiet) National Park in Namibia (Ministry of Environment and Tourism, 2009).

The Tsau//Khaeb (Sperrgebiet) National Park, a relatively new protected area in Nambia, was proclaimed in December 2008. To the west, this protected area is bounded by lower water mark on the Atlantic Ocean and the Orange River in the south with the Namib Naukluft Park in the west and commercial farmlands in the east (Ministry of Environment and Tourism, 2009: 6) and as well located within the Succulent Karoo Biome (Figure 3). The park occupies the region of 26^0 and 28.5^0 S and 13^0 and 17^0 E and it is 2.1 million *ha*.

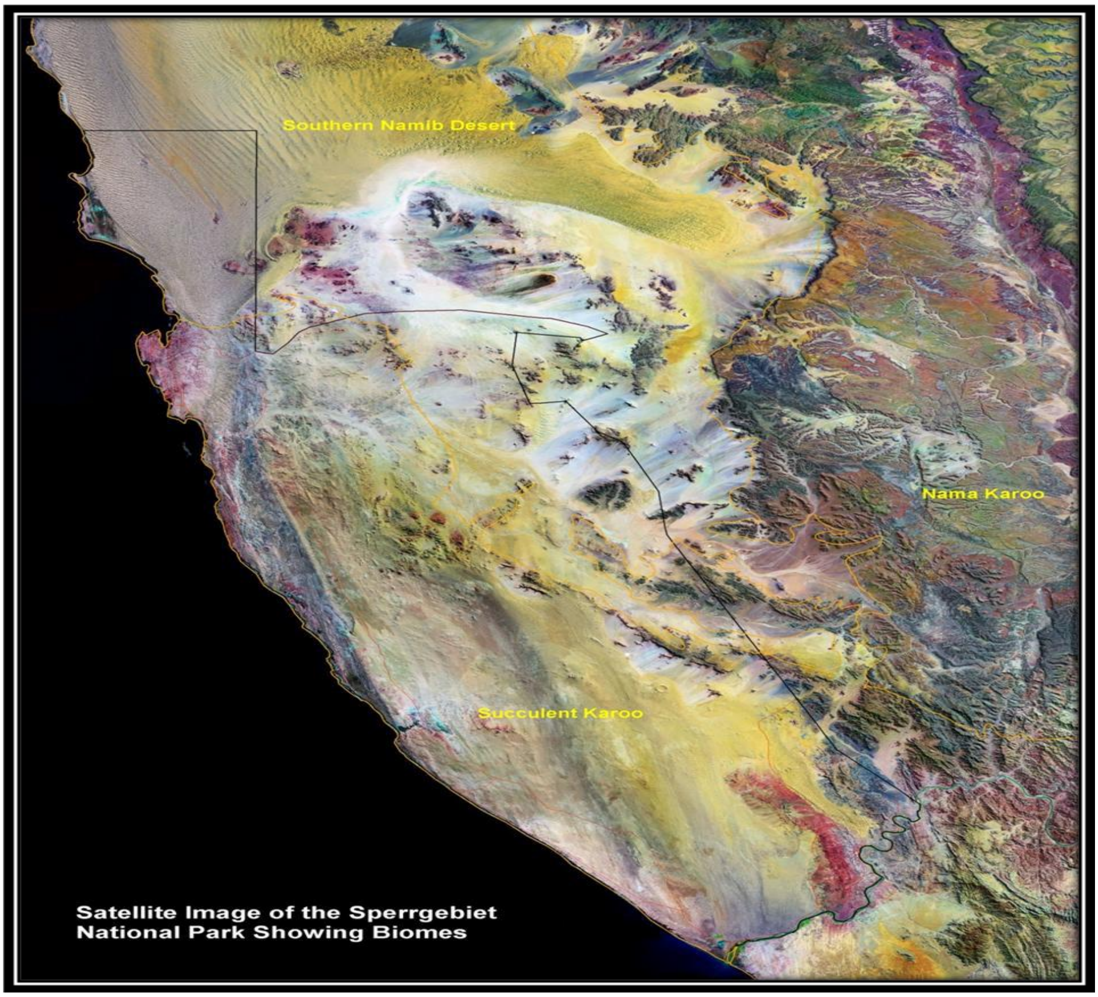

Figure 3: Satellite image of the Tsau//Khaeb (Sperrgebiet) National Park (Source, Ministry of Environment and Tourism, 2009).

The main landscape within the park consists of sandy and rocky coastal plains, sandy and gravels inland plains, mountain ranges, inselbergs, and the Orange River valley, including a highly transformed river system (Ministry of Environment and Tourism, 2009: 11).

Figure 4. The lower Orange River- Sperrgebiet portion (source: Google map, January 2014)

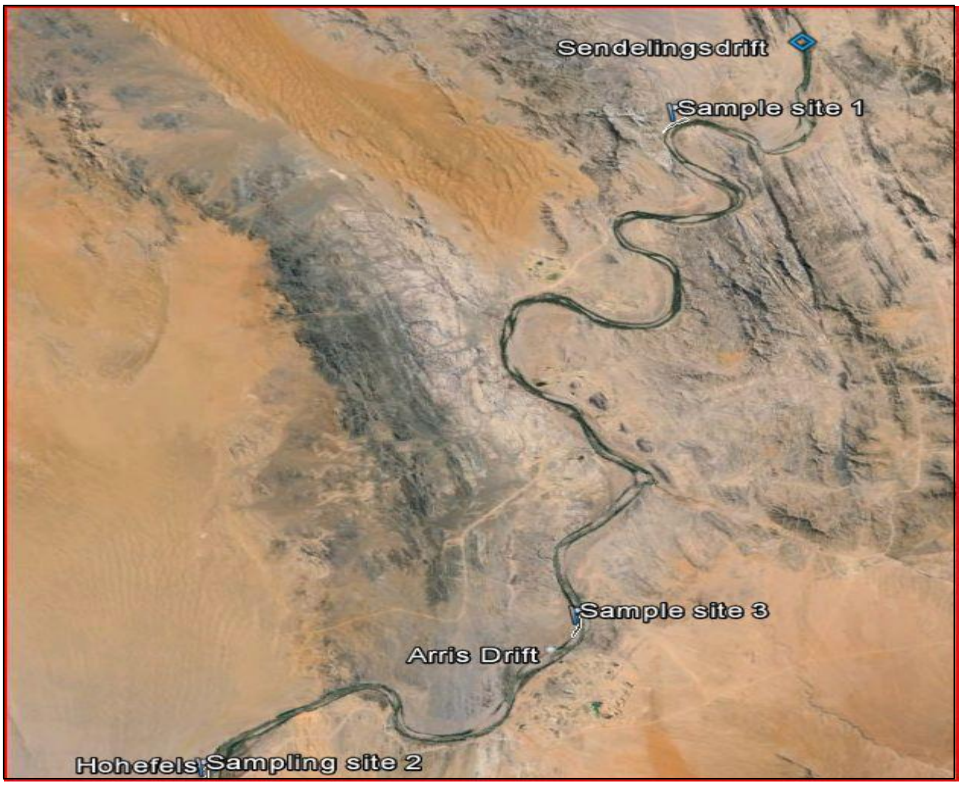

Figure 5. Sampling sites (source: google map: January 2014).

The study was carried out in the riparian zone in the lower Orange River between Sendelingdrift Tourism Access point and Hohenfels campsite within the Tsau//Khaeb (Sperrgebiet) National Park in Namibia (Figure 4). Invaded sites are located between Hohenfels and Swartkops, while uninvaded sites are located between Sendelingdrift and Arrisdrift (Figure 5).

3.2 Land-use

Various stakeholders have independently made plans to use the Sperrgebiet in different ways. Irrigation from the Orange River is considered to enhance the agricultural potential of at least a small piece of the area. However, potential land-users have not considered that access was denied to this large area only to serve the buffer zone of the rich coastal diamond mining areas, where diamond mining has been the major land-use in this area since 1908 (Pallet, 1995: 3).

The land-use plan was commissioned in 2001 to determine the future use of the Sperrgebiet, after diamond mining showed signs of scaling down (Ministry of Environment and Tourism, 2009: 15). Mining makes only up a small proportion of the area, covering about 30% of the entire park. It was concluded that the area be proclaimed a national park. In addition, following its proclamation in December 2008, although diamond mining is being carried out; conservation and tourism will be the main activities in the area.

The Orange River and its tributaries provide water to human, industries, agriculture and wildlife, making it one of the most important rivers in Southern Africa (Pallet, 1995:14). Mining and prospecting activities will continue, however, conservation and tourism are the principal future land-uses of the area. Furthermore, Pallet (1995: 3) emphasized that the integrated land use planning must take place in order to utilize the land in the Tsau//Khaeb (Sperrgebiet) National Park more effectively.

3.3 Vegetation

With regard to vegetation, the entire Tsau//Khaeb (Sperrgebiet) National Park falls within the succulent Karoo Biome which is one of biodiversity hotspots in the world (Burke, 2005: 4; Ministry of Environment and Tourism, 2009: 11). The Tsau//Khaeb (Sperrgebiet) National Park consists of a variety of vegetation types, and it supports a rich, diverse vegetation dominated by succulents, most of them are endemic to the succulent Karoo (Pallet, 1995:7).

However, for the purpose of this study, only the vegetation of the lower Orange River particularly the riparian zones are described. The area between Sendelingdrift and Hohenfels, where the study was carried out, is part of the lower leaches of the Orange River that runs through a hyper-arid part of Southern Africa (O'Keeffe *et al.,* 1994:39, Pallet, 1995:46).

The area covers approximately 80 km of a linear strip consisting of riparian properties. According to Pallet (1995: 14), the Orange River valley, is one of the three areas in the Tsau//Khaeb (Sperrgebiet) National Park that is highly sensitive to developments due to its habitat type and geographical location. Generally, the riparian vegetation within the study area can be described as dense, roughly impassable woody thicket dominated by the willow, *Salix mucronata*.

The growth of smaller herbaceous species is limited due to dense growth which results in competition for light, space and nutrients (O'Keeffe *et al.,* 1994: 39). The area is also part of the Orange-Senqu River Basin (Figure 6), the 10^{th} largest river basin in Africa to the south of the Zambezi, covering an area of approximately 0.9 million km^2 according to the Orange-Senqu Strategic Action Programme (2012: 3).

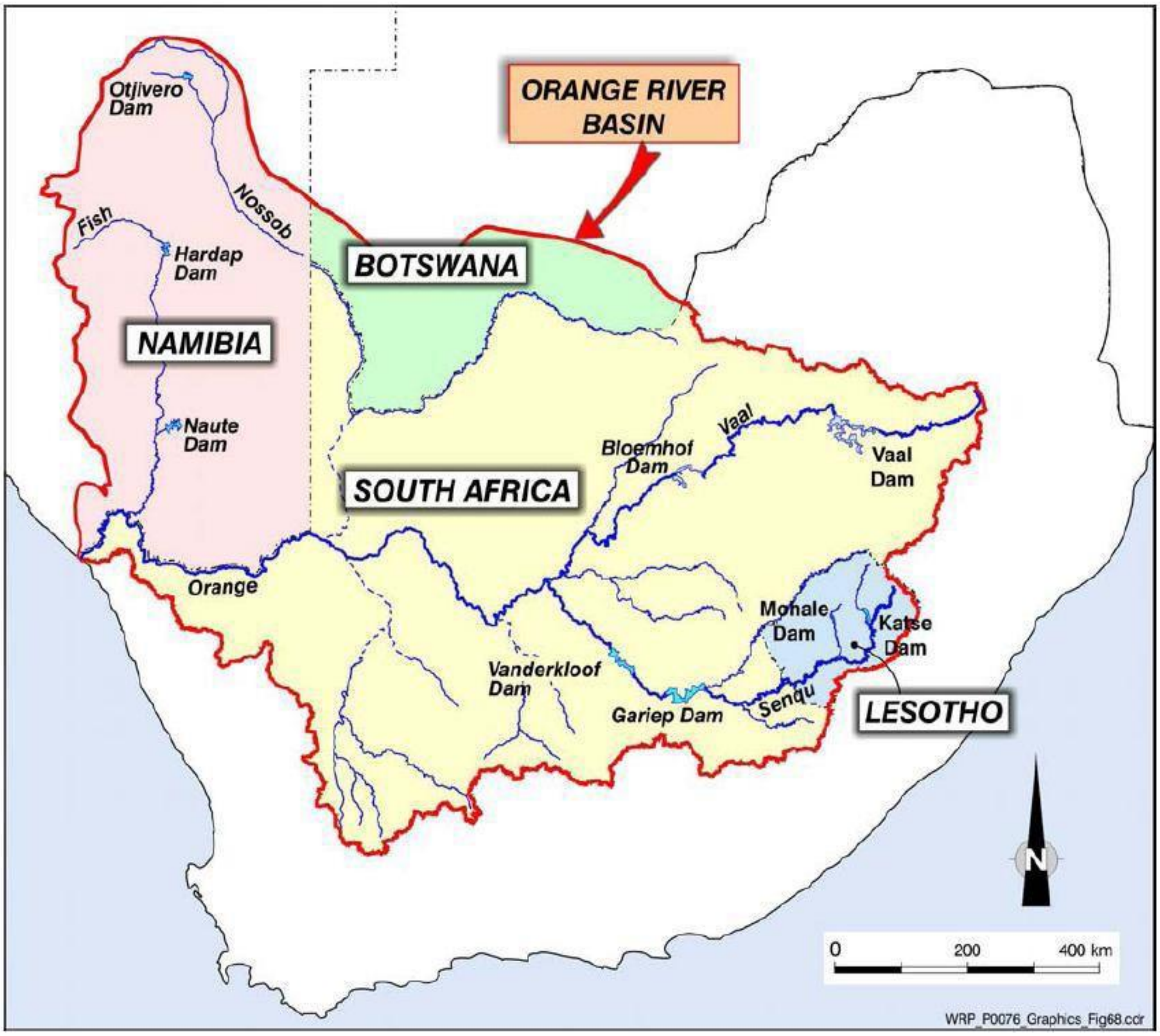

Figure 6. Orange-Senqu river basin (Source: Macfarlane, 2013).

Furthermore, according to Bezuidenhout and Jardine (2001: 1), and Burke (2006: 74) and Joubert (2009: 385), riverine forest and shrubland occurred along the lower Orange River and vegetation is characterized by *Rhus pendulina*, *Tamarix usneodes*, *Acacia karoo, Salix mucronata, Ziziphus mucronata* that make up the canopy of the river banks. Apart from indigenous plant species, the Orange River is also invaded by exotic invaders such as *Datura inoxia, Datura stramnium, Ricinus communis, Prosopis* spp, *Nicotiana glauca* and *Eucalyptus camaldulensis* (Bezuidenhout & Jardine, 2001: 4; Palgrave, 2002: 578; Burke & Mannheimer, 2004: 82; Joubert, 2009: 385). River banks appear to be stable with dead wood and brushing contributing to this stability.

Moreover, the linear oasis of the lower Orange River supports dense riverine woodland upstream from the river mouth. The Orange River, according to Orange-Senqu Strategic Action Programme (2012:21), is the most turbid river in Africa, whereby the Orange River mouth is a wetland of global significance (Ministry of Environment and Tourism, 2009: 15).

3.4 Climate

The whole Tsau//Khaeb (Sperrgebiet) National Park including the lower Orange valley falls within the winter rainfall area with a mean annual precipitation of less than 100 mm per year. Rainfall in this area varies greatly from year to year and from place to place within the Tsau//Khaeb (Sperrgebiet) National Park (Pallet, 1995: 38). With particular reference to the lower Orange River zone, the walls of the Orange River are moistened by a fog which regularly moves up the river (Ministry of Environment and Tourism (2009:17).

Pallet (1995: 17) further indicated that the climate of the area is dominated by strong south winds, limited winter rainfall and precipitation from fog that forms along the coast of the Atlantic Ocean. The Tsau //Khaeb (Sperrgebiet) falls within the southern sector of the Namib Desert and it is dominated by strong southerly winds in summer and short east winds in winter. Inland temperatures can be extreme, however high temperatures expected of a desert environment are moderated by the coastal winds and fog.

CHAPTER 4: METHODOLOGY

4.1 Data collection (vegetation sampling)

Vegetation sampling was conducted at two sites within the study area between June and September 2013. This was a once off sampling, and the sampling sites (invaded and uninvaded sites) are similar in terms of rainfall, temperatures and wind intensity (Pallet, 1995: 37). The only area transformed by invasive alien plants in the riparian zones of the lower Orange River within the Tsau//Khaeb (Sperrgebiet) National Park is the Hohenfels area (Ministry of Environment and Tourism, 2009: 10). Hohenfels area was used as an invaded site and the un-invaded site was randomly selected within the riverine forest for a comparative study.

Site 1: Sendelingdrift is not invaded by alien plants, and it was used as a reference site (uninvaded). Site 2: Hohenfels is highly invaded and transformed by various exotic species such as *Nicotiana glauca, Rinus communis*, *Prosopis* spp, *Datura inoxia* and *Eucalyptus camaldulensis* therefore used as an invaded site. Assessment of significant impacts of exotic invading plant species on vegetation communities by using comparative studies of invaded and uninvaded plots can help identify prospective impacts of exotic alien species and provide valuable information in terms of landscape management and biodiversity conservation (Heyda *et al.,* 2009: 394).

Three standard plots measuring 20 m x 50 m were placed with the long axis to the riverine vegetation in each site (Figure 7). These plots were randomly established from the water's edge inland in each study site, depending on the accessibility of the dense vegetation in places.

A 50 m tape was placed along the centerline and a 20 m tape was used across the main tape to divide the plot in 10 subplots, each measuring 10 m x 10 m. This represents a total of 30 subplots in each site. This method was also used by Heyda *et al.* (2009: 399) when they measured the impact of *Impatiens glandulifera* on species diversity of invaded riparian vegetation. Due to almost impenetrable properties of this riparian area, this method was found more suitable for the purpose of this study.

The taxonomic identification of all woody vegetation including seedlings, in each sampling plot was recorded. In terms of invasive alien vegetation, invasive herbs such as *Datura inoxia*, and *Ricinus communis* were also recorded. Furthermore, to assess the impacts of invading plant species on riparian resident communities, the following variables were evaluated and measured in each plot: number and abundance of alien invading plants, species richness, resident species and invader's height (m), length at a foliar level (canopy cover [m]) and stem width (m).

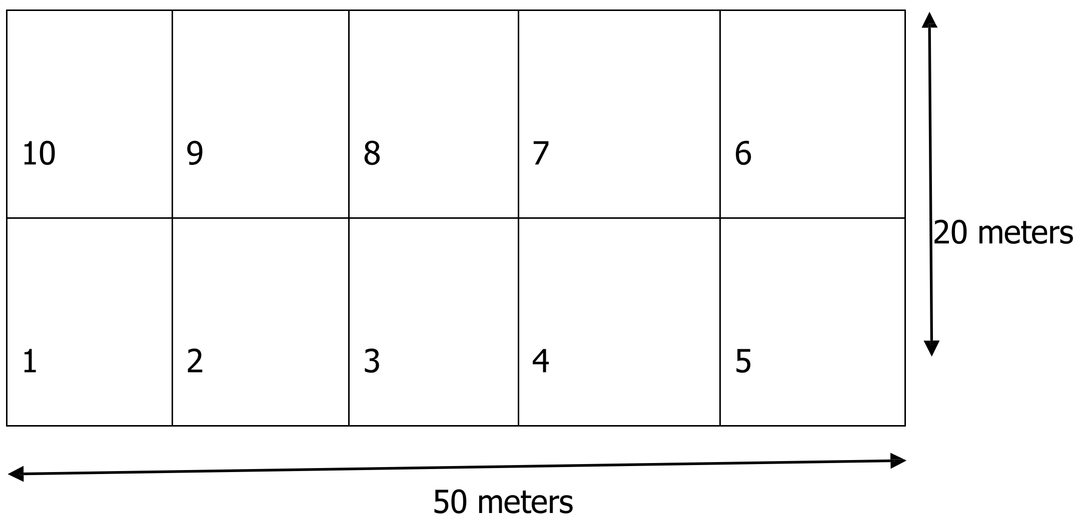

Figure 7. Standard 50 m x 20 m standard plot and a set of 10 subplots.

These plot sizes were adopted from Peet *et al.* (1997: 7) whereby a standard 50 m x 20 m plot was used. All woody plant species observed in each plot were identified using the Trees of Southern Africa field guide and the Trees Atlas of Namibia by Palgrave (2002) and, Curtis and Mannheimer (2005) respectively. The height and canopy cover were estimated by using a 2 m measuring pole, whilst the stem width was measured by using a measuring type.

Height is described as the vertical length from the ground to the highest part of the plant (Chatanga, 2007: 32); this is the part of the plant which was measured in terms of plant height. Only the height of the tallest plant was measured in case of multi-stemmed plants.

4.2 Data management and Data Analysis

A data entry template was created in Microsoft Excel where all the collected data were entered (Appendix 1). The data captured was then exported to the Statistical Package for the Social Sciences (SPSS) for cleaning and analysis. The frequency procedure was used to clean categorical data whilst the explore procedure was applied to continuous data. Since the variables analyzed in the study included continuous and categorical variables, methods which suit the data types were employed accordingly.

For categorical data, the frequency procedure was used to show the number and proportion of study subjects falling in a particular category. This was applicable to characterize the plant species whether they were from the invaded or un-invaded sites. The graphical technique was also used to pictorially depict the study findings. The Levenes' test for the equality of variances was used to test if variances were equal. This was performed concurrently with the t-test for the equality of means, all tested at the 5% significance level. A t-test was used to compare the height, stem width of resident and exotic invaders of two study sites. According to Ashcroft and Perreira (2003: 43), the t-test is helpful in testing for significance between results collected from two investigational conditions.

The Shannon Index formula ($H^1 = {}^{\Sigma}pi1npi$) was used to determine species diversity and richness, as well as mean for all the measured variables. P*i* in this equation represents the proportion of plant species, whilst i and 1n represent natural logarithm (Chatanga, 2007: 36). The following formula was used to determine the density (abundance) of plant species in each study site:

$$\% \text{ of abundance} = \frac{\text{Number of plants per species}}{\text{Number of plants per site}} \times 100$$

This formula is derived from Chatanga (2007:30).

Variables investigated are invasive alien plant abundance (%), resident species abundance (%), aerial canopy cover (m), height (m) and breadth (m) of both exotic invaders and native species. The results were formulated in tables and graphs to depict correlation and differences between the invaded and un-invaded categories.

CHAPTER 5: RESULTS

5.1 Species richness

A total number of 625 plants were recorded for the two sampling sites (study sites) of which is 60% of the plant species were recorded in the invaded site, and 40% were recorded in the un-invaded site (Table 2). The un-invaded category had the highest record of species richness with a total record of 13 plant species, while the 9 species were recorded in the invaded area. The most common exotic invader recorded are *Datura innoxia, Eucalyptus camaldulensis, Nicotiana glauca, Prosopis* spp and *Ricinus communis*. The least recorded native woody species was *Lycium bosiifolium* and it was only recorded in the un-invaded category (Table 2).

Table 2. Number of indigenous woody species and invasive alien plants (woody and forbs marked with an asterisk), species richness and diversity recorded at each sampling site.

Species	Invaded		Uninvaded	
	(n=90)	%	(n=90)	%
Acacia karoo	20	5	27	11
*Datura inoxia**	45	12	6	2
Diospyros lycoides	14	4	6	2
*Eucalyptus camaldulensis**	122	33	0	0
Euclea pseudebenus	0	0	37	15
Lycium bosiifolium	0	0	12	5
*Nicotiana glauca**	41	11	3	1
*Prosopis spp**	53	14	1	1
*Ricinus communis**	43	12	5	2
Salix mucronata	0	0	20	8
Searsia pendulina	8	2	23	9
Sisyndite spartea	0	0	59	23
Tamarix usnoides	26	7	36	14
Ziziphus mucronata	0	0	18	7
Total	372	100	253	100
Total % of plants counted	60		40	
Mean	4			
Species richness	9			
Shannon diversity Index	1.94		2.22	
code n= number of subpots				
code* = invasive alien plants				

The mean of species richness also varied noticeably between two sampling sites, with the mean species richness of the invaded area of 4 whilst the un-invaded grouping recorded 3. Strong evidence existed depicting that high density of alien plants influenced the density and richness of native vegetation at a site level (Figure 7).

5.2 Species diversity

Species diversity differs greatly between the invaded and uninvaded sites as revealed by Shannon diversity Index (Table 2). The uninvaded sites had the highest diversity of 2.22 than the invaded sites which had 1.94.

5.3 Species composition

In terms of species composition, *Eucalyptus camaldulensis* is the most common invader in the invaded area covering 33% followed by *Prosopis* spp and *Datura inoxia* covering about 12% each.

Eucalyptus camaldulensis has also formed homogenous stands at the invaded site as shown in Figure 6. The least exotic plant species recorded in an invaded area was *Nicotiana glauca* which makes up 11% of abundance. *Ricinus communis*, *Datura inoxia* and *Nicotiana glauca* were also present in the un-invaded site; contributing about 2% and 1% respectively (Table 2).

Salix mucronata which is the most dominant woody species along the river banks (O'Keeffe *et al.,* 1994: 39) is absent from the invaded category, however it forms 8% in the un-invaded plots. The most common indigenous species recorded in the un-invaded site is *Sisysndite spartea* covering 23%. The results further showed that the abundance of both *Euclea pseubedenus and Acacia karoo* are relatively high, each forming 15% and 11% respectively.

Figure 8. The homogenous stand of *Eucalyptus camaldulensis* at the invaded category in the riparian zones of the lower Orange River, Tsau//Khaeb (Sperrgebiet) National Park (Picture: K. Shilongo, September 2013).

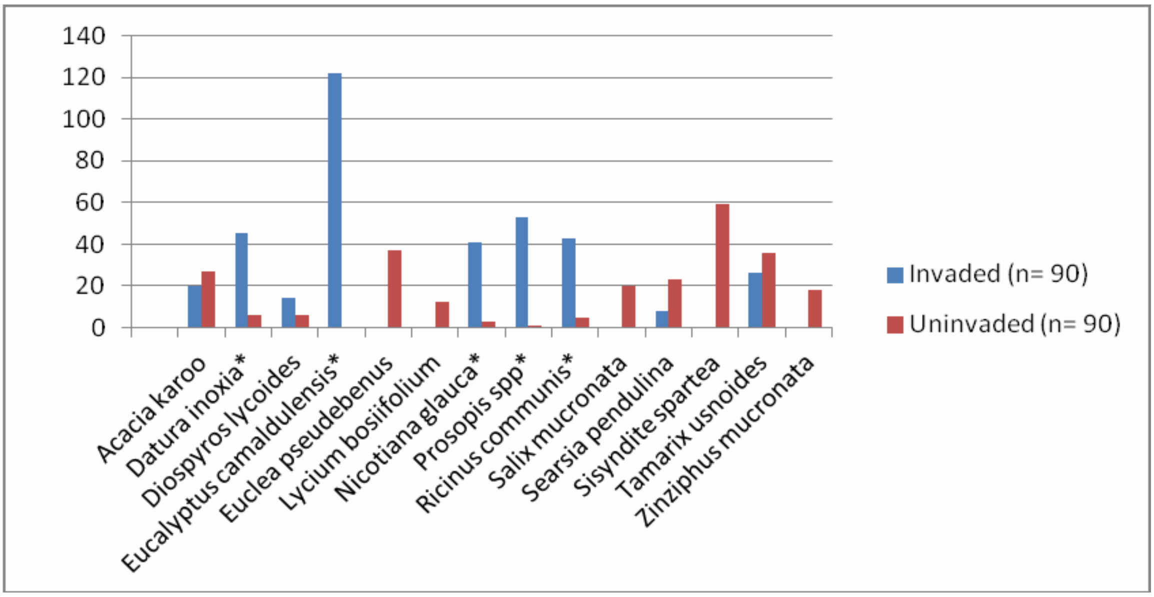

Figure 9. Number of indigenous woody species and exotic (woody and forbs marked with *) in the lower Orange River within the Tsau//Khaeb (Sperrgebiet) National Park.

The native species with low abundance in un-invaded site are *Lycium bosiifolium* and *Diospyros lycoides* each forming up about 1% and 2% of density respectively (Table 2). Moreover, other species such as *Tamarix usnoides* and *Searsia pendulina* occurred in both sites. In the invaded site, *Tamarix usnoides* forms up to 7% of abundance, and it has the third highest formation in the un-invaded site with 14% of abundance. The results of this study also showed that *Ricinus Communis* exhibit negligible impacts on the composition and structure of the studied area.

5.4 Vegetation structure

Presented in Appendix 2 and Table 3 are the descriptive statistics for the three variables; canopy cover, stem width and height. The subgroup size, the mean, the standard deviation and the corresponding 95% confidence intervals were also presented.

It is shown that for canopy size, the mean canopy size was higher (3.4 m) in the invaded sites compared to the un-invaded sites (2.49 m). With regard to stem width, the un-invaded sites had a mean of 0.395 m whilst the invaded sites had a much higher mean stem width of 2.50 m. In terms of height, the un-invaded sites had a mean height of 4.05 whereas the invaded sites had a mean height of 3.04 m (Table 3).

Table 3: Descriptive Statistics (mean, standard deviation and CI) of measured variables between the sites.

	Site	**N**	**Mean**	**Std. Deviation**	**95% CI**
Canopy cover	Un-invaded site	157	2.4982	1.21138	2.31 – 2.69
	Invaded sites	182	3.4000	1.44658	3.19 – 3.62
Stem width	Un-invaded site	156	0.3954	0.40919	0.33 – 0.46
	Invaded sites	182	2.4990	1.45946	2.29 – 2.71
Height	Un-invaded site	157	4.045	1.8845	3.75 – 4.34
	Invaded sites	182	5.402	3.0044	4.96 – 5.84

5.5 Comparison of means

To show the difference in canopy cover, stem width and vegetation height between the invaded and un-invaded sites, the t-test for the equality of means was performed at the 5% significance level.

5.5.1 Canopy cover

Assuming equal variances in canopy cover (F = 7.809, p = 0.005), a t-test for the equality of means showed that there was a significant difference in the canopy cover between the invaded and un-invaded sites (p = 0.00). As shown in Table 3, the stem width and canopy size for the invaded sites was on average 0.9 m larger than that of the un-invaded sites. Figure 10 below clearly depicts that observations in invaded sites were higher than those from the un-invaded sites.

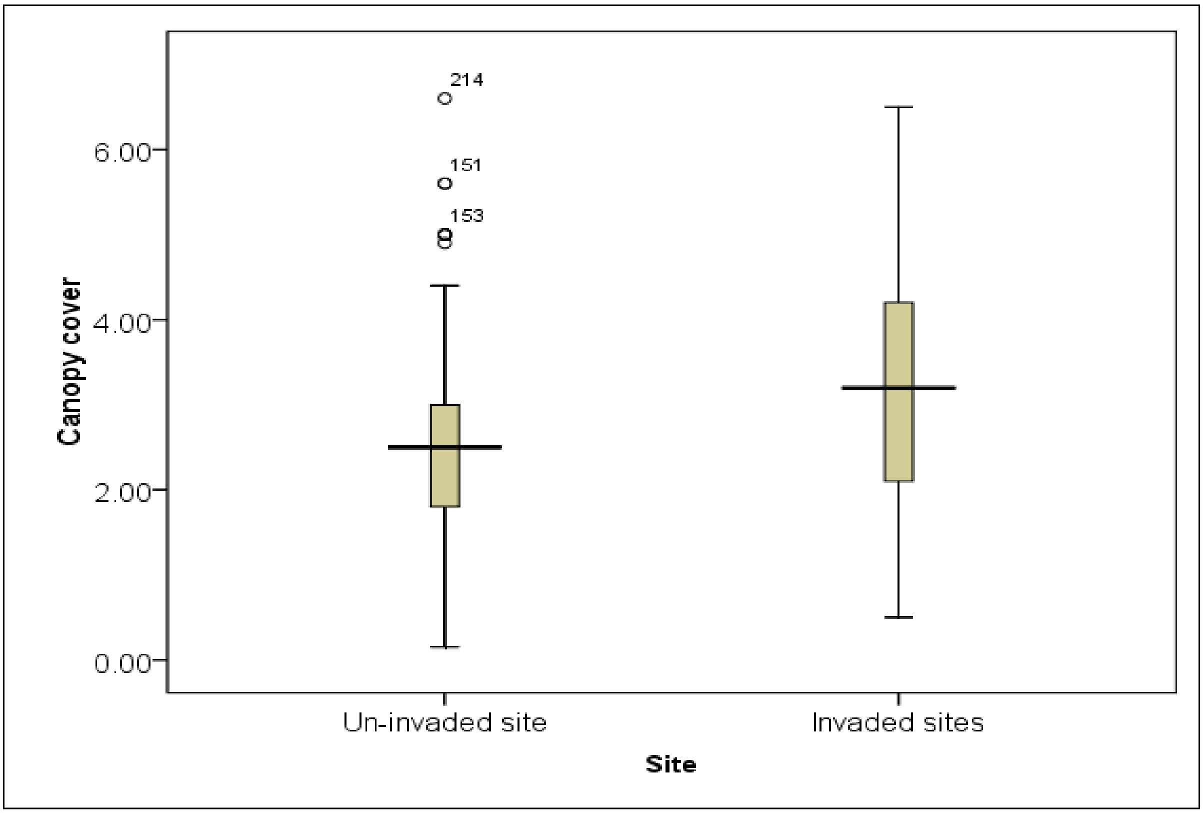

Figure 10. Canopy covers average of woody species between the invaded and un-invaded categories.

5.5.2 Stem Width

Equal variances assumed (F = 302.02, p = 0.00), a t-test for the equality of means showed that there was a significant differences in the mean stem width between the invaded and un-invaded sites (p= 0.00). Invaded sites have stems which are on average 2.1 m bigger in size than those from the un-invaded sites. Figure 11 gives a pictorial presentation of the stem width for the invaded and un-invaded sites.

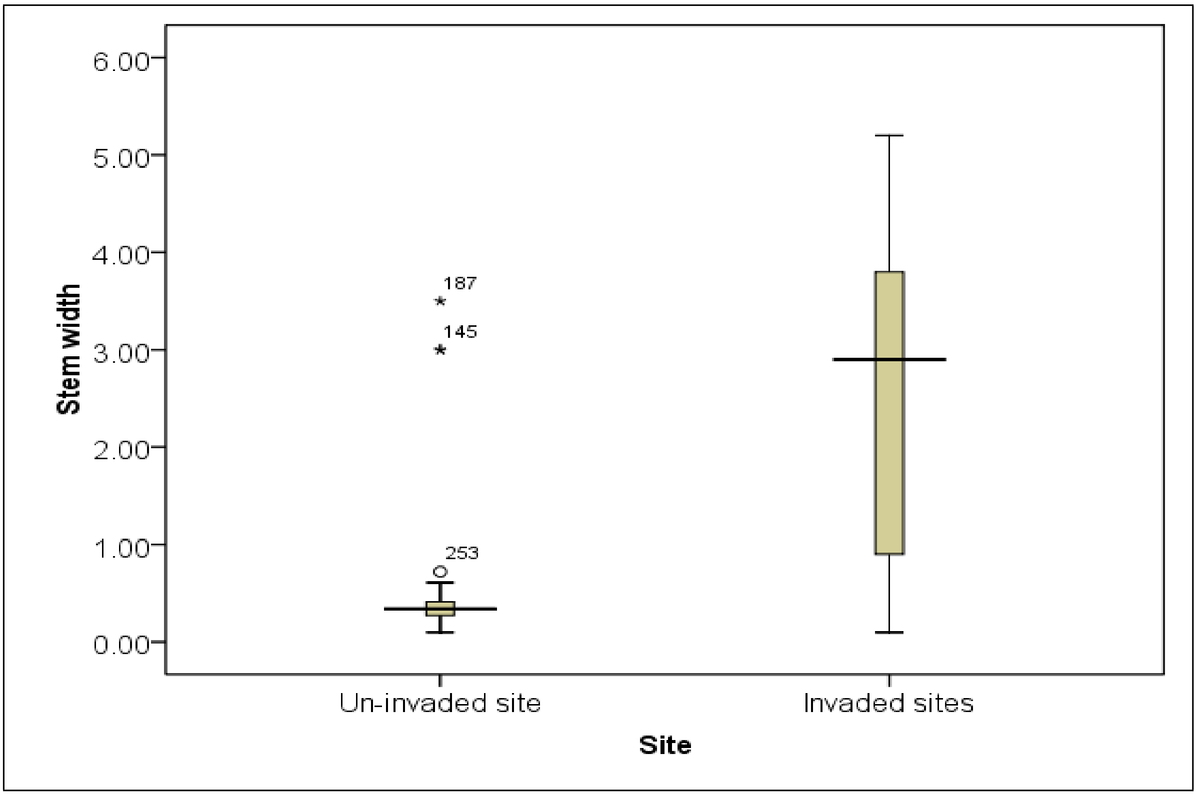

Figure 11: Pictorial presentation of the stem width for the invaded and un-invaded sites

5.5.3 Height

Assuming equal variances (F= 45.07, p = 0.00), a t-test for equality of means proved that there was a significant difference in the mean height of the vegetation (p = 0.00). As presented in Table 4, and pictorially depicted in Figure 12, the mean height of vegetation in the invaded sites was 1.36m higher than that of the un-invaded sites.

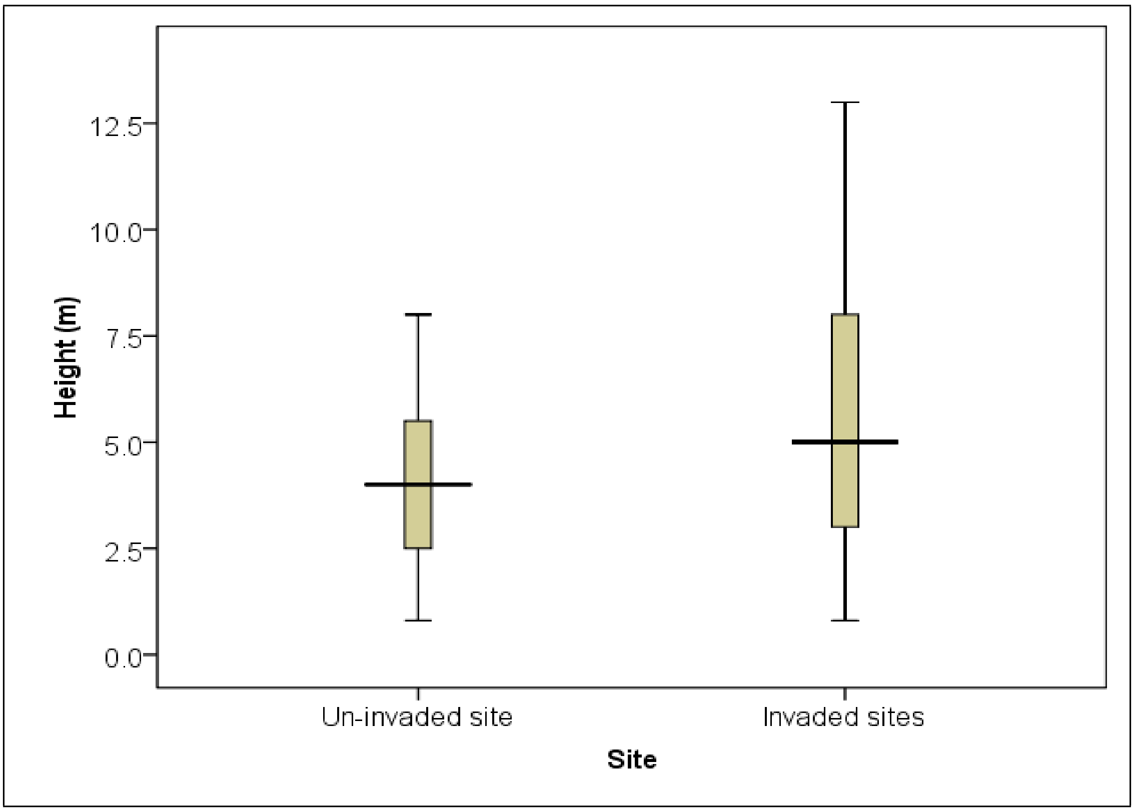

Figure 12: Pictorial presentation of the species height for the invaded and un-invaded sites

The result showed that there is a significant difference between the two sites in terms of measured variables of the vegetation composition. Richardson and van Wilgen (2004: 47) also noted in the study that species such as *Eucalyptus camaldulensis* and *Prosopis* spp become abundant in South African riverbeds in arid areas where they form closed canopies. With specific reference to vegetation structure, canopy cover was recorded high in the invaded site with the mean of 3.4, while the un-invaded site had a mean of 2.4 (Table 3). The invaded category also had the highest records of stem width and height variables with the means of 2.4 and 0.4 respectively.

Exotic invading plants in the invaded category have higher canopy cover on average with the median of 2.5, interquartile range of 2.12 and range of 6.0 (Appendix 2).

Table 4. Levene's Test for Equality of Variances and t-test for Equality of means summary output of the basis of canopy cover, height and stem width in the lower Orange River.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Canopy cover	Equal variances assumed	7.809	.005	-6.166	337	.000	-.90185	.14626	-1.18955	-.61414
	Equal variances not assumed			-6.247	336.715	.000	-.90185	.14438	-1.18584	-.61785
Stem width	Equal variances assumed	302.021	.000	-17.422	336	.000	-2.10363	.12074	-2.34114	-1.86612
	Equal variances not assumed			-18.611	213.624	.000	-2.10363	.11303	-2.32643	-1.88082
Height	Equal variances assumed	45.066	.000	-4.890	337	.000	-1.3570	.2775	-1.9029	-.8111
	Equal variances not assumed			-5.050	309.138	.000	-1.3570	.2687	-1.8857	-.8282

CHAPTER 6: DISCUSSION

6.1 Impacts on species diversity, richness and composition

It is shown in Figure 9 on page 34 that the invaded category is highly dominated by *Prosopis* spp and *Eucalyptus camaldulensis*, which indicates that the two exotic invading species had the high significant effects with regards to species diversity, composition and richness. This study has also established that *Prosopis* spp and *Eucalyptus camaldulensis* pose the highest significant effects on both species diversity and richness. These exotic plants have vigorous growth, high canopy and are much taller than native species (Palgrave, 2002: 839) and utilize resources (nutrients light and water) at the expense of native species (Naiman & Decamps, 1997: 638). Hence, due to these reasons, it is likely that these species play a role in suppressing the indigenous plant species as portrayed in the invaded category. The results of this study are also consistent with those of Heyda *et al.* (2009: 399) who established that species diversity and richness were reduced in invaded plots. In addition, the Orange River ran through a hyper-arid area towards the Atlantic Ocean (O'Keeffe *et al.,* 1994: 39), which make the riparian zones within the lower Orange River a favourable habitat for exotic invaders. *Eucalyptus camaldulensis* has also formed homogenous stands at the invaded site as shown in Figure 8; this is also another means of restraining native species.

Subsequently, the reduction in species richness and diversity recorded in the invaded category of the present study is caused by the fact that invading exotic species suppresses the recruitment of indigenous species and consequently decreases their establishment. Conversely, *Ricinus communis* had negligible impacts on the diversity and richness of native vegetation.

These invaders prefer invading the wet and human-disturbed areas (Curtis & Mannheimer, 2005: 634). This can be attributed to the fact that the species perhaps cannot out-compete resident woody species. However, this needs to be investigated. Another reason as to why *Ricinus communis* and *Nicotiana glauca* insert negligible impact on resident vegetation is that the two species are non-vascular. This is also emphasized by Gregory-Hood and Naiman (2000:105) who found riparian zones particularly in South Africa more vulnerable to exotic vascular plant invasion.

Holmes *et al.* (2008: 544) advised that native riparian vegetation can recover from the stress of invading species following exotic eradication at areas that are heavily infested. A related study to the present research carried out by Heyda and Pysek (2006: 147) in Czech Republic, found out an increase in species richness and diversity takes place after the eradication of exotic plant species *Imaptiens glandulifera*. Thus, there is strong evidence that invasive plant species leads to the reduction of species diversity and richness in invaded riparian ecosystems. In terms of species composition, the present study established that the high density of exotic plants in the riparian zones changed the species composition with specific reference to presence and absence of native species in both study sites.

The resistance of resident species to infestation varies among native species (Heyda *et al.,* 2009: 401). The dominant lower Orange River riparian species *Salix mucronata* was totally absent from the invaded category, which implies that the cape willow tree is extremely susceptible to invasion, particularly that of *Prosopis* spp and *Eucalyptus camaldulensis*. Therefore the study suggests that more studies investigating the impacts of invasive alien species on individual species such as *Salix mucronata* and *Rhus lancea* are required.

According to Chatanga (2007: 56) invasions in riparian ecosystems are promoted by periodic disturbances such as flood that scatter seeds and remove native species as potential competitors. Heyda and Pysek (2006: 148) considered that riparian communities are supplied with extreme quantity of nutrients. This is perhaps the case of lower Orange River riparian communities that they are supplied with excessive quantity of resources such as water and nutrients from upstream where agricultural activities are conducted. Hence, it is likely that these conditions support the strong dominance of exotic invaders such as *Eucalyptus camaldulensis* and *Prosopis* spp.

6.2 Impacts of invasion on vegetation structure

This study revealed that invasive alien plant species impact on the structure of the riparian vegetation of the lower Orange River. In terms of the canopy cover, it is likely that the formation of homogenous stands both by *Eucalyptus camaldulensis* and *Prosopis* spp do suppress the native vegetation. In terms of height, invading species particularly *Prosopis* spp and *Eucalyptus camaldulensis* have aggressive growth and are taller than indigenous plants species. This was also confirmed by Holmes *et al.* (2005: 553) who indicated that majority of exotic invaders are tall trees that consume large quantity of water that native species and dense homogenous stands may augment the resistance of the water flow. *Beater et al.* (2008: 503) also considered that change in height structure of the invading species is also a sign of changes in the community structure of resident species. Canopy cover and height of the invading species particularly the (*Eucalyptus camaldulensis*) and (*Prosopis* spp) are the aggressive invaders that led to the reduction of species diversity and richness in the invaded category.

Moreover, the findings of the current study, particularly at invaded sites is not in agreement with the study of O'Keeffe *et al.* (1994: 39) who found out that *Salix mucronata, Acacia karroo*, *Euclea pseudebenus, Rhus lancea* and *Rhus pendulia* make up the canopy within the riparian zones of the Orange River. These species were absent in the invaded sites. Exotic invading plants in the invaded category have higher canopy cover on average with the median of 2.5, interquartile range of 2.12 and range of 6.0 (Appendix 2).

This study is also consistent with the finding of Heyda *et al.* (2009: 400), who also considered that the effects of an exotic species is directly linked to the degree of dominance of exotic invading plants. Species such as *Searsia pendulina, Salix mucronata* and other riparian woody species that usually form up high canopy were explicitly overtopped by *Eucalyptus camaldulensis.* The shading of native species by exotic invading species is influenced by competition for light, as aliens out-compete native species for this resource (Beater *et al.,* 2008: 503). Furthermore, Beater *et al.* (2008: 503) considered that indigenous species are likely to become canopy dominants after the clearing of invasive alien plants.

It is also shown in the study of Heyda and Pysek (2006: 147) that transformation of vegetation communities through invasion of exotic plant species cause vital implications to riverine habitats for wildlife and may increase the risk of catastrophic perturbations. Curtis and Mannheimer (2005: 632) felt that species such as *Eucalyptus camaldulensis* are not a threat to Namibia. However, there is no study that measured the impact of these species particularly in watercourses and riverbanks in Namibia particularly the Orange River. Studies conducted in Namibia largely focused on the distribution and densities of invasive alien plants (e.g. Burke & Mannheimer, 2004: 79; Shapaka *et al.,* 2008:19, Henschel & Parr, 2010: 5).

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

7.1 Conclusions

Invasive alien plants have significant adverse impacts on the structure and composition of the riparian vegetation of the lower Orange River to the detriment of biodiversity and ecosystem of the area. This research attempted to assess the impacts of alien invasive plants on the structure and compositions of the indigenous riparian woody communities in the lower Orange River. This study also confirmed that invasive alien plants impact adversely on the composition and structure of indigenous vegetation within the riparian zones in the park. The adverse impacts includes suppressing the canopy cover, height and stem width of the resident woody vegetation, decrease in species diversity and richness of the native vegetation and habitat alteration (homogenous stands of *Eucalyptus camaldulensis* and *Prosopis* spp).

The exotic plant invasion has been demonstrated to be mainly linked to downstream of the lower Orange River, which intimidates biodiversity since this area is quite rich in both fauna and floristic diversity. Transformation of vegetation communities through invasion of exotic plant species cause vital implications to riverine habitats for wildlife and may increase the risk of catastrophic perturbations. Apart from adverse impacts on plants communities, invasive species such *Ricinus communis* and *Datura inoxia* contains poisonous compounds that may be implicated in killing wild animals through poisoning. Moreover, *Eucalyptus camaldulensis* is highly flammable. Thus exotic plant infestations in the lower Orange River is deleterious to the conservation and maintenance of biodiversity in the Tsau//Khaeb (Sperrgebiet) National Park. Furthermore, assessment of impact of exotic invading plants riparian of the communities of the lower Orange River is a difficult exercise as the invasion is a long-standing progression that was not observed from onset.

Much of the differences in species diversity and richness in the riparian zones of the lower Orange River are explained by the number of species between the invaded and uninvaded sites. Alien infestation has been linked to low-lying portion (downstream) of the lower Orange River. Furthermore, this study has provided strong evidence that alien invasion reduces the biodiversity of an area by reducing species diversity and richness. It has also been shown that alien invasive plants, particularly the *Eucalyptus camaldulensis* and *Prosopis* spp are significantly transforming indigenous vegetation structure and composition in the lower Orange River within the Tsau//Khaeb (Sperrgebiet) National Park.

7.2 Recommendations

In terms of environmental management, the present study has tried to link these research findings to practical issues in terms of management of invasive plant species within the Tsau//Khaeb (Sperrgebiet) National Park. This study will contribute to the better understanding of the ecological impacts of invasive species and its importance in terms of prioritizing management efforts onto the agendas of conservation managers within the Tsau//Khaeb (Sperrgebiet) National Park.

Thus, it is important that the nature conservation body managing the Tsau//Khaeb (Sperrgebiet) National Park should attempt to eradicate and control invasive alien plants along the lower Orange River particularly at the invaded category. However, this control and eradication have to be effectively managed to prevent further invasions of other exotic invaders. It should also be borne in mind that eradication and ecological restoration, clearing of invasive alien plants, do create jobs and empower unemployed people. Moreover, it is also valuable to introduce new legislation that clearly deals with invasive alien plants, particularly now that the impacts of climate change may increase the density of exotic species in arid and semi-arid environments.

Therefore, further research on environmental impacts is required in order to develop an understanding of environmental effects of exotic invading plants as this will be used to quantify the economic impacts. Furthermore, there is a need of future studies to identify the considerable value of invasive alien plants particularly the *Prosopis* and *Eucalyptus camaldulensis.* With the impact of climate change predicted to result in amplification of flood and drought the events which may increase the vulnerability of riparian ecosystems and functioning to alien invasion, it is advisable that alien infestation be made a conservation priority in Namibia, particularly in ephemeral and perennial rivers.

Additionally, the Directorate of Regional Services and Parks management as a conservation body responsible for the management of protected areas in Namibia, including the Tsau//Khaeb (Sperrgebiet) National Park, should also start planning for the control and eradication of invasive alien plants, particularly the aggressive invaders. Namibia through its Ministry of Environment and Tourism need to revive its commitment in terms of exotic alien control and research. Since most of empirical investigations done on plant invasions were more on ecological impacts, there are research needs in the region of potential economic and social impacts of the invasive alien plants. Finally, since only a once-off assessment was conducted in this study, it is suggested that a long term study is required to provide a much more detailed understanding of the effects of alien invasive plants in this section of the park.

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APPENDICES

Appendix 1: Field data collection form					
Name of data collector: Kosmas Shilongo					
Date of assessment					
Site: Invaded					
Additional site notes:					
Species	Canopy cover	Stem width	Height (m)	Notes	

Appendix 2: Descriptive statistics summary of measured variables in invaded and un-invaded categories.

	Site			Statistic	Std. Error
Canopy cover	Un-invaded site	Mean		2.4982	.09668
		95% Confidence Interval for Mean	Lower Bound	2.3072	
			Upper Bound	2.6891	
		5% Trimmed Mean		2.4608	
		Median		2.5000	
		Variance		1.467	
		Std. Deviation		1.21138	
		Minimum		.15	
		Maximum		6.60	
		Range		6.45	
		Interquartile Range		1.40	
		Skewness		.482	.194
		Kurtosis		.267	.385

Invaded sites	Mean		3.4000	.10723
	95% Confidence Interval for Mean	Lower Bound	3.1884	
		Upper Bound	3.6116	
	5% Trimmed Mean		3.3864	
	Median		3.2000	
	Variance		2.093	
	Std. Deviation		1.44658	
	Minimum		.50	
	Maximum		6.50	
	Range		6.00	
	Interquartile Range		2.12	
	Skewness		.245	.180
	Kurtosis		-.630	.358

	Site		Statistic	Std. Error
Stem width	Un-invaded site	Mean	.3954	.03276
		95% Confidence Interval for Mean Lower Bound	.3307	
		Upper Bound	.4601	
		5% Trimmed Mean	.3441	
		Median	.3400	
		Variance	.167	
		Std. Deviation	.40919	
		Minimum	.10	
		Maximum	3.50	
		Range	3.40	
		Interquartile Range	.14	
		Skewness	6.193	.194
		Kurtosis	41.212	.386
	Invaded sites	Mean	2.4990	.10818
		95% Confidence Interval for Lower Bound	2.2856	

	Mean		
	Upper Bound	2.7125	
	5% Trimmed Mean	2.5040	
	Median	2.9000	
	Variance	2.130	
	Std. Deviation	1.45946	
	Minimum	.10	
	Maximum	5.20	
	Range	5.10	
	Interquartile Range	2.90	
	Skewness	-.332	.180
	Kurtosis	-1.236	.358

	Site		Statistic	Std. Error
Height (m)	Un-invaded site	Mean	4.045	.1504
		95% Confidence Interval for Mean Lower Bound	3.748	
		Upper Bound	4.342	
		5% Trimmed Mean	4.039	
		Median	4.000	
		Variance	3.551	
		Std. Deviation	1.8845	
		Minimum	.8	
		Maximum	8.0	
		Range	7.2	
		Interquartile Range	3.0	
		Skewness	-.200	.194
		Kurtosis	-.981	.385
	Invaded sites	Mean	5.402	.2227
		95% Confidence Interval for Lower Bound	4.963	

Mean	Upper Bound	5.842	
5% Trimmed Mean		5.374	
Median		5.000	
Variance		9.027	
Std. Deviation		3.0044	
Minimum		.8	
Maximum		13.0	
Range		12.2	
Interquartile Range		5.0	
Skewness		.212	.180
Kurtosis		-1.083	.358