PLANT COMMUNITY DISTRIBUTION AND DIVERSITY, AND THREATS TO VEGETATION OF THE KROMME RIVER PEAT BASINS, EASTERN CAPE PROVINCE, SOUTH AFRICA

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Environmental Science at Rhodes University

By

Nsor Collins Ayine

June 2007

ABSTRACT

This study examined the current plant diversity status and the impact of drivers of change on the peat basins of the Kromme River peatland. It was conducted at six sites over sixty one years in the Eastern Cape Province of South Africa. I reviewed the rapid habitat and biodiversity loss of wetlands globally and discussed the distribution of wetlands and specifically peatlands in South Africa. Plant species diversity was assessed using Modified-Whittaker plots. The influence of environmental variables on floristic composition and distribution was investigated using ordination techniques (DCA and CCA). Land use dynamics were assessed by applying GIS techniques on orthorectified aerial images. Six different peat basins were subjectively classified into good, medium and poor condition peat basins. The good condition peat basin (Krugersland) was the most diverse in plant species (4.1 Shannon-Weiner's index) ($p > 0.20$; $F = 11.04$; $df = 2$), with the highest mean number of plant species (32.5 ± 3.4). This was followed by the medium condition class (Kammiesbos) (26.5 ± 9.0) and poor condition class (Companjesdrift) (22.5 ± 8.9). On average, species composition was not evenly distributed across the peat basins ($p > 0.21$; $F = 0.94$; $df = 2$), since 77.8% of the Shannon-Weiner evenness index obtained were less than one. However, there were variations in plant species richness across six peat basins as confirmed by One-way ANOVA test ($p = 0.0008$, $F = 1241.6$, $df = 4$). Key environmental variables that influenced plant species distribution and structure were erosion and grazing intensity, potassium, phosphorus, soil pH and calcium.

Total species variance accounted for in the first two axes for ground cover and plant height were 40.7% and 56.4% respectively. Alien species (e.g. *Acacia mearnsii* and *Conyza scabrida*) were common in degraded peat basins, whereas good condition peat basins supported indigenous species (e.g., *Cyperus denudatus*, *Chrysanthemoides monolifera* and *Digitaria eriantha*). Analysis of aerial images revealed a general progressive decrease in the peatland area between 1942 and 1969 in the good (Krugersland) and poor (Companjesdrift) condition class, with a marginal increase from 1969 to 2003. Peatland area in the good and poor condition class decreased by 5.3% and 8.3% respectively between 1942 and 1969, with a marginal increase of 1.5% and 4.1% respectively from 1969 to 2003. Annual net rate of change in peatland area over the 61 year period was -0.32% (good condition class) and -0.79% (poor condition class). Transformed lands were impacted by drivers of change such as alien invasives, agricultural activities, erosion and sediment transport. The area under alien invasives increased by 50% between 1942 and 2003, with an annual net rate of change of +0.82 (good condition class) and +1.63% (poor condition class).

TABLE OF CONTENTS

TABLES

FIGURES

PLATES

APPENDICES

DEDICATION

I dedicate this thesis to my godfather (Mr. Ken Ofori-Atta) and godmother (Dr. Angela Ofori-Atta), for their relentless sacrifice in sponsoring my entire M.Sc. studies at Rhodes University, as well as their spiritual guidance and direction. May God almighty richly bless you.

ACKNOWLEDGEMENTS

I thank Dr. James Gambiza (my supervisor), for his insightful guidance and comments from the start of this project to the end. The knowledge gained from his tutelage in research design/analysis and his supervisory role is of great value to me. To Professor Charlie Shackleton (Head of Environmental Science Dept), I say God bless you for the assistance and encouragement you offered me throughout the research period. I also thank Mrs. Lil Haigh, researcher at the Institute for Water Research (IWR-Rhodes) for her diverse assistance during field collection and excellent advice and comments at every stage of this research. Her keen interest and knowledge in wetlands has inspired me to continue my future research work in wetlands ecology. Both Professor Christo Fabricius and Dr. Kevin Whittington-Jones deserve greater commendation for their advice and show of concern throughout the study period. Mr. Henry Holland, a GIS consultant, offered invaluable assistance in the analysis of the aerial photographs of the study area, for which I am very grateful. The identification of plant species was made possible through the immense assistance of Mr. Tony Dold (a Botanist at the Schonland herbarium in Grahamstown) whom I am indebted to. I owe Dr. Sukhmani Kaur Mantel a debt of gratitude for her insightful comments on some of my draft chapters. Mr. David Appiah (Secretary) at the Ghana High Commission in South Africa, deserve a worthy praise for facilitating the transfer of my monthly maintenance stipend throughout the study period. The Ghana government will go down in my anal history, for partly sponsoring my MSc. Programme. Finally to Mr. and Mrs.Wayne Beaman (my spiritual mentors from Canada), I say God bless you for your constant prayers and spiritual guidance for me.

Chapter One: General introductions

The Millennium Ecosystem Assessment (MA) defines a driver of change as ‘any natural or human-induced factor that directly or indirectly causes a change in an ecosystem’ (Alcamo and Bennett, 2003). According to David *et al.* (1998) the spread of alien species, over-hunting, pollution (including siltation) and diseases (caused by either alien species or nature pathogens), are some of the causes that have led to habitat destruction and species loss. O’Connell (2003) pinpointed five main anthropogenic factors that have contributed to wetland loss. These include: (a) change in area (habitat loss), (b) change in water regime, (c) change in water quality, (d) unsustainable exploitation of resources and (e) the introduction of alien species. Bunn *et al.* (1997) in a review of wetlands research and development priorities, listed water regime, habitat modification, eutrophication and other pollutants and invasion by exotic species as the main ecological threats to wetlands. A report from the BIOFORUM project indicated that land drainage from local, regional and European scales has affected biodiversity in wetlands and other surface water bodies, through a loss of habitats suitable for wetland biota (Young *et al*. 2004).

Similar threats on the biodiversity hotspot of the Cape Floristic Region reported by Rouget *et al*. (2003), predicted that 30% of the currently remaining vegetation could be transformed within the next 20 years. The effects of these anthropogenic factors, according to Hails (1996) results in wetland and biodiversity loss. The consequence of these factors according to the author, will lead to: (a) a decline in plant and animal species, (b) a decline in economic livelihoods and in the cultures of large numbers of people and (c) a loss in ecotourism.

1.1 Overview of the present state of wetlands globally

The Millennium Ecosystem Assessment (Alcamo and Bennett, 2003) reported that globally, the biodiversity of freshwater systems is deteriorating rapidly, more so as a result of human activities than natural causes. A global overview indicates that massive historical losses of wetlands have occurred worldwide, much of this prior to the launch of the Ramsar Convention (Moser *et al.* 1997). The loss and degradation of wetlands reduces their ability to provide goods and services to humankind and to support biodiversity (Moser *et al*. 1997). All of these consequences of wetland and biodiversity loss are associated with economic costs, and with a reduction in the opportunities for sustainable economic development (Moser *et al.* 1997). In industrialized countries, the consequences of the loss and degradation of wetlands have often been mitigated with expensive artificial constructions, such as major flood protection schemes or water purification plants. However, loss of wetlands in developing countries is likely to have a more direct impact than in developed countries, because mitigatory measures are less likely to be implemented due to financial and technical constraints. In addition, the consequences of wetland loss and degradation are likely to be more severe in arid and semi-arid countries (Kotze *et al*. 1995) because of the scarcity of wetland resources.

Generally, wetland loss is difficult and costly to reverse, although wetland restoration and wetland creation (the introduction of some wetland functions to formerly non-wetland areas) are increasingly popular applied sciences and conservation tools (Hollis, 1993). Approximately 60% of the benefits that the global ecosystem provides to support life on earth (such as freshwater, clean air and a stable climate) are being degraded or used unsustainably. Moreover, scientists warn that the harmful consequences of this degradation to human health that are being experienced currently could grow significantly worse over the next 50 years (http://www.maweb.org. Accessed on 18th January, 2006). While it is important that the proximate causes of wetland loss and degradation are identified, the underlying causes are largely socio-economic and political (Kotze *et al.* 1995; Hollis 1992; Anon, 1996). These include: (a) poverty and economic inequality, (b) population pressures from growth, immigration and mass tourism, (c) social and political conflicts, (d) sectoral demands on water resources, (e) centralized planning processes and (f) financial policies (Moser *et al.* 1997).

1.1.1 Peatlands in South Africa

According to IMCG Global Peatland Database, peat is sedentarily accumulated material consisting of at least 30% (dry mass) of dead organic material. Grundling *et al.* (2004) defines peat as a brownish-black organic soil that is formed mostly in acidic, anaerobic wetland conditions, and comprises partially decomposed, loosely compacted organic matter.

The South African geology and climate limits the areas of permanent water where it is possible for peat to form and consequently their rare occurrence in South Africa (Adam and Grundling, 2004). The limited peat resources occur in valley bottoms on the highveld and escarpments of the Drakensberg eastern coastline and in inter-dune valleys and valley bottoms along the coast (Adam and Grundling, 2004). Most South African peatlands have a dominant vegetation of reeds (*Phragmites australis*), Carex species, bulrush (*Typha capensis*), grasses and other sedges (*Cyperus papyrus*) to a lesser extent (Grundling, 2004). The reed and sedge peat tend to be fibrous to medium fine, the grasses and sedge peats are mostly medium to fine-grained. The peat deposits within the Kromme River catchment fall under the Cape Fold Mountains Peatland Eco-region (CFMPE) sensu, and forms the seventh largest eco-region (4.49% of the total peatland area) (Marnewick *et al.* 2001).

The rarity of and threats to peat resources, led to the first ever scientific conference on peatlands and mires in South Africa by International Mires Conservation Group; principally to widen the interest in peatland-related issues among scientific communities to countries south of the equator (Grundling and Dada, 2004). About 11 peatland eco-regions have been identified in South Africa (Marneweck *et al.* 2001). Adam and Grundling (2004) discovered between 16 000 to 20 000 ha of mires and peatlands, of which 15% are located in the Kwa-Zulu Natal coastal plains. An example is the Maputaland peatland, the largest and rarest peatland type in South Africa that contains 60% of the known peat resources (Grundling, 2004). The predominant geology of the southern areas of South Africa in which the study area is located (Figure 3.0), is the Cape Supergroup consisting of Table Mountain Sandstone (TMS) interspersed with shales, siltstones and in the southern regions, Enon conglomerate (Haigh *et al*. 2002).

1.1.2 Research context

In some parts of South Africa, such as the Drakensberg, work on land use influence on plant community composition and diversity has been carried out by O'Connor (2005). However, the same cannot be said about the Kromme River peatland, since no work has been carried out. Research work within the Kromme River peatland (Haigh *et al.* 2002) has centred on palynological analyses and geomorphological changes, with little or no work carried out on the effect of drivers of change on indigenous species richness within the peat basins. Historically, the Kromme River landusers changed from being predominantly pastoralists to commercial orchard farmers from about 1775 until present times (Haigh *et al.* 2002). The study by Haigh *et al.* (2002) in the Kromme River Peatland revealed that the outflow from the Churchill Dam has reputedly become reduced. Whether this is due to the reduced rainfall or changes in river conformation is difficult to determine, as there is no gauging station above the dam. On the other hand, more than 60% of the wetland catchment has already been damaged beyond repair due to agriculture, channel and bank erosion and the proliferation of alien vegetation at the expense of conservation and rehabilitation (Natural Bridge Communications, 2005). The continuous land use impacts on wetlands in South Africa, such as observed in the Kromme River Peat basins, could in part be due to the upsurge in human dependency on the wetland resources.

The high ecological value of the Kromme River complex, as reported by the Working for Wetlands Project in the Natural Bridge Communications (2005), suggests that it may be a hub for some of the rare wetland species that could be absent in other parts of the landscape within the Eastern Cape Province. Hence the question of sustainable use of resources deserves serious consideration. The concerns highlighted in reports on the continuous destruction of the wetlands resources by some researchers (e.g., Haigh *et al*. 2002) and other parastatal agencies such as the Working for Water Programme, has motivated for this research to be carried out. This research work therefore attempts primarily to investigate the extent of the threat to plant diversity, emanating from anthropogenic activities and natural causes that the Kromme River Peatland Complex is experiencing. The study also seeks to find baseline information on the plant diversity potential of the wetland, since no reported publications could be found on this aspect.

The outcome of this research work will be of use to the provincial and national level wetland management authorities.

1.1.3 Research Aim

The aim of this thesis was to assess plant community composition and diversity and identify the most important environmental factors that affect community distribution, as a basis for inferring future change given activities (such as farming, grazing, use of commercial fertilizers etc.) and processes (such as erosion and consequent drawing down of the water table or sediment deposition and conversion of peatland to floodplain etc.) in the wetland and its catchment.

The objectives of this study include the following:

(a) to identify and describe the major plant communities of the Kromme River Peatland;

(b) to determine the most important environmental factors that affect their distribution (including, amongst other things, disturbance and erosion);

(c) to consider historical variation on those factors that affect community distribution given activities and/or environmental processes in the catchment and the wetland, and how they relate to community change over time and

(d) to predict future change in community composition and distribution on the basis of possible likely future scenarios of environmental change.

1.1.4 Thesis structure

The introductory Chapter (1) gives an overview of the thesis. Chapter 2 presents the literature review and Chapter 3 describes the methods used in the study. Chapter 4 presents the results and Chapter 5 is the general discussion. The conclusions of the study are presented in Chapter 6.

Chapter Two: Literature review

Wetland is a general term that describes a variety of different, complex aquatic ecosystems such as seeps, floodplains, valley bottoms, dams, springs and pans (Palmer *et al*. 2002). The transition from terrestrial to aquatic conditions produces what we describe as ‘wet-lands’ and makes these ecosystems among the most complex in the world. The international definition of wetlands according to the Ramsar Convention, is: "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporal, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters" (UNESCO, 1994). This broad definition captures different wetlands (both inland and coastal wetland ecosystems) that some sectors of the society are working for. After a broad review of the different definitions of wetlands, Mitsch and Gooselink (2000) concluded that the various definitions of wetlands are often characterized by three components that include the following:

- wetlands are distinguished by the presence of water, either at the surface or within the root zone;
- they often have unique soil conditions that differ from adjacent uplands, and
- they support vegetation adapted to wet conditions (hydrophytes) and conversely, are characterized by an absence of flood intolerant vegetation.

Within a wetland, the environmental characteristics are determined largely by hydrologic processes, which may exhibit daily, seasonal or longer-term fluctuations, in relation to regional climate and geographic location of the site (Mitsch and Gooselink, 2000). These factors produce a broad range of wetland types globally with many habitats (Mitsch and Gooselink, 2000).

2.1 Global overview of threats to wetlands

'Wetland loss' is loss of area due to conversion of wetland into non-wetland habitats as a result of human activity. 'Wetland degradation' is the impairment of wetland functions as a result of human activity (Moser *et al.* 1996). The authors argue that in practice, wetland loss is rarely independent of wetland degradation, since loss of part of a wetland is likely to impair the functions of the remaining wetland area. Most estimates have indicated more than 50% of the world's wetlands may have been altered, degraded or lost in the last 150 years (Dugan, 1993; Moser *et al.* 1996; OECD, 1996). Habitat loss from one Ramsar region to the other, according to Frazier (1996) (based on the Ramsar Database), was as a result of agricultural impacts and impacts through pollution and the introduction of exotic species (Mooney and others, 1986; Rejmánek and Randall, 1994). By 1985, it was estimated that 26% of wetlands worldwide were drained for intensive agriculture (Moser *et al.* 1996).

The authors further cited examples in Vietnam where no trace remains of the natural floodplain wetlands of the Red River delta which originally covered 1.75 million hectares. Stanners and Bourdeau (1995) also highlighted eutrophication of freshwater ecosystems which occurs in all parts of Europe due to intensive agricultural practices and transboundary pollutants, (acidification). This has become a pan-European problem of major concern that has led to wetland degradation and wetland loss. Symoens and Micah (1994) reported that wetlands are sometimes simultaneously threatened on three fronts: destruction and fragmentation, damage to water quality (through pollution and acidification) and degradation of their biological communities.

In an attempt to seek redress to the ongoing global loss and degradation of wetlands, the Contracting Parties of Ramsar Convention pointed out the following actions to be taken: (a) designation of sites to the Ramsar list and the maintenance of their ecological character, (b) establishing reserves on wetlands and (c) making wise use of wetland resources (Moser *et al.* 1996). Larson (1993) also proposed the 'No Net Loss' wetland policy of the United States of America and Canada, which relates to wetland areas and function and the goal of reversing the loss and degradation of Mediterranean wetlands, be applied to all wetlands globally.

Groombridge (1992) classified the following anthropogenic and natural factors as those that lead to wetland loss: (a) drainage for agriculture, forestry and mosquito control; (b) waste disposal on wetland sites, construction of roads, industries and residential facilities; (c) subsidence due to extraction of ground water, oil, gas and other minerals; (d) discharges of pesticides, herbicides, nutrient from domestic sewage and mining of wetlands for peat, coal, gravel and phosphate and (e) erosion, sea-level rise and drought. David *et al.* (2000) and Brinson and Malvarez (2002) summarize the factors that lead to wetland loss or degradation as a result of human activities. These include: drainage; excavation; water contamination; infrastructural development; change in hydrologic regime; non-native species invasion; diversion and damming of river flows; disconnecting floodplain wetlands from flood flows; eutrophication; grazing and harvest of plants and animals and global warming. The effects of the process of wetland loss or degradation according to Moser *et al.* (1996) reduces the ability of wetlands to provide goods and services to humankind and to support biodiversity.

2.1.1 Plant-environment relations and threats to wetlands in Africa

In spite of the immense pressure on wetlands through drainage for agriculture and settlement, excessive exploitation by local communities and improperly planned development activities, Africa still has a number of pristine wetlands when compared to Europe or parts of North America (Hails, 1996). Using DCA and Shannon-Weiner diversity index, Walpole *et al.* (2004) found out that species diversity and richness declined substantially in some parts of the Masa Mara Nature Reserve in Kenya due to anthropogenic factors. Victor and Dold (2003) stated that the major threats to biodiversity in the Makana Municipality include agricultural activities, alien invasion and urbanization.

Other studies on plant-environment relations, have shown that land use (Smith and Haukos, 2002), water chemistry (Jeppesen *et al*. 2000; Heegaard *et al*. 2001; Lougheed *et al.* 2001), size of the wetland (Rørslett, 1991; Vertergaard and Sand-Jensen, 2000; Oertli *et al.* 2002; Jones *et al.* 2003) and altitude (Kotze and O'Connor, 2000; Jones *et al.* 2003) are some of the predictors for species richness and composition of macrophytes in wetlands. Fluctuating water levels

(Keddy and Reznicek, 1986; Maltchik *et al.* 2005) is another major driving factor influencing species richness and composition in wetlands. Severe changes in composition of plant communities are more likely to occur under heavy grazing (Mwendera *et al.* 1997a, b). With intense of grazing, a shift from shrubs and perennial grasses to annual grasses and forbs is frequently observed, while the removal of perennial plants is usually associated with increased erosion (Mwendera *et al*. 1997a, b). Other factors that influence the transformation of woodland communities to grasslands include fire and elephant disturbance (Dublin *et al.* 1990; Tchamba, 1995). Peat fires have been reported in some parts of South Africa, with the consequence of transforming peatland vegetation and slowly burning away hundreds or thousands of years of stored carbon (Grundling *et al.* 1999).

The desiccation in both the southern and northern Rietvlei peatlands in Petoria, coupled with the concentration of stream flow by causeways, draining for agricultural purposes, increases in sewage outfall and the presence of bluegum, has resulted in erosion and the incising of the stream channels in the wetlands (Grundling, 1998). The author further stated that some 70-90% of the southern and central sections of the Rietvlei peatland has been mined, leading to desiccation. Similar threats (Schmid and Vinke, 1981) have been observed in Rwanda, where a decrease in agricultural production was attributed to the irreversible state of the desiccated peat soil as a result of wetland destruction.

The impact of alien invasives (an environmental driver of change) on some wetlands has partly affected both flora and fauna species. For example, the extensive growth of water hyacinth in the Lower Kafue River in Zambia, has threatened an important economic infrastructure(the Kafue road bridge), which accounts for 80% of Zambia's international trade through the south, and the Kafue Gorge Dam accounting for 60% of the country's hydropower requirements (Malik, 2006). The presence of water hyacinth in Lake Victoria has also impaired water transportation, increased the prevalence of mosquito and the breeding of snails, and caused a reduction in fish diversity (Mailu, 2001; Mironga, 2004). Except for the relic vegetation at the highest altitude, all natural forest in the Seychelles no longer exists due to the impacts of invasive species, with 21% of the county's flora considered threatened (Kueffer and Vos, 2004).

This example points to the fact that invasive species are capable of changing the structure, species composition, abundance and function and consequently the long-term ecological integrity of indigenous communities (Humphries *et al.* 1991; Franklin *et al.* 1999; Cronk and Fuller, 2001).

On nutrient load as a driver of change, Aerts and Berendse (1988) and Verhoeven *et al.* (1993) reported that the overall loss in plant diversity, changes in species composition, conversion of a unique flora to that dominated by a few common species and the replacement of native species by exotics is all connected to nutrient enrichment in several wetland types. In spite of the noted importance of wetlands to local communities, the human pressure on wetlands is expected to increase as populations grow, unless strategic action is put in place for the conservation of wetlands (Tom, 1997).

2.1.2 Threats to wetlands in South Africa

In South Africa, about 90% and 58% of wetland loss were reported in the Tugela Basin in Natal and Mfolozi catchments, respectively (Taylor *et al*. 1995). Wetland erosion has been identified as one of the major causes of loss in some parts of South Africa, namely Ntsikeni Vlei wetland, Mbongolwane wetland, the Zoar wetland, the Upper Wilge wetland (Grundling and Van de Berg, 2004) and the Rietvlei wetland (Grundling, 2004). Grobler *et al.* (2004) revealed that anthropogenic disturbances such as crop cultivation, fire, peat drainage, and the cutting/clearing of natural vegetation have rapidly reduced the once pristine peat swamp forest in the Kosi Bay Lake system. The overexploitation of certain species, the introduction of exotic species and the pollution or toxification of the soil, water and atmosphere have had major effects on South Africa's terrestrial, freshwater and marine biodiversity (White Paper on South Africa's Biological Diversity, 1997).

Haigh *et al.* (2002) stated that the main threats to wetlands and rivers in the Kromme peatland catchment are alien vegetation, especially black wattle infestations along the riparian corridor in both the main river and its tributaries, and inappropriate farming practices. The authors further stated that there is evidence of severe bank erosion, overgrazing and excessive burning in large parts of the river system of the Kromme peatland catchment. David and Claridge (1993) summarize the impacts of anthropogenic and other natural processes due to loss and degradation of wetlands. These include impaired or reduced water supply to people, to an aquifer, or to another wetland; reduced water flow regulation and flood control; prevention of saline intrusion to both ground and surface water; impaired protection against natural forces (coastal erosion and hurricanes and flooding); inability to retain sediments and nutrients; inability to remove toxins from effluents/polluted water; unavailability of natural wetland products; inaccessibility to water transport; reduction in the gene bank for future commercial exploitation or maintenance of wildlife populations; limitation of recreation and tourism opportunities; loss of socio-cultural significance as heritage sites; limitation of the opportunity for research and education and the inability to contribute to the maintenance of existing processes and natural systems at global, regional and local levels (e.g. microclimate, carbon cycling etc).

2.1.3 General benefits of wetlands to humans and animals

Wetland benefits refer to ‘those functions, products, attributes and services provided by the ecosystems that have value to humans in terms of worth, merit, quality or importance. These benefits may derive from outputs that can be consumed directly, indirect uses that arise from functions or attributes occurring within the ecosystem, or possible future direct output or indirect uses’ (Howe *et al*. 1991 in Kotze *et al.* 2005). The enormous benefits derived from wetlands have led to the direction of human effort towards the conservation, restoration and management of this unique ecosystem. Wetlands are among the most productive life-support systems in the world and are of immense socio-economic and ecological importance to mankind (Hails, 1996). They are critical for the maintenance of biodiversity and perform a great role in the biosphere (Hails, 1996). Kotze and Breen, (1994) pointed out livestock grazing, fibre for construction and handcraft production, fertile land for cultivation, valuable fisheries, and hunting waterfowl and other wildlife, as some of the direct benefits of wetlands. For example, mangrove trees produce approximately 7 400 m^3 of charcoal and 400 tonnes of bark per annum for tannings in Panama and 120 000m^3 of firewood in Hunduras per annum (Lacerda, 1993), while the Inner Delta of the Niger River supports over 550 000 people with about a million sheep and a million goats using the floodplains for post-flood dry season grazing (Hails, 1996). In the Okavango Delta, palm Hyphae, *Phragmites australis*, and palm hearts are harvested for subsistence foods (Hails, 1996).

The Ramsar Convention Bereau (1996) reported that wetlands are an integral part of the hydrological cycle, playing a major role in the provision and maintenance of water quality and quantity. The natural filtering role of wetlands according to Collins (2005) helps in purifying water by trapping pollutants and helps in flood reduction and ground water recharge. Nitrogen and phosphorus removal (Mitsch and Gosselink 2000; Keddy, 2002) is one of the key indirect roles of wetlands.

Grundling and Marneweck (1999) describe peat as a partially-decomposed and loosely compacted brownish-black organic soil that is formed mostly in acidic, anaerobic wetland conditions. Peatlands are globally important as carbon stores and sinks (Gorham, 1995). They store more carbon than all the forests of the world and constitute a global carbon pool of about 412×10^{15}g as compared to 694×10^{15}g in all global plant biomass, 1600×10^{15}g in all soils (including peat) and $>70 \times 10^{15}$g in the atmosphere (Gorham, 1995). Under waterlogged conditions peatlands preserve a unique palaeo-ecological record, including valuable archaeological remains, which has been recognized by the Ramsar Convention Bereau (2002) and by the European Archaeological Council’s 2001 Strategy and Statement of Intent for the Heritage Management of Wetlands.

Chapter Three: Materials and methods

3.1 Study area

3.1.1. Kromme River Peat basins (valley floor marsh)

The Kromme River Catchment valley floor marshes are fairly typical of the southern Cape valley floor wetlands found in sandstone and dominated by palmiet (*Pronium serratum*). Although the rainfall is not as high as in Kwazulu-Natal in the foothills of the Drakensberg, the conformations of the streams are such that constriction in outflow allows water to accumulate or form wetlands and sometimes peat basins, as described above. The palynological analyses of peat cores taken from the central basin indicate that accumulation of peat commenced at least 5620 ± 70 years before present (BP) (Haigh *et al.* 2002). The accumulation rate of 0.72 mm/yr compares well with rates of other Holocene peatlands on the Maputaland Coastal Plain (0.43-1.22 mm/yr) and Highveld (0.49-0.73-0 mm/yr). The deposit can be described as a palmiet-sedge peat; fibrous to fine-grained in texture; sometimes a bit clayey; often with dispersed sand grains or less frequently, charcoal or thin ash horizons (Haigh *et al.* 2002). This peat basin has been severely impacted and degraded by inappropriate landuse activities, as well as road development, especially in the last 60 years (Haigh *et al.* 2002). The selection of the site for this study was mediated by the fact that a preliminary catchment study had been carried out and that the area was easily reached by road. In addition, the river system forms an important water source for the Nelson Mandela Metropolitan Municipality.

3.1.2. Location and physiography of the Kromme River Valley

The Kromme River occupies the easternmost part of an inter-montane valley within the Cape Fold Belt, and flows eastwards into the Indian Ocean west of Humansdorp at St. Francis Bay. The proposed study area is located between latitudes 33° 55` S and 33° 59` 15`` S, and longitudes 24° 15` E and 24° 26` 20`` E above the Churchill Dam (34° 05` S and 24° 29` E) (Fig 1). The 48 km long peatland complex is situated upstream of the Churchill Dam in the Eastern Cape Province. The altitude of the upstream basin is in the range of 350m to 300m above mean sea level, with an average slope of 0.6% (Haigh *et al.* 2002). The major geological formations are the Late Precambrian Nama Group (Cango Formation), the Ordovician to Denovian Cape Supergroup and Tertiary to recent deposits. Enon conglomerates of the Cretaceous System form small but prominent areas of sculptured hills (Bond, 1981).

Of the Cape Supergroup, Table Mountain Group rocks are the main mountain-forming substrates. Five formations have been identified in this group as relevant to the Southern Cape Mountains (Johnson, 1976; Toerien, 1979). The Peninsula Formation (quartzitic sandstone) is the thickest, with up to 2150 m in the Eastern Cape (Truswell, 1982) and it normally forms the highest peaks and southern slopes of the mountains. A narrow 35 to 50 m thick, black shale band (Cedarberg Formation) follows. The Tchando Formation (reddish-brown sandstone containing frequent to subordinate shale bands) overlies the Cedarberg. The Kouga Formation (300 to 400 m) follows as distinctive white quartzitic sandstone. The uppermost and most northerly positioned strata, formed by dark-grey impure sandstone and shale reaching up to 150 m in thickness, is collectively described as the Bavianskloof Formation (Truswell, 1977; Bond, 1981). The main rock type is quartzite with subordinate shale horizons forming the bedrock of the Kromme River basin. Younger shales of Devonians Gydo formation can be seen within the centre surface of the valley alongside older feldspathic sandstones and quartzitic sandstones (primary sources of sediments are largely confined to in situ weathering of the bedrock and the continuous downslope transport of colluvial sediments). The predominant soil type is dark organic-rich loam within the immediate vicinity of the peat basin. In addition there exist alluvial soils and lighter structureless sands at the basement and along the course of the wetland (High *et al.* 2002). Below is a typical example of the rock type commonly found within the Kromme catchment.

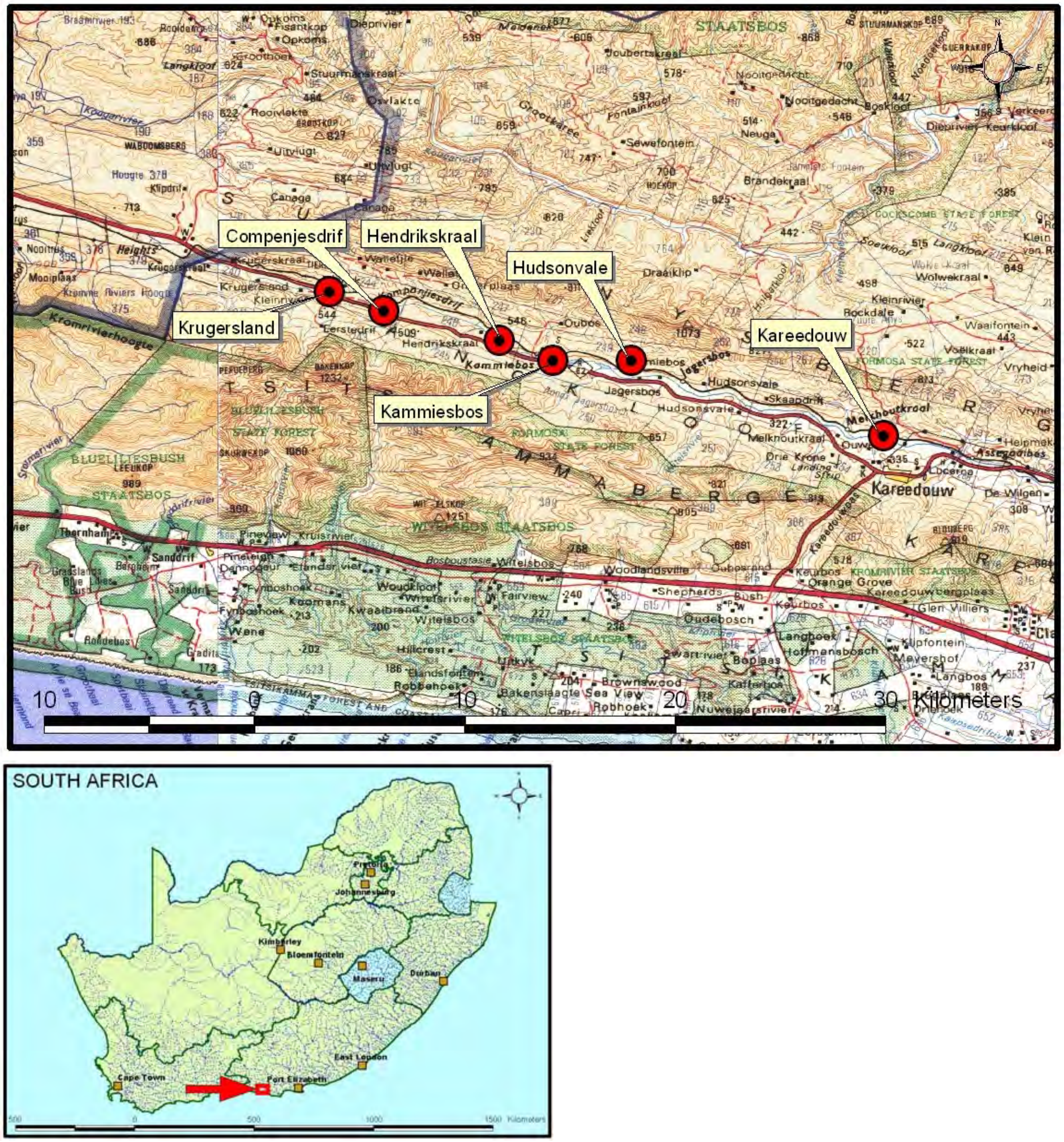

Figure 1.0: A map of Kromme River Peatland showing its position in South Africa as indicated by the red arrow. The sample sites in the six peat basins are denoted by red-black circles

Plate A: Picture of typical Kromme sandstone on top of the southern end of the catchment

3.1.3 **Topography**

The drainage network forms a trellis drainage pattern, except for the Diep River area to the north of Kareedouw which has a dendritic pattern. Altitudes on the adjacent mountain ranges reach an elevation of 1073m in the Suuranysberge to the north and heights of 1251m (Witelskop) in the Tsitsikamma Mountains to the south. The sides of the valley are steep with slopes between 20% and 30% on the north facing mountains and 25% and 60% on the south facing slopes respectively (Haigh *et al.* 2002).

3.1.4 Climate and hydrology

The general climate in the Southern Cape region and in particular the Kromme Catchment, exhibits a bimodal pattern with spring and autumn generally the wetter periods. The western end tends to an average annual rainfall of 500-800 mm. The entire catchment experiences occasional flooding. During the wettest year (1981), 1082 mm were received but during the driest year (1949), only 286 mm. May (53 mm) is the wettest and January (33 mm) the driest month of the year. The largest flood recorded at the Churchill Dam, the first impoundment downstream of the study area, occurred on the 22nd November 1997 (1947-2000), when floodwaters to a depth in excess of 900 mm overflowed the dam wall. The mean annual runoff from the four quaternary catchments of the Baviaanskloof to the north of the Kouga Mountains is 527; 428; 437; 393 mm (448 mm avg.) (Haigh *et al.* 2002).

3.1.5 Vegetation

The southern Cape is characterized by three major vegetation types (Haigh *et al.* 2002). These include the Coastal Tropical Forest, Karroid vegetation and the False Sclerophyllous Bush (Fynbos) types. Afromontane Forest is found on the moister Southern slopes while the arid parts sustain Valley Bushveld, Succulent Mountain Scrub (spekboomveld), Karroid Broken Veld (containing dwarf trees, shrubs and grass) and Mountain Renosterveld. The Kromme Catchment vegetation is primarily a mixture of grassy and mountain fynbos. The dominant vegetation of the peat basin is palmiet (*Pronium serratum*) with smaller areas of grasses, reeds, sedges and ferns (Haigh *et al.* 2002).

3.1.6 Extent of Kromme peat deposits

The Kromme River consists of a series of valley floor marshes, defined by alluvial fans deposited by the tributaries. These alluvial fans effectively act as constrictions, above which the sub-basins, where peat has developed, are formed. The peat complex that can be characterized as fens, formed over a period of approximately 5000 years (Haigh *et al.*

2002). The bottom of the fen with palmiet (*Prionium serratum*) peat, tend to be a sandy medium-fine to fibrous peat. The two western peat basins occur on the farms Krugersland and Companjesdrift and cover approximately 240 ha. Krugersland is the most westerly basin (140 ha) and the central peatland (~100 ha) is on the farms Hendrikskraal/Kammiesbos. The eastern peat basin stretches from Jagersbos to Hudsonvale and covers approximately 150 ha. Peat thickness varies from 0.5 m to 2.8 m with an average of 1.6 m which gives a total estimated volume of 12 900 000 m^3. Peat utilization and impacts within the catchment include agriculture, alien plant invasions, draining, dams, fences, grazing, head-cut and donga erosion, peat fires, roads and water abstraction (Haigh *et al.* 2002).

3.2 Vegetation sampling techniques

The six peat basins (valley floor marsh) were subjectively classified into three different condition classes in terms of the state of vegetation cover and severity of land disturbance. These were good condition class (Krugersland and Hudsonvale peat basins), medium condition class (Kammiesbos and Kareedouw peat basins) and poor condition class (Companjesdrift and Hendrikskraal peat basins).

The Modified-Whittaker nested vegetation sampling method was used for plant data collection (Stohlgren *et al.* 1995). Twenty four Modified-Whittaker georeferenced plots were randomly located in six peat basins according to their designated condition class, from west to east. All plots were 20 x 50 m^2 and each contained ten 1 m^2 non-overlapping sub-plots, two 10 m^2 non-overlapping subplots and one 100 m^2 subplot, all nested within the 1000m^2 (Figure 3.1). All the plot locations were at 33° 52.589`S, 24° 02. 843 E (Krugersland), 33° 53. 059`S, 24° 04.231 E (Companjesdrift), 33° 53.802`S, 024° 07. 207 E (Hendrikskraal), 33° 54. 294`S, 24° 08.580 E (Kammiesbos), 33° 54. 298`S, 24°10.592 E (Hudsonvale) and 33° 56.168`S, 24° 17.038 E (Kareedouw) (Figure 3.0).

All vascular plant species were identified to species level where possible, and estimated for height (m) and percentage ground cover. Each species was estimated and recorded in the $1m^2$ subplots, using the Domin-Krajina cover abundance scale (Mueller-Dombois and Ellenberg, 1974). Woody species with a stem diameter >18 cm and a diameter at breast height (dbh) greater than 35 cm were recorded only in the 100 m^2 subplots. The Modified-Whittaker technique (1) reduces bias and under-reporting of species richness due to spatial auto-correlation and (2) detects more and unique species per plot compared to both intensive and extensive plot design type (Stohlgren *et al.* 1999; Barnett and Stolhgren, 2002). The peat basins were distributed over a distance of approximately 38 km, and are 3-4 km apart.

Some plant species were identified in the field with the aid of literature such as a *Field Guide to Wild Flowers of KwaZulu-Natal and the Eastern Cape Region* (Pooley, 1998) and *Grasses of Southern Africa* (Van Oudtshoorn, 1999). Plant specimens that were difficult to identify were preserved in a plant press and taken to the herbarium at the Schonland herbarium for identification (see acknowledgements).

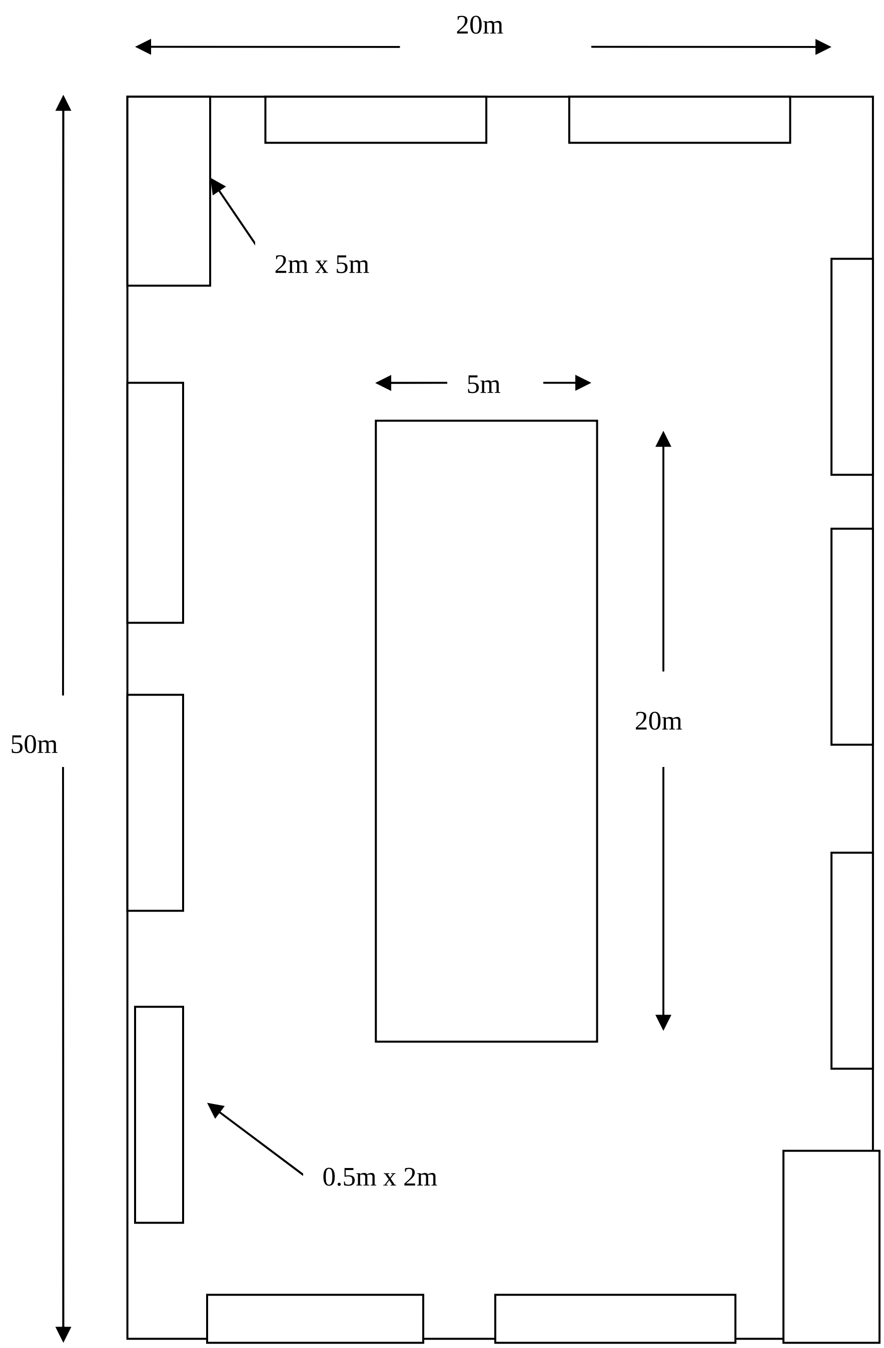

Figure 3.1: A schematic layout of the Modified-Whittaker nested plot

3.3 Assessment of environmental gradients

The analysis of the environmental gradient data was undertaken to determine the extent of its influence on species composition and distribution as well as similarity/dissimilarity of peat basins. Twenty four 500 g soil samples were randomly collected from each Modified-Whittaker plot at a depth of about 10cm and analyzed for their pH and macro/micro elements such as total nitrogen, potassium, phosphorus, calcium, aluminium, zinc and organic carbon concentration. Grazing intensity was assessed based on the extent of the grazed area and exposure of the soil surface. A field scoring was administered: 1 = severely grazed, 2-3 = slightly severe and 4-5 = low grazed area. A field description of major erosional features was carried out with the aid of a textbook on terrain analysis and geomorphologic mapping (van Zuidam, 1985). Erosion intensity was also scored, based on the extent of degradation as applied in grazing intensity.

A total of 12 water samples, two from each peat basin, were collected from the upper and lower extremes. Since the Modified-Whittaker plots were randomly distributed around the riparian zones of the main river course in all the six peat basins, it resulted in the sampling of both upper and lower points of each peat basin. Not all plots were randomly located on permanently wet areas. Prior to sampling, all bottles (250 ml size plastic bottles were used) were washed with nitric acid to rinse off any traces of chemical substances. During sampling, bottles were lowered about 20 cm into the water and the lids tightly closed while the bottles were still beneath the water. This was to ensure that the water samples were air tight so as not to influence the water quality. Water samples were stored in an ice chest and later transferred to the laboratory for analysis.

3.4 Analysis of aerial photographs of land use dynamics

Aerial photographs of the study area were obtained from the department of Survey and Mapping in Cape Town, South Africa. Only available images that cover the catchment area were considered for land use change analysis. Aerial photos that cover the largest peat basins were geo-rectified (1942, 1954, 1969 and 1986). These images were used to compare with the 2003 colour aerial photographs which had been orthorectified by Surveys and Mapping. All images previously in analogue form were scanned onto compact disc (CD) in JPEG and TIFF image formats. Orthorectification and georeferencing of images were performed using TNTmips 7.2 from MicroImages Inc (http://www.microimages.com). Onscreen digitizing of aerial images was carried out with the aid of Manifold Systems version 7x (http://www.manifold.net) to ascertain the changes on the marsh, riparian zones and floodplains. Geographic Information Systems (GIS), coupled with field studies and historical aerial photography, provide a means of researching a temporal change for large areas (Johnston and Naiman, 1990).

Transformed areas were quantified and the remaining hard copies and digital photographs that were not geo-rectified were visually assessed. Hard copies obtained from Surveys and Mapping were of higher quality compared to scanned images, especially those of 1954. These were inspected and corroborated with scanned images for detailed features. Rainfall records before the date of each photograph were noted. For general classification of the state of marsh conditions across the peat basins (as a result of changes over the investigative period), both hard copies and scanned geo-rectified images were used. Hard copies were studied with the aid of a parallax bar and stereoscope. The selected aerial photographs of 1942, 1954, 1969 and 1986 consistently captured about three-quarters of the total land-cover of the study area throughout the years mentioned above. Both Krugersland and Companjesdrift peat basins were selected for detailed analysis of changes in peatland area (in hectares) since they constitute the greater portion of the entire peatland catchment, with historical land use activities and available high quality geo-rectified images for 1954, 1969 and 2003.

The greater marsh areas were divided into Krugersland basin 1 (seasonal and permanent zones plus channel), Krugerland basin 2 (seasonal to permanent plus channel) Krugersland main basin (peat basin) and Companjesdrift basin 1 (peat basin above the weir). For the detailed study of deterioration, Companjesdrift basin 2, below the weir, was considered. To compare changes in channel size from both aerial photos and orthorectified images, a 2D

Piecewise Affine model was employed to resample aerial photographs to fit into the orthophoto projected space. Aerial images of 1969 (the poorest quality) were used as the baseline to identify the stretch of the channel where information was available for all three years. The images of the other two channels were overlaid. This was followed by a splitting of the 1954 and 2003 channel polygons, using the northern and southern limits of the 1969 channel polygon (i.e. extending a line across the polygons from 1969 to 1954 and 2003). This process subsequently produced polygons for 1954, 1969 and 2003. As a result of the high cost involved in the orthorectification and georeferencing of aerial images, only orthorectified images and maps of Companjesdrift was presented in the thesis, and that of Krugersland analysis was carried out onscreen. This explains why images of Krugersland were not presented in the thesis.

Aerial photographs of 1954 and 2003 channel polygons were georegistered. In order to compensate for the high distortion inherent in aerial photos, a cubic convulation interpolation method was applied to calculate new pixel values where voids need to be filled in the projected aerial photo (formed due to distortions) (Mr. Henry, *pers. comm.* April, 2007). The resultant image was then used to identify features. In the case of this study, different land cover classes were identified and digitized for further analysis of the land use change. The marshes were classified according to functionality (i.e. permanent or seasonal zones or floodplain). The riparian zones were classified only when distinct in character from the edge of the river channel or very steep due to erosion. For the purpose of this land use analysis, lands considered as 'transformed' include orchards, pasture (including those planted with Kikuyu and areas cleared, but formerly covered with exotic species) and cultivated or previously cultivated lands. Control points used in the georeferencing process were along the railway line and the main N2 road, since they form the visible boundary mark of the peatland. Annual net rates (ANR) of change in peatland size and area invaded by alien species in any two of the aerial photographs were obtained by calculating the differences in hectares and dividing this by the number of years separating the aerial photographs.

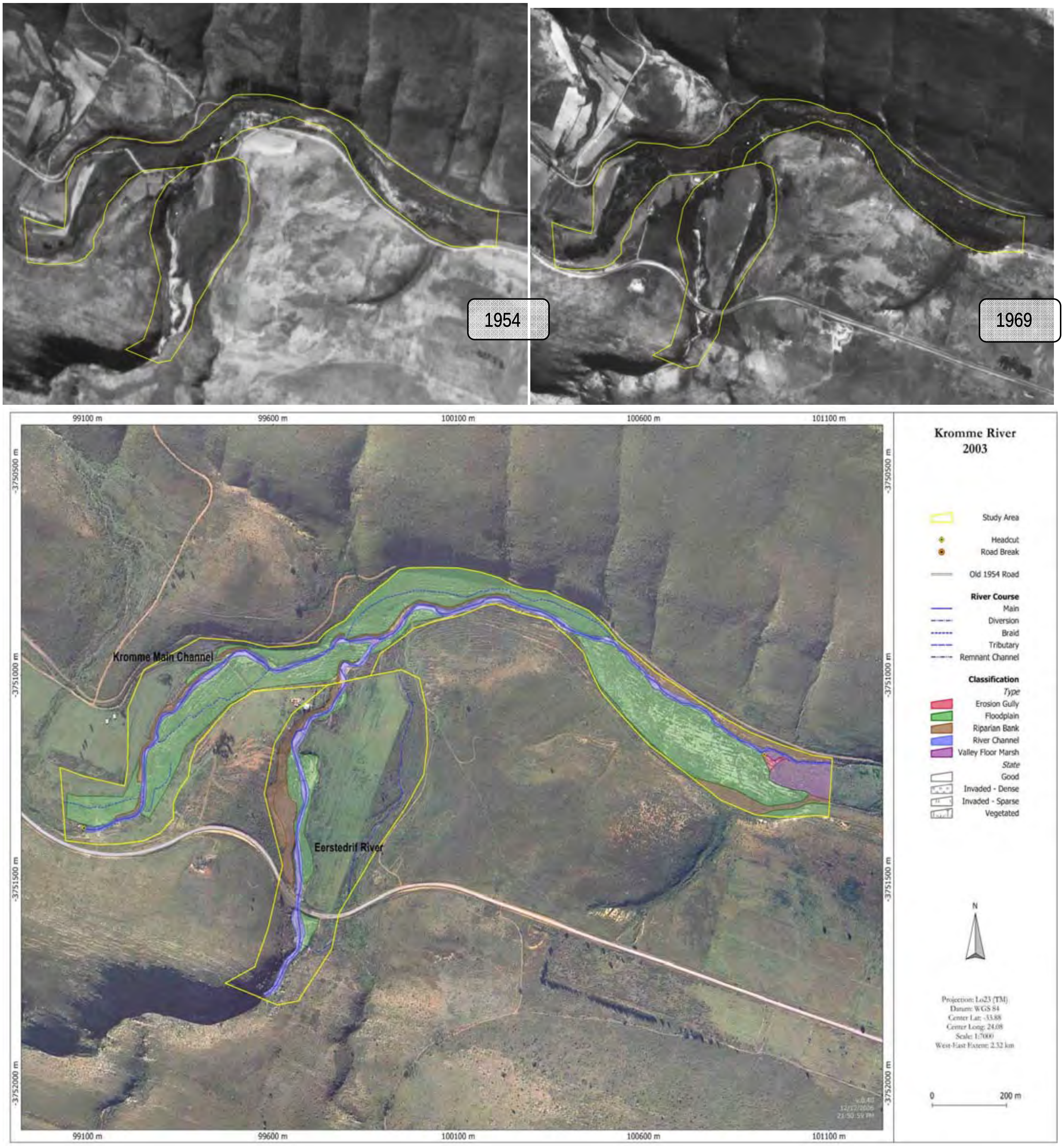

Figure 3.2: Aerial photograph of the study area in Companjesdrift basin2, showing the outline and classification of the area where detailed analyses were conducted. Key features include the increasing extent of the channel erosion, sedimentation in the floodplain and the gradual decline in cultivated area

3.5 Statistical analyses of vegetation and environmental relationships

3.5.1 Vegetation

Multivariate statistics was used to analyze both plant and environmental variables. While classification techniques were applied to only ground cover and plant height, both plant composition and environmental variables were analyzed using ordination techniques. Community analysis package version 1.41 (Henderson and Seaby, 1999) was used in the analysis of mean ground cover and plant height in all 24 Whittaker plots, using detrended correspondence analysis (DCA) and cluster anaysis (Hill and Gauch, 1980). This was primarily to determine the compositional variation of plant species in the respective sample plots. The mean ground cover and plant height was calculated only in the 1 m^2 sub-plots. DCA techniques have the ability to handle large, complex data sets and uncover long ecological gradients, as well as help in data reduction and data exploration (Kent and Coker, 1992; McGarigal *et al.* 2000). Only plants sampled in the 1 m^2 sub-plots were subjected to DCA and cluster analysis.

Complete-linkage clustering (furthest neighbour method) (Sneath and Sokal, 1973) was applied to cluster plant species of similar ground cover. This amalgamation method looks for the most similar pair, and further fusions depend on finding the minimum distance between the furthest points in existing groups. The degree of matching between each pair of sub-plots was computed on the basis of similarity of species cover and plant height, using the coefficient of squared Euclidean distance (Crowford and Wishart, 1967; Noest and Van der Maarel, 1989). The Polythetic aggloromerative method of similarity analysis was used to produce the dendrograms for ground cover and plant height under detrended correspondence analysis (DCA) since the technique has the ability to cluster data sets, as well as address redundancy and outliers simultaneously (Mcgarigal *et al.* 2000).

Canonical correspondence analysis (CCA) (TerBraak, 1986) was performed to examine the relationship between plant species distribution and associated environmental gradients or variables using the Environmental community analysis version 1.3 (ECOM.exe)

(Henderson and Seaby, 2000). Again, CCA was only applied to plants recorded in the 1-m^2 sub-plots. CCA is a direct method of ordination with the resulting product being the variability of the environmental data, as well as the variability of species data (Kent and Coker, 1992). Shannon-Weiner Diversity Index was applied to assess species diversity per sample plot, as was recorded from the respective peat basins. Below is the Shannon-Weiner Diversity model:

$$\textbf{Diversity } (H') = -\sum_{i=1}^{s} P_i \ln P_i$$

Where **s** = the number of species

P_i = the proportion of individuals or the abundance of the **ith** species expressed as a proportion of the total cover

ln = the log $base_{n.}$

The index makes an assumption that (1) individuals are randomly sampled from an 'infinitely large' population and (2) all the species from a community are included in the sample. Also, values for the diversity index usually lie between 1.5 and 3.5, with exceptional cases of values exceeding 4.5 (Kent and Coker, 1992). With the above assumption of Shannon-Weiner's index, one Whittaker plot of three different sub-plots (10 m^2, 100 m^2 and 1000 m^2), each from the three condition classes (good, medium and poor condition peat basins) (section 5.1.3 and 5.1.4) was randomly sampled and the species diversity calculated. A One-way- ANOVA test was applied to test for the differences in species diversity/evenness and species richness from one peat basin to the other, using Statistica version 7.

Species relative abundance (evenness or equitability) was also computed using Shannon-Weiner index diversity model below:

$$\textbf{Equitability (J)} = \frac{H'}{H'_{max}} = \frac{\sum_{i=1}^{s} P_i \ln P_i}{\ln s}$$
(evenness)

Where **s** = the number of species

p_i = the proportion of individuals of the ith species or the abundance of the ith species expressed as a proportion of total cover

ln = log $base_n$

The assumption on species evenness, according to Shannon-Weiner's index is that the higher the value of **J** (equitability) the more even the species are in their distribution within the quadrat (Kent and Coker, 1992).

3.5.2 Environmental gradients

(a) Soil variables

Soil fertility is an important environmental variable that influences plant growth and development directly. Therefore, 11 soil fertility variables, plus erosion and grazing intensity were analyzed, to determine the vegetation/environmental relations. Analyses were carried out in line with the standard methods and guidelines of the South African Fertilizer Society (1974) at the Döhne Analytical laboratory in Stutterheim. Since plant roots occupy a certain volume of soil, the volumetric method was adopted as opposed to the more conventionally used mass method. Macro elements such as phosphorus, potassium, calcium and magnesium were analyzed using the AMBIC-2 METHOD developed by Van der Merwe *et al.* (1984). This method is based on the volume of soil and not the weight as in the case of AMBIC-1 and is suitable for the determination of phosphorus in a wide range of soils (acid to alkaline, sand to clay) and other micronutrients such as copper, iron and manganese. Determination of organic carbon was carried out using the Walkley-Black method.

(b) Water quality analysis

A Merck SQ 118 mass photospectrometre was used to analyse the water samples for six variables: namely ammonium, nitrite, nitrate, orthophosphate, pH and electrical conductivity in accordance with the South African water quality guidelines for aquatic ecosystems at the Institute of Water Research (IWR) at Rhodes University. Results of water samples are presented in appendix 4. Water variables were not included in the data matrix for CCA analysis.

Chapter Four: Results

4.1 Plant communities and species richness of the Kromme River Peatland

Three different plant communities were identified, as a result of spatial and temporal changes in environmental variables, such as soil nutrients, erosion and overgrazing. They included: (a) the fringing forest of the riparian zones; (b) the fen and palmiet plant communities of the valley floor marsh and (c) the grassy fynbos plant communities of the floodplains. A total of 65 different plant species were recorded across the six peat basins (Appendix 1), with Krugersland peat basin recording the highest mean number of species, mostly herbs and grasses (32.5 ± 3.4) (Table 4.0). Areas with low species richness were identified within poor condition peat basins such as Companjesdrift (22.5 ± 8.9) and Hendrikskraal (22.3 ± 7.0). There were significant differences in plant species richness in the good, medium and poor condition peat basins ($p = 0.0008$, $F = 1241.6$, $df = 4$). Exotic species which formed 15.4% of total plants sampled were made up of woody species and grasses (e.g., *Eucalyptus grandis, Acacia cyclops and Acacia mearnsii Conyza scabrida, C. albida*, *Centella asiatica*, *Hypochaeris radicata*, *Persicaria lapathifolia* and *Rubus cuneifolius*). Of the 65 species identified, 23% were indigenous wetland plants (e.g. *Cyperus denudatus*, *C. rotundus*, *C. textiles*, *Fuineria hirsute*, *Juncus lomotophyllus, Nymphaea nouchali*, *Thelypterus sp*, *Pronium serratum*, *Phragmites australis*, *Paspalum dilatatum*, *Pennisetum macrourum*, *P. setaceum*, *P. llandestinum and Persecaria lapathifolia*), while the remaining 61.6% represented indigenous non-wetland plants species.

Table 4.0: Species richness recorded in the 24 sample plots across the six peat basins

Peat basin type	Plot A	Plot B	Plot C	Plot D	Mean	Std. dev.
Krugersland peat basin (Good class)	28	36	32	34	32.5	3.4
Hudsonvale peat basin (Good class)	31	24	24	24	25.8	8.0
Kammiesbos peat basin (Medium class)	30	26	27	23	26.5	9.0
Kareedouw peat basin (Medium class)	22	23	25	26	24	7.3
Companjesdrift peat basin (Poor class)	20	20	26	24	22.5	8.9
Hendrikskraal peat basin (Poor class)	25	20	26	18	22.3	7.0

4.1.1 Determinants of vegetation structure and composition

4.1.1.2 Ground cover composition

Hierarchical cluster analysis separated vegetation into five floristic associations across the six peat basins, based on variations in peat condition type (Figure 4.0). Below is a description of the five floristic associations.

Cluster 1: Plant species in this cluster were predominantly grassy-fynbos community and associated with poor condition peat valley floor marshes of Companjesdrift and Hendrikskraal. These peat basins were characterized by eroded channels, headcuts, and stream bank erosion and overgrazing. Soils in this peat basin were quartzitic sand stone. Plant species common in this transformed peat basin were alien invasives (e.g., *Conyza albida and Acacia mearnsii, Hypochaeris radicata*). The plant community was sparsely distributed.

Clusters 2 and 4: Sample plots in this cluster were associated with medium condition peat class of Kammiesbos and Kareedouw, and were located in the seasonal zone of the peat valley floor marsh (Figure 4.0). Plant species of this group were characteristic of indigenous wetland plants (e.g., *Pronium serratum and Phragmites australis)* and non-wetland plants (e.g., *Stoebe sp)*, with some pockets of fynbos communities (*Rhus rehmaniana, Rhus dentata*).

Clusters 3 and 5: Sample plots in this cluster were associated with the good condition class of Krugersland and Hudsonvale, confined within the permanent wet zone of the valley floor marsh, with characteristic dark heavy soils. There were isolated boulders in some of the sample plots. Floristic compositions of this group were the indigenous fen and palmiet plant communities (e.g., *Cyperus denudatus, Thelypteris sp. Pronium serratum* and *Pennisetum macrourum)*.

4.1.1.3 **Patterns of plant height distribution and composition**

Hierarchical Cluster Analysis separated the vegetation into four floristic associations, based on plant height (Figure 4.1). These associations are described below:

Clusters 1, 2 and 4 were a mixture of sample plots from medium and good condition peat basins. Species in these clusters were typical of palmiet-fen communities (e.g., *Typha capensis, Pronium serratum, Phragmites australis* and *pennisetum macrourum)* were associated to this habitat type. Average height of typical wetland plants like *Phragmites australis, Typha capensis, Pronium serratum and Pennisetum macrourum* was 2.5 m. These plants were confined to the fringes of the riparian zone. These communities were relatively less impacted by human-induced disturbance. There were few patches in some of the sample plots.

Cluster 3: With the exception of one sample plot from the good condition class (KB), the remaining sample plots from this cluster were associated with poor condition class peat basin. The association of plant species from sample plot (KB) with plots predominantly from the poor condition peat basin could be due to similarity in plant height. Sample plots in this peat basin were characterized by erosional features and over grazing. This cluster was different from the other clusters due to the extent of degradation and the predominance of alien species such as *Conyza albida, Conyza scabrida and Acacia mearnsii.* Community composition in this peat basin was mainly grasses and woody species. The vegetation was sparsely distributed, with many patchy areas and sediment deposits. Soils in this degraded site were typically compacted.

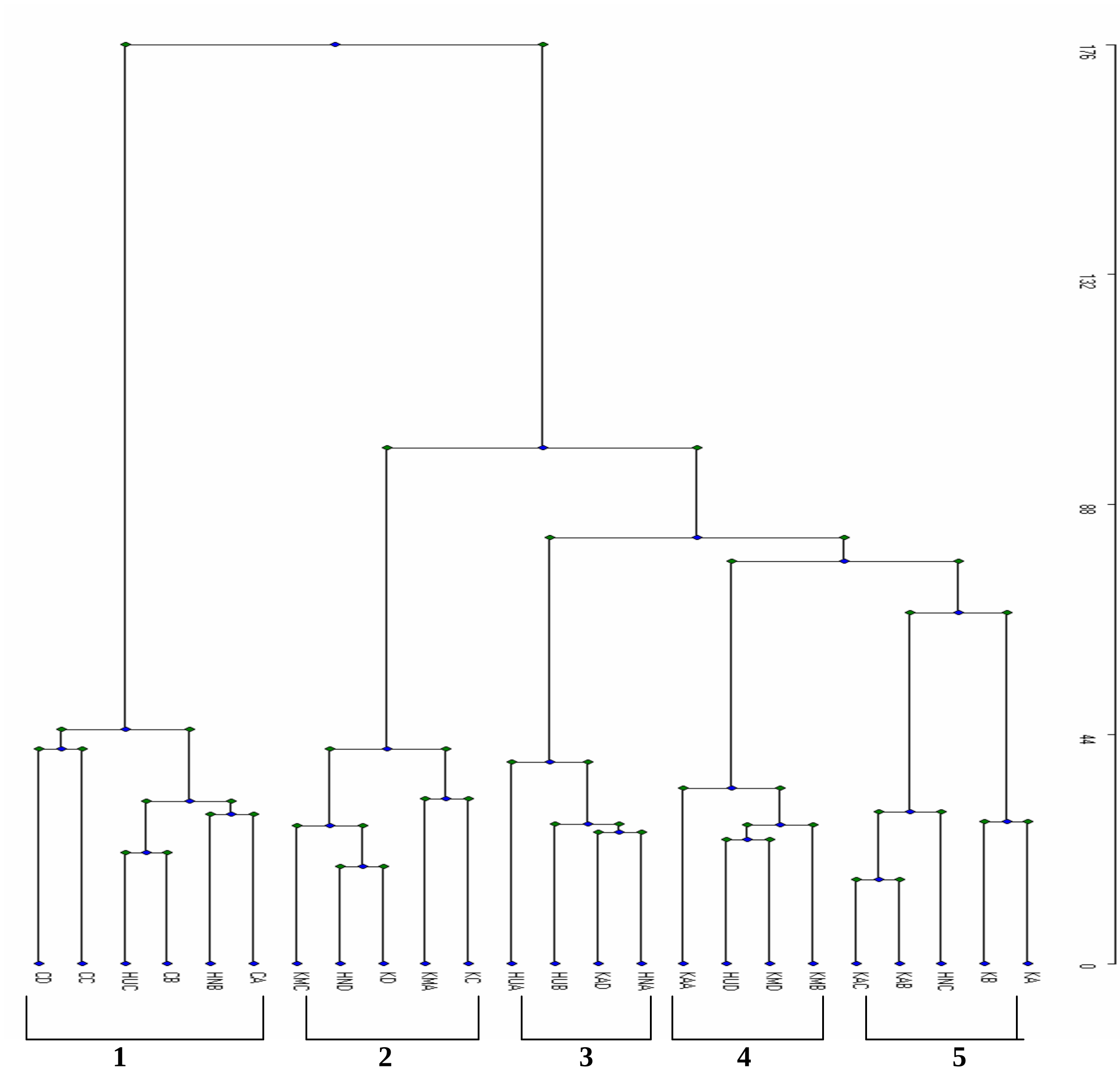

Figure 4.0: Hierarchical Cluster Analysis (HCA) dendrogram showing five clusters of plant communities based on similarity in ground cover using the coefficient of squared Euclidean distances. The abbreviations denote different sample plots in the six different peat basins. Plots KA, KB, KC and KD were in Krugersland peat basin; CA, CB, CC and CD were in Companjesdrift peat basin; HNA, HNB, HNC and HND were in Hendrikskraal peat basin; KMA, KMB, KMC and KMD were in Kammiesbos peat basin; HUA, HUB, HUC and HUD were in Hudsonvale peat basin and KAA, KAB, KAC and KAD were in Kareedouw peat basin. The last letters refer to replicate (i.e. A to D). Complete linkage was used. Note the five groups of plots clustered separately**.**

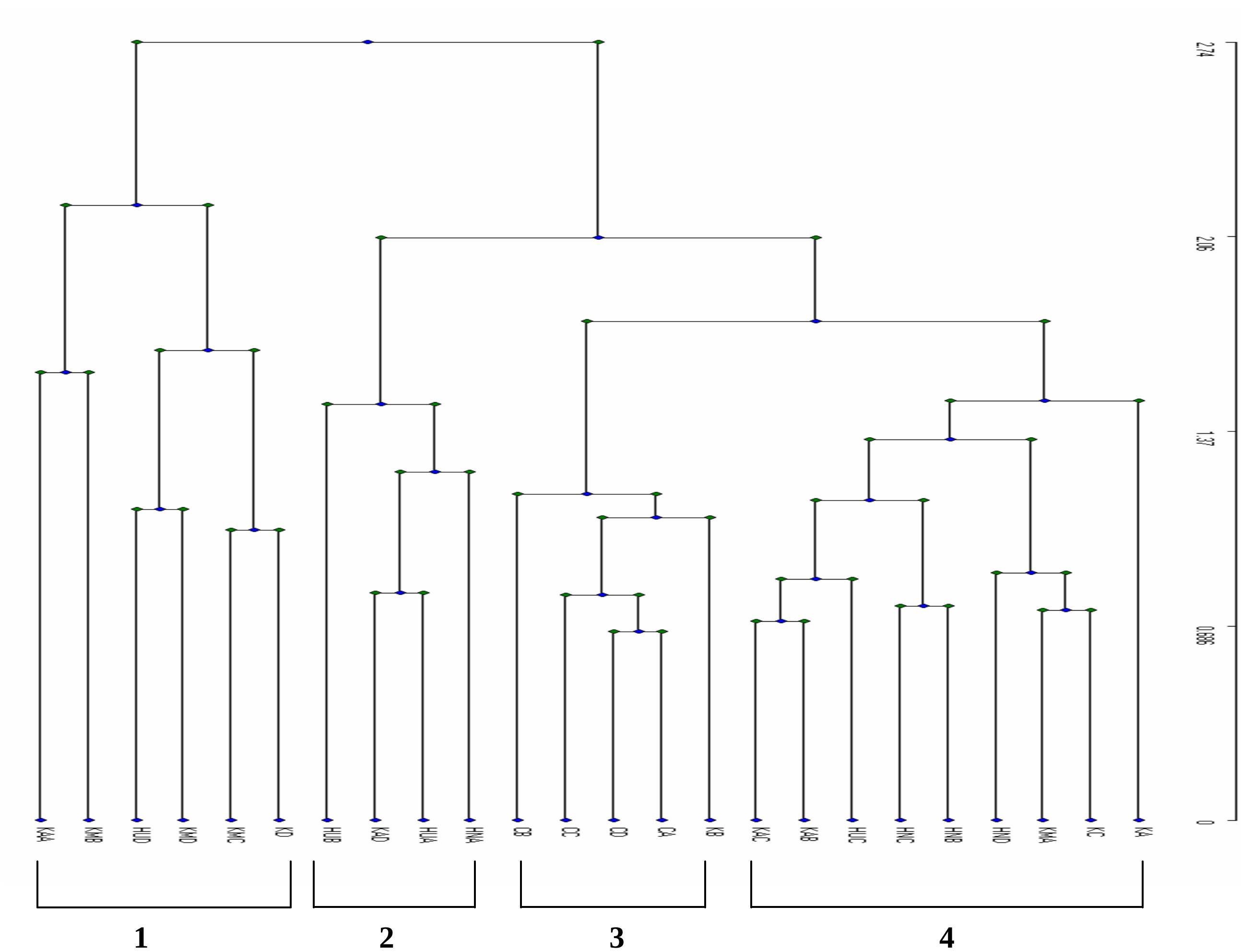

Figure 4.1: Hierarchical Cluster Analysis (HCA) dendrogram showing four clusters of vegetation based on plant height, using the coefficient of squared Euclidean distances. The abbreviations denote different sample plots in the six different peat basins clustered on the basis of similarity in plant height and peat condition type as indicated in Figure 4.1. Complete linkage type was used. Note the four groups of sample plots clustered separately.

4.1.2 Vegetation-environment relationships

4.1.2.1 Indirect ordination on sample plots based on ground cover composition

Detrended correspondence analysis (DCA) separated the sample plots into five groups (Figure 4.2). Group 1 was associated with poor condition valley floor marshes of Companjesdrift and Hendrikskraal peat basins, with the associated plants predominantly alien species of the fringing forest communities (e.g., *Eucalyptus grandis, Hypochaeris radicata, Conyza albida, Conyza scabrida* and *Acacia mearnsii*). Erosion and overgrazing were the disturbance features associated with group 1. Community compositions were relatively less densed and located mostly on the floodplains of the peat basins.

Groups 2 consisted of vegetation plots associated with peat basins in a medium condition class (e.g. Kammiesbos peat basin), with less severe human impact and dominated by graminoids and dicots (e.g. *Eragrostis curvula, Digitaria eriantha* and *Euryops tysonii*). Some sample plots in group 2 were located in transformed lands (e.g., floodplains). There were cobbles and boulders in some plots.

Groups 3, 4 and 5 were associated with both good and medium condition class (Krugersland, Hudsonvale and Kareedouw peat basins), where the valley floor marsh was in a reasonably good state. Species in the good and medium condition class were characterisctic of wetland plants (e.g., *Typha capensis, Phragmites australis, Nymphaea nouchali, Cyperus denudatus, Pronium serratum, Paspalum dilatatum* and *Juncus lomotophylus*), interspersed with other terrestrial plants (e.g., *Pteridium aquilinum, Persicaria lapathifolia*, *Bidens pilosa*, *Zantedeschia albomaculata* and *Arundinella nepalensis*).

The first two axes (axis 1 = 0.54, axis 2 = 0.34) accountered for the total variation in species composition among sites. These axes were associated with transformed valley floor marsh peat basins brought about by over grazing, land clearance and patchy conditions.

4.1.2.2 **Indirect ordination of sample plots based on plant height composition**

Three groups of sample plots were separated alongside vegetation composition based on the condition class of peat basins (Figure 4.3). Species in Group 1 were associated with the degraded peat basin in Companiesdrift. Plots in group 1 were severely eroded. Plant communities; mostly woody species were confined within the riparian zones. They were a mixture of alien invasives and indigenous non-wetland plants such as *Eucalyptus grandis, Conyza scabrida, C. albida, Helicrysum felinum Buddeja saligna, Senecio sp* and *Leonotis leonorus.*

Groups 2 and 3 were associated with good and medium valley floor marshes of Krugersland, Kammiesbos and Hudsonvale peat basins. Predominantly wetland plants, with few indigenous non-wetland plants were associated with these peat basins. Variations in species composition were accountered for by the first two axes (axis 1 = 0.47, axis 2 = 0.31).

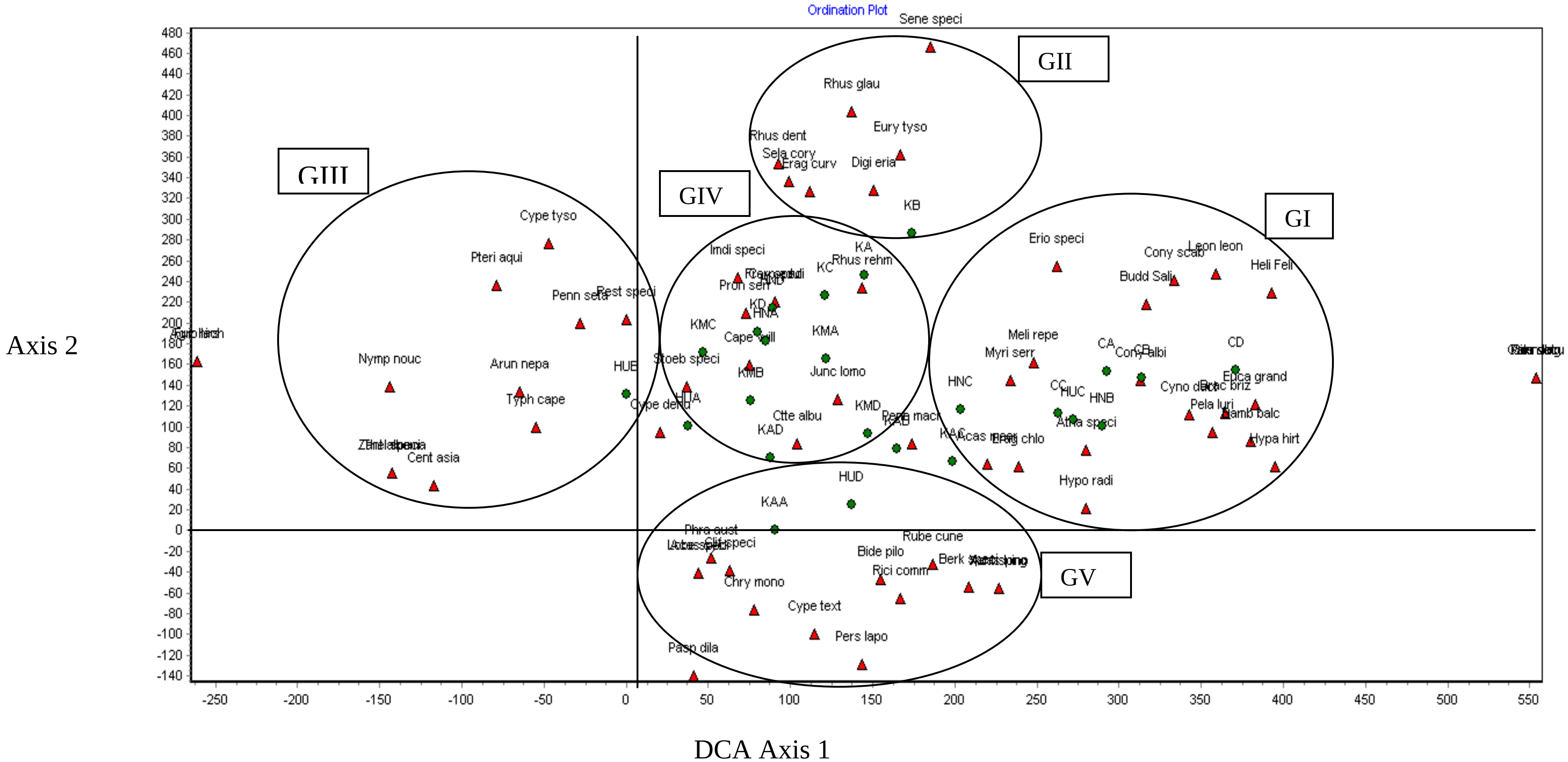

Figure 4.2: DCA ordination diagram showing the separation of ground cover into three groups along axes 1 & 2. The graph shows the species and sample sites relationship in all six peat basins. The abbreviations represent sample plots (as indicated in Fig. 4.1) and the associated plants. The red triangle denote plant species, while the green circle denote sample sites

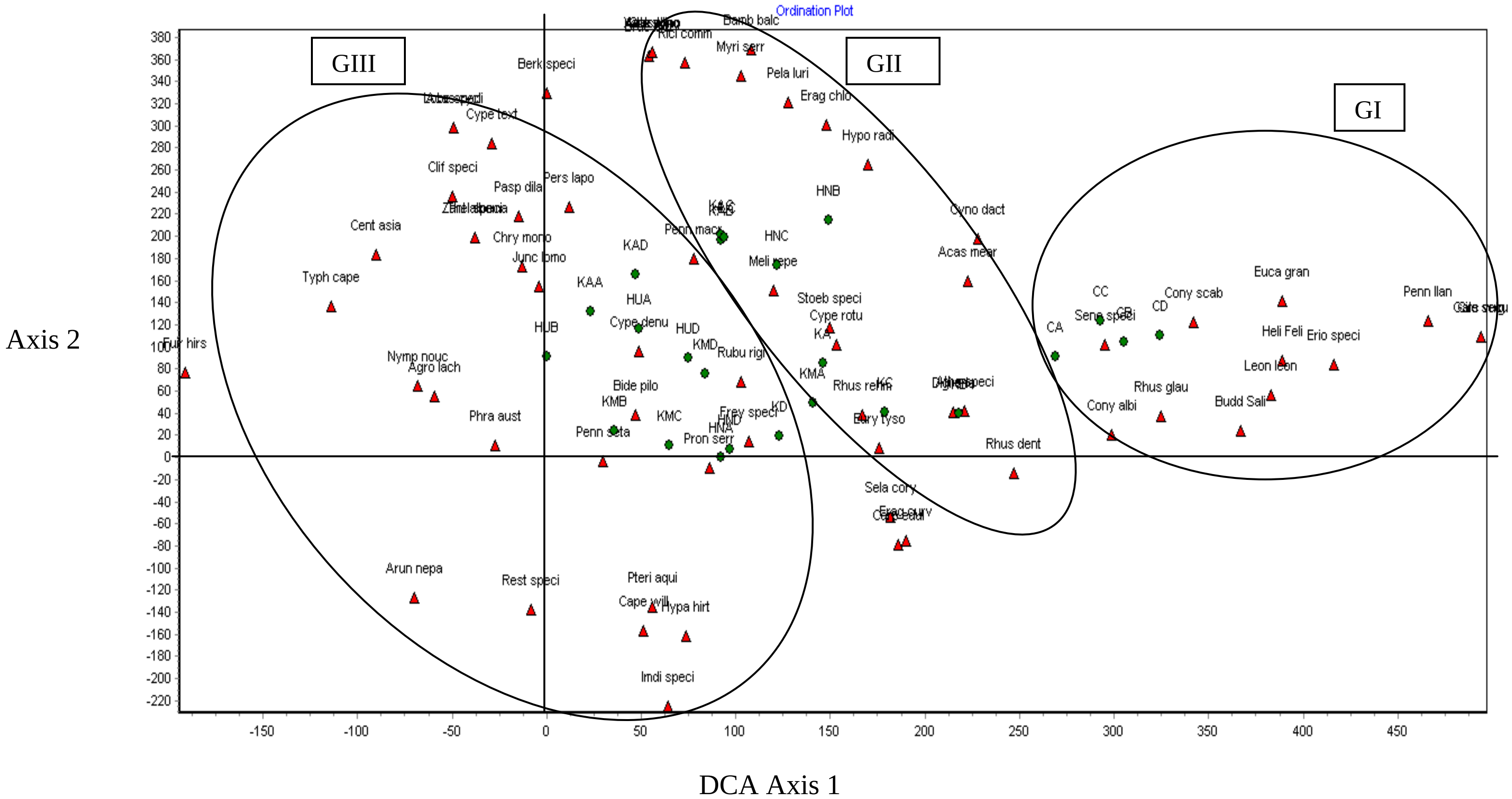

Figure 4.3: DCA ordination diagram showing the separation of plant height into three groups along axes 1 and 2. The graph shows the species and sample sites relation in all six peat basins. The abbreviations represent sample plots (as indicated in Fig. 4.1) and the associated plants. The red triangles denote plant species, while the green circles denote sample sites

4.1.2.3 **Influence of environmental variables on ground cover**

Key environmental variables that influenced community distribution and species composition were soil pH, phosphorus, potassium and grazing intensity (Figure 4.4). Increases in grazing intensity and pH negatively correlated with the explainable variations in community composition in good and medium condition peat basins along axis 1 and positively correlated with potassium and phosphorus. However, observed community composition in both medium and poor condition peat basins was influenced by phosphorus and potassium (Figure 4.4). Variations in community distribution and composition in these peat basins positively correlated with potassium and phosphorus along axis 1 (Figure 4.4). Species composition in sample plots influenced by potassium and phosphorus were predominantly alien species (e.g., *Acacia cyclops, Bambusa balcooa*) and graminoids (e.g. *Brachiaria brizantha* and *Berkheya sp*). The influence of magnesium, aluminium, acid saturation and organic carbon on community composition was not significant. The first two axes accounted for 31.6% of the total variation in community composition (Table 4.1). The strength of environmental influence on plant species was further confirmed by the high species-environment correlation coefficient associated with each axis. CCA ordination illustrated a disturbance gradient from the poor to medium and good condition peat basins respectively.

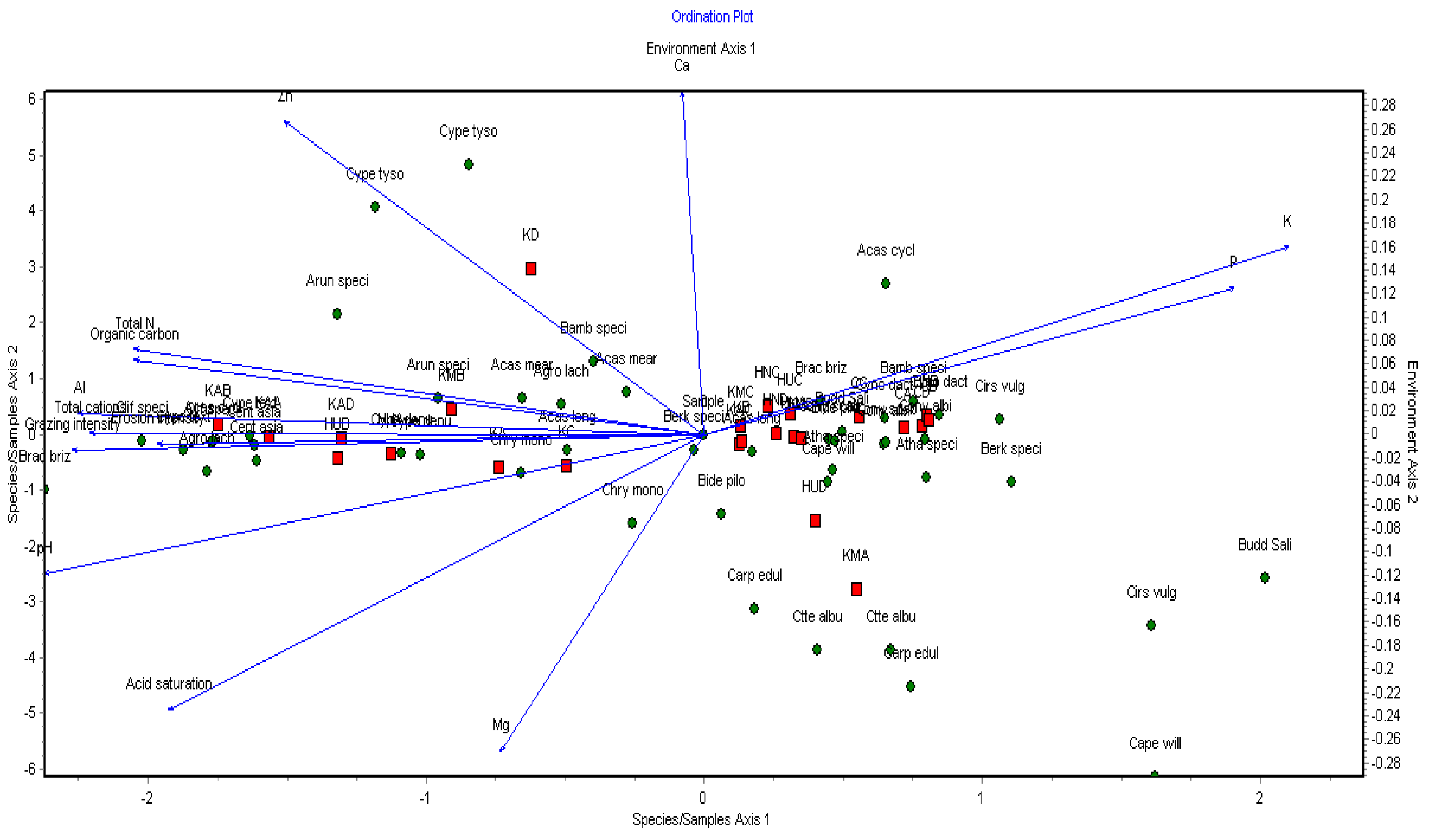

Figure 4.4: Canonical correspondence analysis (CCA) diagram showing the influence of edaphic factors on ground cover in the six peat basins. The red squares represent sample sites, the green circles represent plant species and the arrows represent each of the environmental variables plotted pointing in the direction of maximum change of explanatory variables across the six peat basins.

Table 4.1: Summary of CCA axis lengths for ground cover, showing the levels of correlation between axes and environmental gradients, percentage variance of species and species-environment relationships

	Axis1	Axis 2	Axis 3	Axis 4
Canonical eigenvalues for ground cover	0.600	0.447	0.391	0.227
Species-environmental correlation	0.927	0.186	0.956	0.896
Cumulative percentage variance	18.2	31.6	43.41	50.26
Number of species (response variables)	65			
Number of environmental variables	13			
Total variance in species data	3.317			

4.1.2.4 **Influence of environmental gradients on plant height**

Variation in plant height was greatly influenced by erosion intensity, calcium, potassium, grazing intensity and acid saturation (Figure 4.5, Table 4.2). Calcium and potassium largely influenced the observed variation in community composition in both good and medium valley floor marshes. Community composition from two sample plots from medium condition valley floor marshes were influenced by acid saturation along axis 1. Alien invasives (e.g., *Bambusa balcooa*, *Acacia mearnsii and Conyza scabrida*) were more common in degraded sites. There were, however, fewer grasses present (e.g., *Cynodon dactylon*). The good and medium valley floor marshes (peat basins) along axis 1 were mainly dominated by indigenous species (e.g., *Cyperus denudatus, C. textiles, Centella asiatica, Digitaria eriantha, Chrysanthemoides monolifera, Carpobrotus eduli, Cirsium vulgare, Chenopodium album* and *Arundinella nepalensis*). The positioning of environmental gradients in Figure 4.5 indicated that variation in community composition along axis 1 was positively correlated with potassium and calcium and negatively correlated with erosion and grazing intensity. The second axis showed a positive correlation with erosion and grazing intensity and negatively correlated with potassium and calcium. The first two axes, accounting for 53.9% of community variance, largely illustrated the observed patterns (Figure 4.5, Table 4.2).

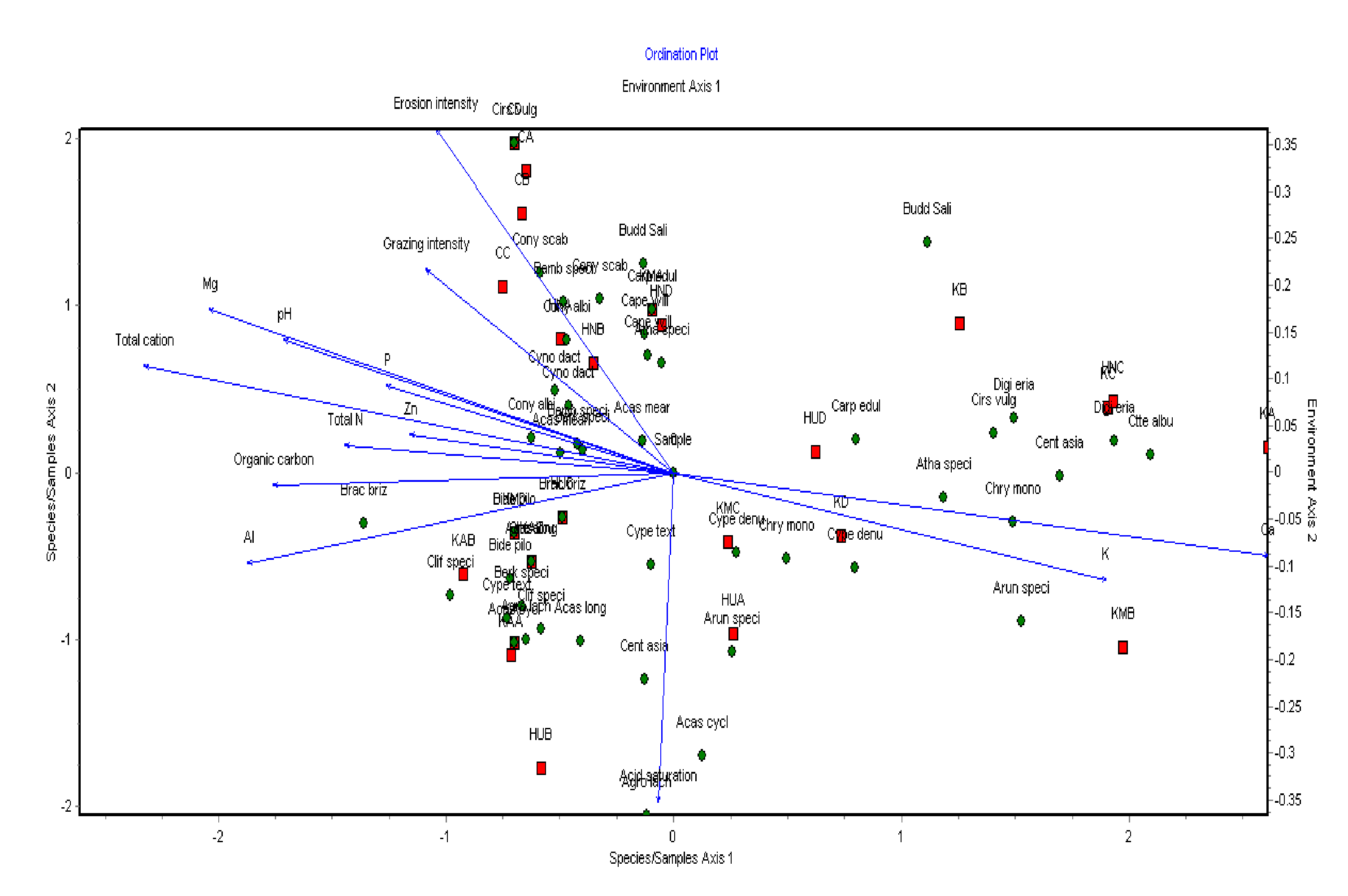

Figure 4.5: Canonical correspondence analysis (CCA) diagram showing the influence of edaphic factors on plant height across the six peat basins within Kromme peatland. The red squares represent sample sites, the green circles represent plant species and the arrows represent each of the environmental variables plotted pointing in the direction of maximum change of explanatory variables across the six peat basins.

Table 4.2: Summary of CCA axis length for plant height, showing the levels of correlation between axes and environmental gradients, percentage variance of species and species-environment relationships

	Axis1	Axis 2	Axis 3	Axis 4
Canonical eigenvalues for plant height	0.924	0.4033	0.250	0.214
Species-environmental correlation	0.703	0.957	0.597	0.896
Cumulative percentage variance	37.55	53.94	64.11	72.84
Number of species (response variables)	65			
Number of environmental variables	13			
Total variance in species data	2.303			

4.1.3 Status of Kromme peatland plant diversity

Species diversity (H′) recorded in the good, medium and poor condition peat basins was in the range of 1.7 to 5.8 (Table 4.3). On average, the good condition site (Krugersland peat basin) recorded the highest diversity index of plant species (4.1 ± 1.47), followed by the medium condition peat basin-Kammiesbos (3.8 ± 1.76) and poor condition peat basin-Companjesdrift (2.5 ± 1.26) (Table 4.3). There were significant differences ($P > 0.20$; $F = 11.04$; $df = 2$) in species diversity among sample plots in the good, medium and poor condition class of the peat valley floor marsh. Though species diversity was high, they were not evenly distributed across the six peat basins ($P > 0.21$; $F = 0.94$; $df = 2$). Seven out of the nine sample plots had 77.8% of Shannon-Weiner evenness index less than one. Only two of the sample plots from good and medium condition class had 22.2% of the index values greater than one (Table 4.4).

Table 4.3: Results of plant community distribution analysis, showing diversity index values and mean for good, medium and poor peat basin condition classes (P = 0.20; F = 11.04; df = 2)

Peat condition type	Shannon-Weiner diversity index values	Mean diversity index	Std. dev
Krugersland (good)	Plot A= 3 Plot B = 3.6 Plot C = 5.8	4.1	1.47
Kammiesbos(medium)	Plot A = 1.9 Plot B = 4.1 Plot C = 5.4	3.8	1.76
Companjesdrift (poor)	Plot A = 1.9 Plot B = 1.7 Plot C = 3.98	2.5	1.26

Table 4.4: Results of community evenness distribution analysis, showing index values and mean for good, medium and poor peat basin condition classes (P = 0.21; F = 0.94; df = 2)

Peat condition type	Shannon-Weiner diversity index of equitability (J)	Mean index	Std. dev
Krugersland (good)	Plot 1= 0.66 Plot 2 = 0.77 Plot 3 = 1.16	0.86	0.26
Kammiesbos (medium)	Plot 1 = 0.39 Plot 2 = 0.84 Plot 3 = 1.08	0.77	0.35
Companjesdrift (poor)	Plot 1 = 0.41 Plot 2 = 0.37 Plot 3 = 0.84	0.54	0.26

4.1.4 Interpretation from aerial images

4.1.4.1 Changes in the two biggest peat basin conditions (Krugersland and Companjesdrift) examined from aerial images

Of the peat basin areas examined between 1942 and 2003 for Krugersland and Companjesdrift, the size (in hectares) under Krugersland decreased by 5.3% from 1942 to 1954 and 1.9% between 1954 and 1969 (Table 4.5a). However, there was a marginal increase of 1.5% of the peatland area between 1969 and 2003. The annual net rate of change of the peatland area over the 61 year period (i.e., between 1942 and 2003) was -0.32% (Table 4.5a). Companjesdrift peat basin also decreased by 14.6% between 1942 and 1954 and a further 8.3% between 1954 and 1969. The clearisng of the alien invasives probably contributed to a marginal increase of 4.1% of the peat basin area between 1969 and 2003, with a -0.79% annual net rate of change between 1942 and 2003 (Table 4.5b).

4.1.4.2 Impact of drivers of change on the peat basin

The area under alien invasives increased by 50% from 1942 to 2003, with a +0.82% annual net rate of change in the good condition class (Table 4.5a). There was a progressive increase in the area under alien invasives under poor condition class between 1942 and 1969, with a +1.63% annual net rate of change (Table 4.5b). All alien species were cleared by 2003, explaining why there was no record in terms of area occupied by alien invasives in 2003. (Tables 4.5a & b). Flood events regarded as natural drivers of change were recorded in 1956, 1968 and 1981 (Figure 4.7).

The historical change in land use practices over the years has largely impacted on the community distribution, by creating patchy conditions in the peat basins and subsequently reducing the diversity index, species richness and evenness distribution of the peat basins, as evident in Tables 4.3 & 4.4.

Table 4.5: Observed changes on the two biggest marsh peat basins (Krugersland and Companjesdrift) impacted by agents of land transformation between 1942 and 2003 as measured from aerial photographs of the peatlands

a.*Krugersland peat basin (Good condition class)*

Year	Size of intact peat basin (ha)	Size of invaded area (ha)	Other transformation agents (including agricultural activities)
1942	77	4	-
1954	63	5	Pasture and orchard farms
1969	58	9	Erosion, sediment deposits and pasture
2003	62	6	Orchard farms, drainage and erosion
Annual net rate of change over 61 year period (%)	-0.32	+0.82	

b. *Companjesdrift peat basin (poor condition class)*

Year	Size of intact peat basin (ha)	Size of invaded area (ha)	Other transformation agents (including agricultural activities)
1942	56	5	Pasture farms
1954	35	6	Pasture farms
1969	23	12	Erosion, sediment deposits and pasture
2003	29	0	Sediment deposits, drainage and erosion
Annual net rate of change over 61 year period (%)	-0.79	+1.63	

Fig 4.6: A section of 2003 aerial photographs on top of Krugersland peat basin, showing a complete transformation of the valley floor marsh to cultivated lands. The presence of sparse alien invasives can be clearly seen within the cultivated areas and along the drains

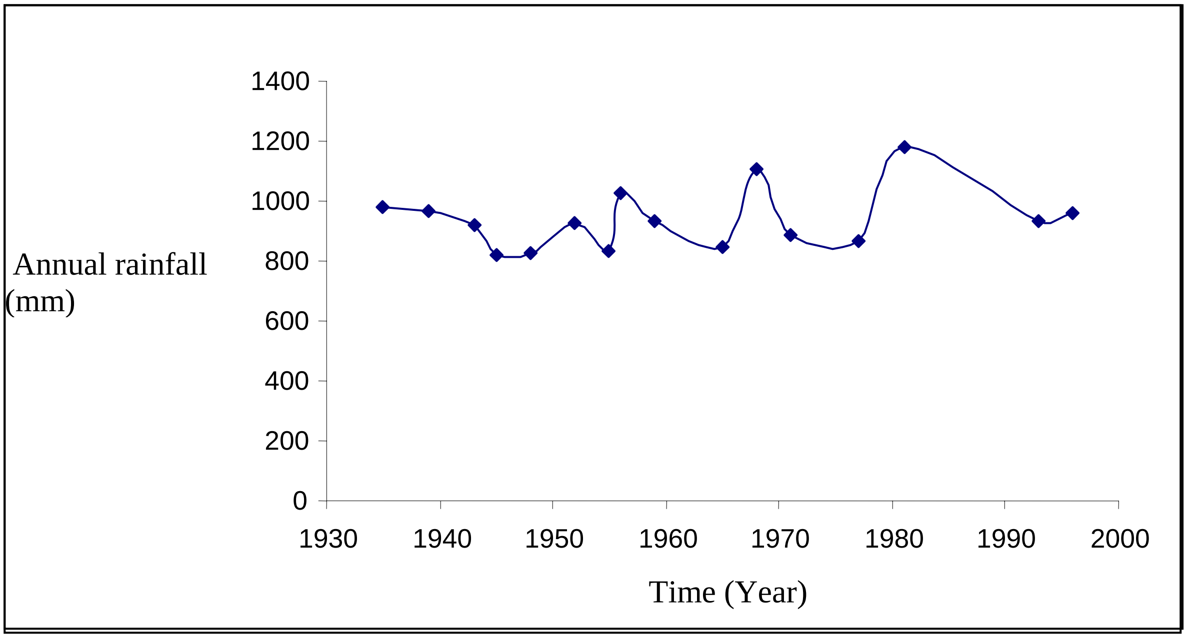

Fig 4.7: Mean annual rainfall of Kromme River catchment from 1935 to 1996. Notice the rainfall peaks above the 1000mm mark recorded during flood events in 1956, 1968 and 1981.

4.1.4.3 The relationship between community distribution and its determinants with insights from the GIS mapping

The analysis of aerial images indicated that historical variation of the land use practices directly impacted on the pattern of community distribution across the peat basins. It can be inferred from Table 4.5 a & b that the historical variation in land use practices (such as orchard and pasture farming) has led to a reduction in peatland area, with a subsequent increase in the area invaded by alien invasives. It can be observed from GIS map of 1954 (Figure 4.8) that the valley floor marsh plant community dominated by *Pronium serratum, Thelypteris sp.* and *Phragmites* australis was virtually undisturbed, with relatively sparsely alien invasives and the absence of erosion and sediment deposits. However, the subsequent years (Figures 4.9 and 4.10) saw the increases in agricultural activities, over grazing and erosion processes. These human-led activities largely influenced the changes in community distribution and composition as confirmed by ordination and classification (Figures 4.0 to 4.5).

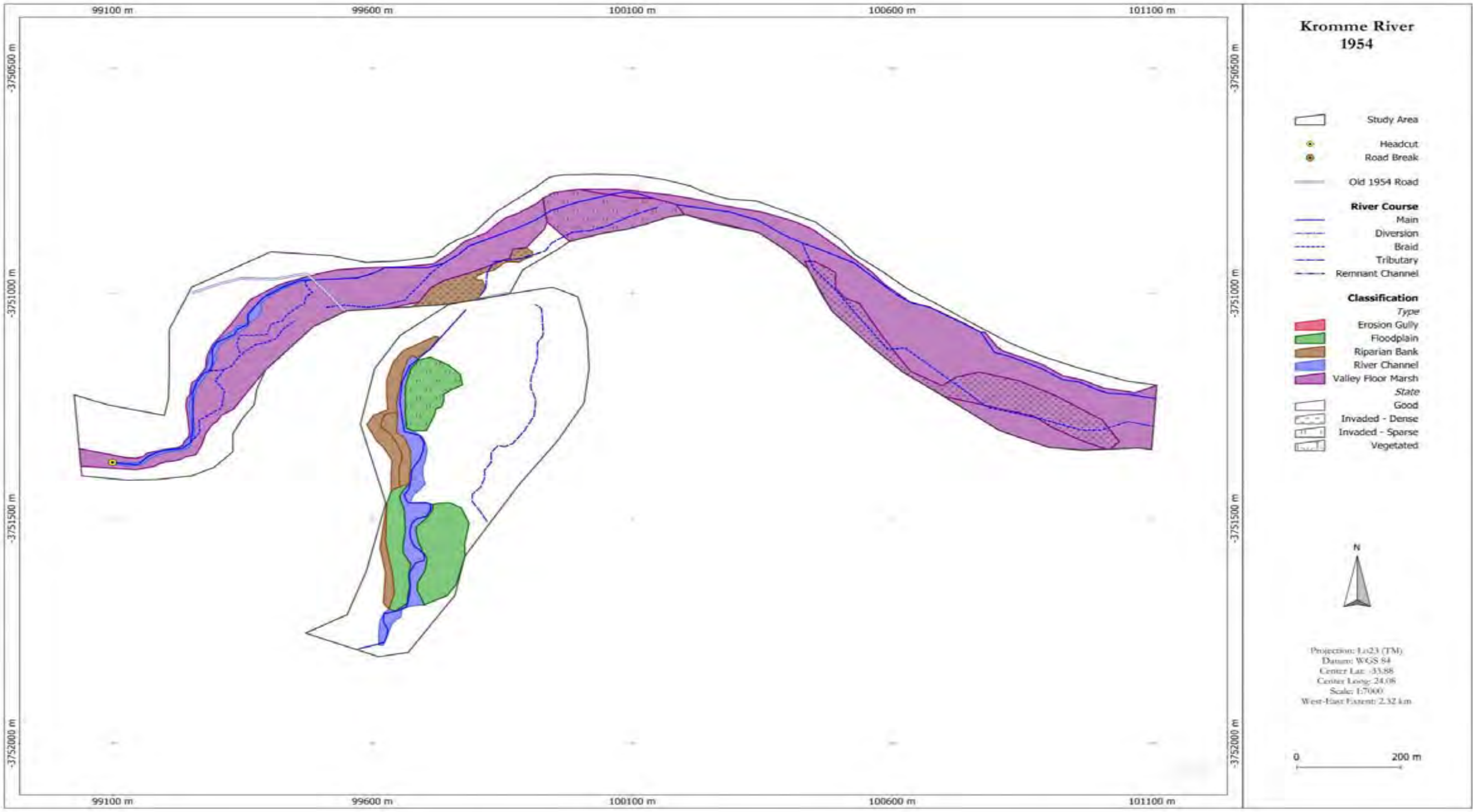

Fig 4.8: An orthorectified map of Companjesdrift peat basin, showing the areas of transformed land within the study area in 1954. Note the small area of alien invasion and the riparian bank. Erosional features were absent

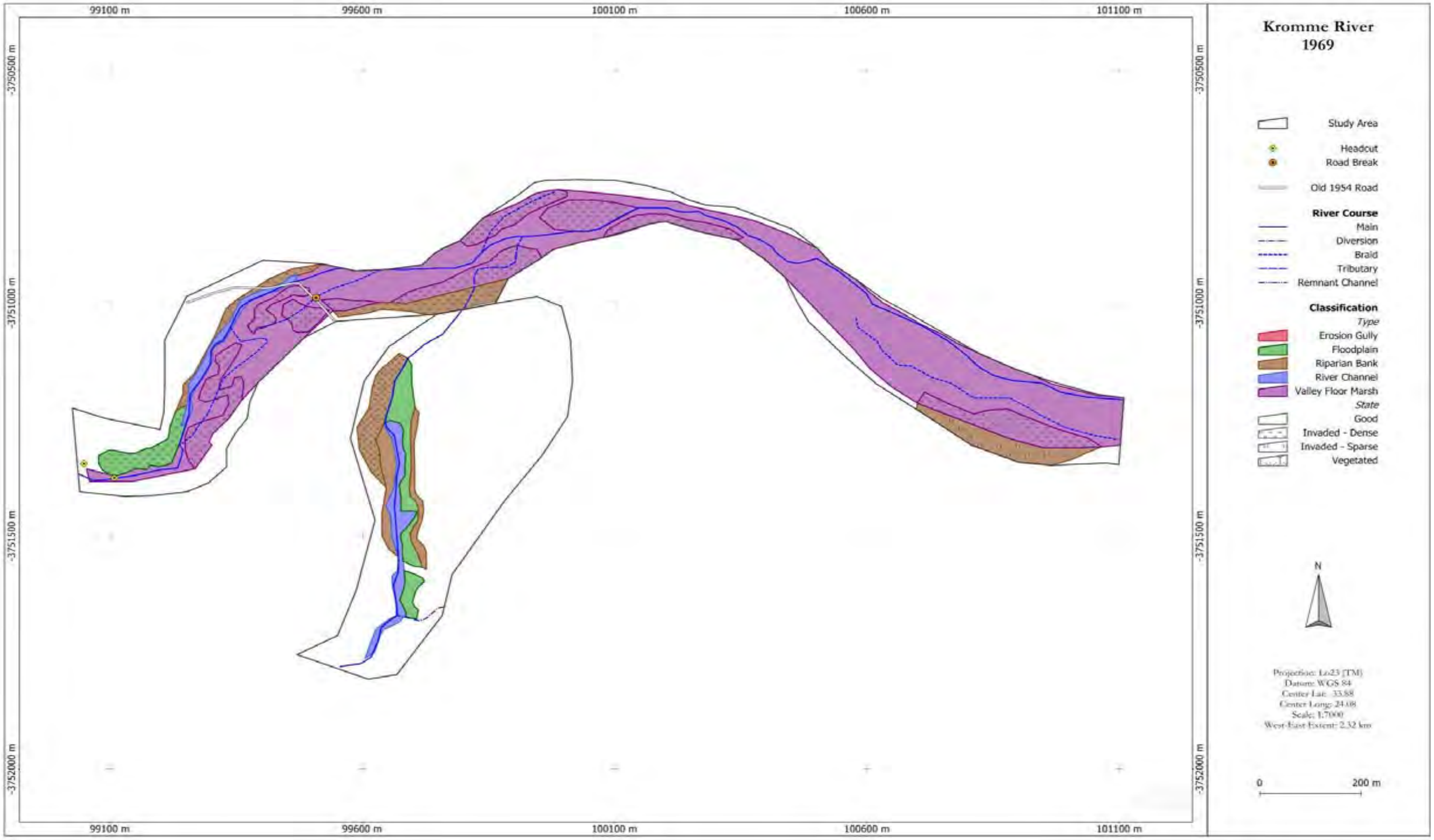

Fig 4.9: The map of Companjesdrift peat basin showing the areas of transformed land within the study area in 1969, with an increase in the area occupied by alien species

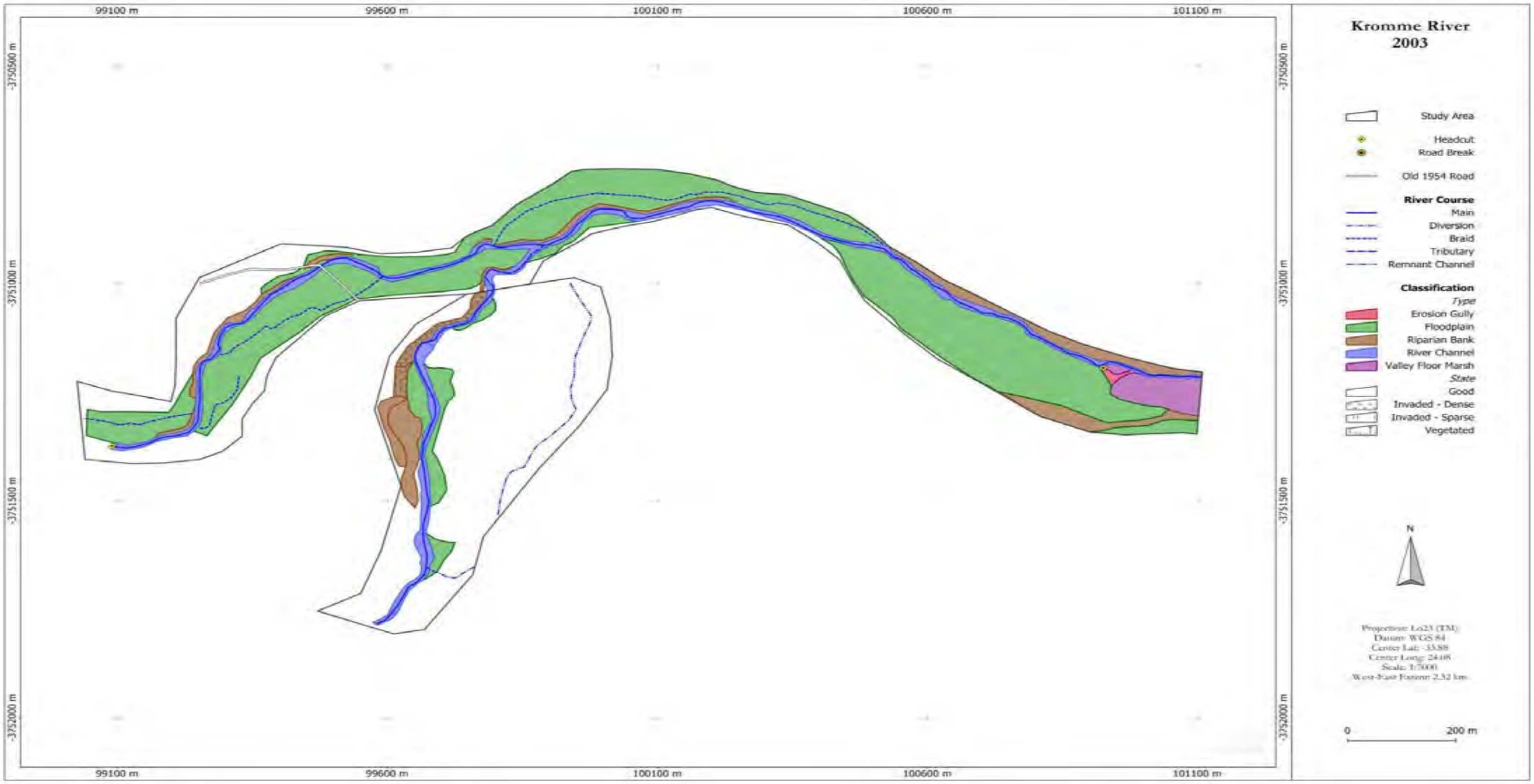

Fig 4.10: The map of Compagniesdfrift peat basin, showing the position and areas of transformed land within the study area in 2003. All alien species were cleared. About 95% of the valley floor marsh was transformed into floodplains and riparian zones, with visible erosional features

Chapter Five: General discussion

5.1 Plant species composition and diversity among sites

There were differences in species composition among the sites (poor, medium and good condition peat basins), as evidenced in HCA classification (Figures 4.2 to 4.5). Species composition in poor condition peat basins of Companjesdrift and Hendrikskraal clustered in group 1, were more dominated by woody alien species such as *Acacia mearnsii and Conyza albida*. Indigenous wetland plants were virtually absent in most degraded sample plots in the floodplains of the peat basin, where alien species were dominant. This suggests that the presence of alien invasives appears to threaten the existence of indigenous wetland plants. The poor condition site was characterized by severe erosion and over grazing and patchiness. Crawley (1986), Pyšek *et al*. (1998) and Richardson *et al*. (2000) reported that disturbed sites are highly suitable for alien species establishment.

Species in the medium and good condition peat basins clustered in groups 2 and 4, 3 and 5 respectively, were predominantly indigenous wetland plants such as *Pronium serratum* and *Phragmites australis*. This could be attributed to the absence of alien species and less impact by over grazing and erosion. Furthermore, the predominance of indigenous wetland plants could be due to the location of these sample plots in permanent and seasonal zones of the peatland, as confirmed by HCA in figure 4.0. This probably explains the presence of these hydrophilic plants in these sample plots.

Heavily impacted sites such as Companjesdrift peat basin recorded low species richness (a total of 90 individuals per site, with an average of four species), whereas the good condition peat basins were highly rich in species (a total of 130 individuals per site, with an average of six different species) (Table 4.0). The classification of species into different clusters reflects in major differences in plant species richness and composition among sites brought about by differences in the condition type in each peat basin. Anthropogenic factors such as cultivation and erosion could be the major determinants accounting for the variations in species richness and composition in this study, since the low number of species recorded was associated with sample plots located on previous farmlands and erosion hot spots. Similar studies indicated that the determinants of species richness and composition of plants in wetlands were land use (Smith and Haukos, 2002), water chemistry (Jeppesen *et al*. 2000; Heegaard *et al*. 2001; Lougheed *et al.* 2001) and size of the wetland (Rørslett, 1991; Vestergaard and Sand-Jensen, 2000; Oertli *et al.* 2002; Jones *et al.* 2003).

Heavy human impacts, according to Molles (1999) generally reduce the number of native species in a community while increasing the presence of alien species. This finding by the author agrees with the observed species richness and composition of Kromme peat basin, where only 23% of the total species identified were indigenous wetland plants and 15% being alien invasives. The impact of drivers of change such as alien invasives, erosion and over grazing, potentially limits indigenous species richness and composition especially in the poor condition peat basins. High species richness is considered as a desirable property of any community or ecosystem and this criterion has dominated most methods for ecological conservation evaluation techniques (Usher, 1986). Furthermore, species richness is regarded as a fundamental measure of both local communities to regional diversity, since this forms the basis of ecological models and conservation strategies (Nicholas and Colwell, 2001). In reference to these authors' arguements, it can be stated in this study that the relatively low species richness recorded in some sample plots may be an indication of current threats to species diversity by drivers of change such as alien invasives, erosion and over grazing.

Generally, species diversity was high among the peat basins (Table 4.3), since the overall diversity index obtained (1.7 to 5.8) was higher than the Shannon-Weiner diversity index that usually lie between 1.5 and 3.5 (Kent and Coker, 1992). On comparative terms, species diversity (mostly grasses), was higher in both good and medium condition peat basins (Krugersland and Kammiesbos), possibly because of less impact by anthropogenic factors compared to Companjesdrift and Hendrikskraal peat basins (poor condition class) which were heavily impacted. This indicates that peat basins that have been impacted through human activities gradually become less diverse over time. The high species diversity according to Molles (1999) occurs in areas where there is a mixture of different species and where the number of individuals in the total population is evenly distributed. Using the same diversity index to assess the impact of human-induced activities on community composition, Walpole *et al.* (2004) also observed that open grasslands had lower Shannon-Weiner index than the denser, richer habitats in the Mara woodlands in Kenya.

Most of the areas in the good and medium peat basins were under permanent and seasonally wet zones respectively. These zones served as a source of water for the livestock within the catchment. The highly diverse community of these peat basins partly indicates less human impact. On comparative terms, it could be argued that the highly diverse good and medium condition peat basins were relatively more stable in terms of land disturbance to that of the poor condition peat basin that was species-poor and appeared dry during most parts of the year. It can therefore be stated that the relationship between high species diversity and the drivers of change is largely dependent on the type of vegetation community, the degree of human impact and other natural factors as well as its location on the landscape.

Although species diversity was high, it was not evenly distributed across the peat basins. This indicates that plant species were evenly distributed only in peat basins (Krugersland and Kammiesbos), where the degree of impact was relatively less, with a higher diversity index as well as higher species evenness than in the poor peat basin of Companjesdrift (Table 4.4). The low evenness in species distribution among sites reflects substantially in species results where 77.8% of the evenness index obtained was less than one, with only 22.2% greater than one. The low Shannon-Weiner index accounted for the unequitable species distribution across the peat basins. The observed pattern in species richness and diversity in this study was largely influenced by environmental drivers of change among sites such as macronutrients, erosion and over grazing. If two communities contain approximately similar number of species, but differ substantially in evenness, the one with the low evenness index would be less diverse than the one with high evenness distribution (Molles, 1999). Kent and Coker (1992) also indicated that the higher the values of the evenness index (J), the more even the species are in their distribution. The reported findings by Molles (1999) and Kent and Coker (1992) are in line with the observed unevenness species distribution in the Kromme peat basins. With this observation, it can be stated that species evenness was high in sample plots were species diversity was high (e.g., Krugersland and Kammiesbos peat basins) and low in sample plots were species diversity was low (e.g., Companjesdrift peat basin).

5.1.1 Influence of environmental drivers of change on vegetation composition

Several studies on species-environment relations have analysed the environmental determinants such as cultivation (Mensing *et al.* 1998), fire and herbivores (Peel *et al.* 2005), altitude and water depth (Ssegawa *et al.* 2004) and altitude and surface area (Rolon and Maltchik 2005) on species diversity and richness on riparian wetland vegetation and other ecosystems. In this study, soil pH, potassium, phosphorus, calcium, erosion and grazing intensity were the key environmental factors that influenced the observed pattern of species distribution in all sample plots as confirmed by CCA results (Figures 4.4 and 4.5). The influence of overgrazing and erosion was found to be important as far as species composition and distribution were concerned. This was because a decrease in plant species was expected as overgrazing and erosion intensified: a factor that probably accounted for the variations in species richness and diversity in the poor, medium and good condition peat basins. Furthermore, the results of this study showed that peat basins with higher diversity and species richness were characterized by high levels of key macronutrients such as phosphorus, calcium and potassium. Nalubega and Nakawunde (1995) reported that phosphorus was an important macronutrient that sustained the growth of *Cyperus papyrus* dominated vegetation community in Kampala Uganda, while Ssegawa *et al.* (2004) stated that phosphorus contributed the least to explaining sedge assemblages among sites. In this study, however, phosphorus was found to be one of the important environmental variables that influenced species diversity and richness among sample plots in the good and medium condition peat basins.

Although the the high concentration of calcium, phosphorus and potassium may have come from the predominant geologic sandstone formation of the Kromme peatland, with deeper fertile soils, the probable explanation that accounted for the highly diverse communities and species richness (Table 4.3) in the medium and good condition sites, was due to the contribution of agricultural activities within the peat basin to nutrient enrichment. Therefore, agricultural activities such as livestock rearing and orchard plantation, located in the medium and good condition peatlands, could have played a critical role in determining the status of the vegetation community present (e.g., *Pronium serratum, Cynodon dactylon, Pennisetum macrourum* and *Phragmites australis*). Ugolini *et al.* (2001) found out that rock fragments from sandstone and siltstone were a source of high concentrations of exchangeable calcium, potassium and magnesium in northern Italy that supported the growth of grass (e.g. *Agrostis sp*). This finding supports the above argument that the diverse communities from the good and medium peat basins were partly attributed to the presence of high concentration of key macronutrients from the geologic sandstone formation of the peatland.

The low presence of alien invasives from the medium and good condition sites could be attributed to the early establishment of dense stands of indigenous species over alien invasives, leading to the reduction of light penetration into the undergrowth and consequently suppressing the growth of these aliens. Supporting this claim, Tilman (2004) reported that studies with recent invaders suggest that, all things being equal, increasing diversity of native communities should decrease invasion success by decreasing resource availability.

Most of the low species richness and diversity recorded were associated with plots in the poor condition class, much of which has been transformed from pristine marshland into floodplains and riparian zones, with predominantly woody alien invasives. Haigh *et al.* (2002) identified approximately eight major headcuts in channels of the main river course of the Kromme peatland in 1998. The occurrence of severe erosion in some inland wetlands in South Africa indicates early warning symptoms of land degradation (Grundling and van der Berg, 2004), hence the existence of different erosion types (e.g. donga erosion and stream bank erosion) in a significant portion of the peat basins, possibly suggests that the Kromme peatland was under threat.

The influence of overgrazing on poor condition peat basins associated with low species richness and diversity (Table 4.3, Figures 4.5 and 4.6), contrasted with the findings of Chaneton and Facelli (2004), who stated that plant diversity was enhanced at the patch scale by overgrazing in grasslands of the flooding pampa in Argentina. However, Adlar *et al.* (2001) reported that grazing can alter spatial heterogeneity of vegetation through the influence on ecosystem processes and biodiversity. It can therefore be argued that the contrasting finding by Chaneton and Facelli (2004) was on wet grassland community, whereas this study was conducted on a typical valley bottom fen and fynbos peatland. Hence, the influence of grazing on species diversity may vary on different communities.

Axis 1 of the CCA ordination on plant height (Figure 4.5) showed an intercorrelation between erosion and grazing intensity. This indicates that the reduction of ground cover due to overgrazing could render the peat basins vulnerable to erosional processes increase in sediment transport from the slopes of the peat basins. This was evidenced on orthorectified images of the Kromme peat basin (Figure 3.2) where stream bank, channel and headcut erosional features were visible, with little vegetation cover (e.g., Companjesdrift peat basin).

The presence of high concentrations of some key macronutrients (e.g., phosphorus and potassium) in some sample plots were diversity and species richness was low, agrees with the findings by Aerts and Berendse (1988) and Verhoeven *et al.* (1993) who reported that nutrient enrichment, such as phosphorus and nitrogen in several wetlands, led to the overall loss in plant diversity, changes in species composition, replacement of native species to exotics and the conversion of a unique flora by a few common species. It can therefore be argued that the low plant diversity and species richness as recorded in some sample plots could be due to the lack of some key micro nutrients. Furthermore, Aerts and Berendse (1988) and Verhoeven *et al.* (1993) reported that the effect of nutrient enrichment on loss of plant diversity and change in species composition was observed in some wetlands and not in all wetland types. Therefore, the findings by these authors may not be applicable to all wetlands of which the Kromme peatland is an example. This assertion is supported by Bedford *et al.* (1999) who stated that understanding the effects on wetland ecosystem productivity may not be sufficient to predict effects on species diversity, since species may be lost due to particular nutrient limitation.

5.1.2 **Interpretation of changes in the two biggest peat basin conditions (Krugersland and Companjesdrift) examined from aerial images**

Peatland area in both the good and poor condition class decreased between 1942 and 1969, with a slight recovery in the former area after 1969 to 2003. Haigh *et al.* (2002) reported an annual net rate of loss of -0.31% in the Kromme peat basin over a 58 year period (between 1942 and 2000). This figure is comparable to the net annual loss of -0.32% and -0.79% over a 61 year period in the good and poor condition class. Even though there are no figures available indicating the extent of wetland loss worldwide (Moser *et al.* 1997), OECD (1996) estimate that the world may have lost 50% of the wetlands that existed since 1900. Whilst much of the loss occurred in the northern countries during the first half of the century, loss in wetland area in tropical and subtropical regions begun in the 1950s, with increasing conversion to agricultural activities being the principal cause (OECD, 1996).

Overall losses in peatland area, which were originally in a pristine state, can largely be attributed to the impacts of alien invasives, erosion processes and agricultural activities (Figures 4.8 to 4.10, Table 4.6a & b). Heavily eroded and overgrazed areas (e.g., Companjesdrift peat basin) were dominated by alien invasives such as *Acacia mearnsii, Rubus cuneifolius and Conyza albida*). The findings by Crawley (1986); Pyšek *et al*. (1998); Richardson *et al*. (2000) further confirmed that disturbed sites were highly suitable for alien species establishment.

Increased dominance of alien invasives in some parts of the peat basins was as a result of more land being converted into agricultural use, leading to a disturbance of indigenous ground cover. This was evidenced in some parts of the good and poor peat basins which were previously farmlands, dominated by alien invasives. It is thought that the increase in agricultural activities especially in the good condition sites could be attributed to the deep nature of the peat soil, which facilitated easy drainage and hence yielded a good crop harvest. Haigh *et al*. (2002) reported that the Kromme peatland has been subjected to higher impacts through agricultural activities since 1775 as a result of early European settlement. The gradual transformation of the original pristine peat basins into floodplains between 1942 and 2003 (Figures 4.8 to 4.10), due to alien invasion, erosion and agricultural activities, has impacted on plant diversity and distribution. Species invasion has had a varied range of impacts on wetland communities and ecosystems, as it represents a key threat to the ecological integrity and functioning of such ecosystems (Ramsar Convention, 1996). Similar threats to plant diversity by alien trees and shrubs (e.g. dense stands of *Acacia cyclops*) have been observed within the the Cape Peninsula in South Africa (Richardson *et al.* 1996).

The most startling change from the analyses of the peat basin was the gradual recovery of the marsh peatland in both good and poor condition class between 1969 and 2003. The reason for this can be attributed to two reasons: (1) environment related or (2) desktop analysis distortions. The environment related factors include the following: (a) the building of gabions at key points noted for their historical vulnerability to erosional activities, (b) the reduction in the number of hectares for agricultural purposes and (c) the clearing of alien invasives by Working for Wetlands Project from 2000 to 2003. Desktop related distortions include the difference in methods employed for orthorectification and parallax. However, the transformed areas where cultivation was taking place in Krugersland basin and the Companjesdrift have lost their natural ecological functional role. Land use and land cover change can be a major threat to biodiversity as a result of the destruction of the natural vegetation and the fragmentation of ecosystems (Verburg *et al.* 2006).

The occurrence of flood events in 1956, 1968 and 1981 (Figure 4.7), regarded as a natural driver of land use change, is thought to have contributed to the spread of alien invasives through the spread of their seeds as well as reduce the size of the peatland through sediment transport and deposition. Disturbed habitats with the possible immigration of fruit through water are more easily invaded (Pyšek and Pyšek 1995; Pyšek *et al.* 2002). The flood events may have contributed to reducing indigenous species diversity over time, as was observed in the analysis of species diversity (Table 4.3 and 4.4) where only two sample plots from good (Krugersland) and medium (Kammiesbos) classes had values above one (1.161 and 1.084 respectively). A study in Argentina confirmed that flooding reduced both stand and patch species diversity in a wet grassland community (Chaneton and Facelli, 2004). The peat layers on the stream banks in some parts of Companjesdrift peat bassin were heavily eroded to bedrock. This was in part linked to the rooting pattern of *Acacia mearnsii* presence on the fringes of the riparian zone that lacked the binding properties on soil substrate. The pronounced root structure of *Acacia mearnsii* has the tendency to destabilize stream bank soil when uprooted by rapid surface run-off (Haigh *et al.* 2002).

5.1.3 Conclusions

The observed pattern in community distribution, species richness and diversity indicate variations in the different peatland condition classes. This was largely due to the influence of edaphic (erosion, soil pH, phosphorus, potassium and calcium), biotic factors (alien invasives) and overgrazing. These environmental variables accounted for 40.7% and 56.4% of the explained community variation for ground cover and plant height respectively.

High species richness and diversity were attributed to less human impact and high concentrations of key macronutrients. Low species diversity and richness were attributed to anthropogenic factors. Plant species were not evenly distributed, since 77.8% of the Shanon-Weiner index obtained was less than one. The unequal distribution of plant species could in part be attributed to the transformation of pristine land by both anthropogenic and other natural causes. Of the 65 species identified, 23% were indigenous wetland plants, 61.6% were non-wetland plants, with the remaining 15.4% representing alien invasives. Plant species were predominantly grasses.

GIS analysis of aerial images of the study area showed a progressive loss of the good and poor peat basins from pristine state to transformed land from 1942 to 1969, with a slight recovery from 1969 to 2003. Annual net rate of loss was -0.32% and -0.79% respectively. The slight recovery of the peatland area was due to the reduction in the number of hectares put under cultivation and the construction of gabions. The transformation of the peat basins was largely due to the major drivers of change such as alien invasives, erosion, agricultural activities, over grazing and sediment deposits. The net annual rate of increase of alien invasives in particular was +0.82% and +1.63% respectively in the good and medium condition peat basins.

The observation of historical land use variations and its relation to variations in community distribution indicated that the future likely trend will be that of a gradual dominance of alien invasives (e.g., *Acacia mearnsii*) over indigenous species. This phenomenon may cause the peatland to loose its ecological and economic role. Further more, key wetland species such as *Pronium serratum* might only be found in pockets of water zones all year round, since the dominance of alien invasive such as *Acacia mearnsii* may lead to a reduction in the water table, due to their high competitive edge in the exploitation of water over indigenous species. Therefore most hydrophilic wetland plants will gradually be extinct.

5.1.5 **Recommendation**

a. It is evident that the Kromme peat basins have been impacted largely due to anthropogenic causes. It is therefore recommended that Working for Wetlands Project, under the ministry of Water Affairs and Tourism, should draw up an enforceable management plan that will ensure that users of peatland resources take part in sustainable management of this unique wetland type, which is considered rare in Africa.

b. Since peatlands are regarded as unique wetlands in terms of their role in carbon sequestration, it is recommended that a detailed study be carried out to determine the state of Kromme peatland functionality in terms of carbon sink/source processes, in the face of human impacts and other natural threats to its sustainability.

c. Priority attention should be given to the rehabilitation of heavily degraded sites of the peat basins, so as to prevent further damage.

References

1. Adam, J. and Grundling, P-L., 2004. Introduction to Mires and Peatlands of South Africa: International Mire Conservation Group. Pre-Congress field trip. South African Mires and Peatlands. 6 p.

2. Adlar, P.D., Raff, D.A. and Lauenroth, W.K. 2001. The effects of grazing on a spatial heterogeneity of vegetation. *Oecologia*, 128, 465-479.

3. Aerts, R. and Berendse, F. 1988. The effect of increased nutrient availability on vegetation dynamics on wetlands dynamics in wet heathland. *Vegetatio*, 76, 63-69.

4. Alcamo, J. and Bennett, E.M. 2003. *Millennium ecosystem assessment. Ecosystems and human well-being. A framework for assessment.* Island Press. Washington. 87 p.

5. Anonymous. 1996. The Mediterranean wetland strategy: 1996-2006. Venice. 16 p.

6. Barnett, D.T. and Stohlgren, T.J. 2002. A nested-intensity design for surveying plant diversity. *Journal of Biodiversity and Conservation*, 12 (2), 255-278.

7. Bedford, B.L., Walbridge, M.R. and Aldous, A. 1999. Patterns in nutrient availability and plant diversity of temperate North American wetlands. *Ecology*, 80 (7), 2151-2169.

8. Bond, W.J. 1981. Vegetation gradients in the southern Cape Mountains. M.Sc. thesis. University of Cape Town. In International Mires Conservation Group. 2004. Pre-Congress field trip. Southern African mires and peatlands. 76 p.

9. Brinson, M.M. and Malvarez, A.I. 2002. Temperate freshwater wetlands: types, status and threats. *Journal of Environmental Conservation*, 29, 115-133.

10. Bunn, S.E., Boon, P.I., Brock, M.A. and Schofield, N.J. 1997. National wetlands R&D programme: scoping review. Land Water Resources Research and Development. Canberra.

11. Chaneton, E.J. and Facelli, J.M. 2004. Disturbance effects on plant community diversity: spatial scales and dominance hierarchies. *Plant Ecology,* 93, 143-155.

12. Collins, N.B. 2005. Wetlands: The basics and some more. Free State, Department of Tourism, Environmental and Economics Affairs.

13. Crowford, R.M.M. and Wishart, D. 1967. A rapid multivariate method for the detection and classification of ecologically related species. *Journal of Ecology*, 55, 505-24

14. Cronk, Q.C.B and Fuller, J.L. 2001. Plant invaders: the threats to natural ecosystems. Earthscans Publications, London.

15. Crawley, M.J. 1986. The population biology of invaders. Philosophical Transactions of the Royal Society of London. Serie B, *Biological Sciences*, 314 (1167), 711-731.

16. David, P.B., Leslie, B.B., Kristine, A.C. and Andrew, T.W. 2000. Water Environment Federation (Published in the Proceedings of the Conference Watershed 2000). Vancouver, British Columbia.

17. David, S.W., David, R., Jason, D., and Ali, P. and Elizabeth, L. 1998. Quantifying threats to imperiled species in the United States. *BioScience*, 48 (8), 607-615.

18. Davies, J. and Claridge, G.F. (Eds.). 1993. *Wetlands benefits: The potential for wetlands to support and maintain development.* AWB publication 87, IWRB Publication 27, WA Publication 11. 3 p.

19. Dublin, H.T., Sinclair, A.R.E. and McGlade, J. 1990. Elephants and fire as causes of multiple stable states in Serengeti-Mara woodlands. *Journal of Animal Ecology,* 59: 1147-1164.

20. Dugan, P. (ed.). 1993. *Wetlands in danger-A world conservation atlas*. Oxford University press. New York.

21. Fertlizer Society of South Africa. 1974. Manual of soil analysis methods. FSSA Publications 37. 10 p.

22. Frazier, S. 1996. An overview of the world's Ramsar sites. Wetlands International Publications 39. 58 p.

23. Franklin, T., Asher, J. and Barclay, E. 1999. Invasion of the aliens: exotic plants impacts on wildlife. *Wildlife Society Bulletin,* 27(3), 873-875.

24. Gibson, D.J., Seastedt, D.R. and Briggs, D.C. 1993. Management practices in tallgrass prairie: large and small-scale experimental effects on species composition. *Journal of Applied Ecology*, 30, 247-255.

25. Gorham, E. 1995. The biogeochemistry of northern peatlands and its possible responses to global warming: In *Biotic feedbacks in the global climate systems,* Woodwell. G.M. and Mackenzie, F.T. (eds.). New York: Oxford University Press. pp 169-187.

26. Grundling, P-L., 2004. Peatlands on the brink of the final phase in the extinction of a unique Wetland type in Southern Africa. Working for Wetlands Programme, National Botanical Institute, Pretoria. IMCG Scientific Symposium, September 2004. International Mire Conservation Group. 5 p.

27. Grundling, A.T. and Van de Berg, E.C., 2004. Evaluation of remote sensing sensors for auditing and monitoring of rehabilitated wetlands. Compiled for Department of Agriculture: Directorate Land and Resources Management. ISCW Report number: GW/A/2003/59. Project 51/038.

28. Grundling, P-L. and Dada, R.(eds.). 2004. International Mire Conservation Group. Pre-Congress field trip. Southern African Mires and Peatlands. 1 p.

29.Grundling, P-L., Marnewick, G.C., Grundling, A. and Grobler, R. 2004. The Steekamberg Plateau. International Mire Conservation Group. Pre-Congress field trip. Southern African Mires and Peatlands. 19 p.

30. Grundling, P-L. and Marneweck, G.C. 1999. Mapping, characterization and monitoring of the highveld peatlands Compilation of existing data and evaluation of inventory methodology. Compiled for the Department of Agriculture, Directorate Land and Resources Management on behalf of the A gricultural Research Council: Institute for Soil Water and Climate.

31. Groombridge, B. 1992. *Global biodiversity, status of the earth's living resources*. World Conservation Monitoring Centre. Chapman and Hall, London. 297 p.

32. Haigh, E.A., Grundling, P-L. and Illgner, P. M., 2002. Report on the scoping study on the status of the Kromme River peatland complex and recommended mitigatory measures. Department of Water Affairs and Forestry Project X832633.

33. Hails, A.J. (ed.). 1997. *Wetlands, biodiversity and the Ramsar Convention: the role of the Convention in the conservation and wise use of biodiversity*. Ramsar Convention bereau, Gland, Switzerland.

34. Henderson, P.A. and Seaby, R.M. 1999. Community analysis package 1.14. Pisces Conservation Ltd. IRC House, Pennington, Lymington, S041 8GN, UK.

35. Henderson, P.A. and Seaby, R.M. 2000. Environmental community analysis 1.3. Pisces Conservation Ltd. IRC House, Pennington, Lymington, S041 8GN, UK.

36. Heegaard, E., Birks, H.H., Gibson, C.E., Smith, S.J. and Wolfe-Murphy, S. 2001. Species-environmental relationship of aquatic macrophytes in northern Ireland. *Aquatic Botany*, 70, 175-223.

37. Hill, M.O. and Gauch, H.G. 1980. *Detrended correspondence analysis, an improved ordination technique. Vegetatio*. In: Kent, M. and Coker, P. 1992. *Vegetation description and analysis. A practical approach*. John Wiley and Sons Ltd, West Sussex- England. 223 p.

38. Hollis, G.E. 1992. The causes of wetland loss and degradation in the Mediterranean. In: Finlayson, C.M., Hollis, G.E. and Davis, T.J. (eds.). Managing Mediterranean wetlands and their birds. Proc. Symp., Grado, Italy, 1991. IWRB Spec. Publ. No. 20, Slimbridge, UK, 285 p.

39. Hollis, G.E. 1993. Goals and objectives of wetland restoration and rehabilitation. In: Moser, Prentice and van Vessem. 1992.

40. Humphries, S.E. Graves, R.H. and Mitchell, D.S. 1991. Plant invasions of Australian ecosystems. A status review and management directions. *Kowari*, 2, 1-134.

41. Jeppesen, E., Jensen, J.P., Søndergaard, M., Lauridsen, T. and Landkildehus, F. 2000. Trophic structure, species richness and biodiversity in Danish lakes: changes along a phosphorus gradient. *Freshwater Ecology*, 45, 201-218.

42. Johnson, M.R. 1976. Stratigraphy and sedimentology of the Cape and Karoo Sequences in the Eastern Cape Province. PHD thesis, Rhodes University. In International Mires Conservation Group. 2004. Pre-Congress field trip. Southern African Mires and Peatlands. 74 p.

43. Johnston, C.A. and Naiman, R.J. 1990. The use of a geographic information system to analyse long-term landscape alteration by beaver. *Landscape Ecology*, 4 (1), 5-19.

44. Kent, M. and Coker, P. 1992. *Vegetation description and analysis. A practical approach*. John Wiley and Sons Ltd, West Sussex- England. 162 p.

45. Keddy, P.A. and Reznicek, A.A. 1986. Great Lakes vegetation dynamics: the role of fluctuating water levels and buried seeds. *Journal of Great Lakes Research,* 12, 25-36.

46. Keddy, P.A. *Wetland ecology. Principle and conservation*. Cambridge University Press.

47. Kotze, D.C. and Breen, C.M. 1994. Wetlands and people. What values do wetlands have for us and how are these affected by our land use activities? Wetland Booklet 1. Share-Net. Umgeni Valley.

48. Kotze, D.C., Marneweck, G.C., Batchelor, A.L., Lindley, D.S and Collins, N.B. 2005. Wet-Ecoservices: A Technique for rapidly assessing ecosystem services supplied by wetlands. Department of Tourism, Environmental and Economic Affairs, Free State. 5 p.

49. Kotze, D., Grundling, P-L. and Silva, J. 2004. Socio-economic impacts on the tropical peat swamp forests of Maputaland, Southern Africa: In International Mire Conservation Group. Pre-Congress field trip. Southern African Mires and Peatlands. 47 p.

50. Kueffer, C. and Vos, P. 2004. Case studies on the status of invasive woody plant species in the western Indian Ocean. 5. Seychelles. Forest Health and Biosecuirty Working Papers FBS/4-5E. Forestry Development. Food and Agricultural Organisation of the United Nation, Rome, Italy.

51. Larson, J. 1993. Is ‘No net loss’ a useful concept for wetland conservation? *Waterfowl and wetland conservation in th 1990,s : a global perspective*. Proceeding of the IWRB Symposium, St. Petersburg, Florida. November 1992. IWRB Special Publication 26.

52. Lacerda, L.D. 1993. *Conservation and sustainable utilization of mamgrove forests in Latin America and Africa regions*. International Society for Mangrove Ecosystem. In: Hails, A.J. (ed.). 1997. *Wetlands, biodiversity and the Ramsar Convention: the role of the Convention on wetlands in the conservation and wise use of biodiversity*. Ramsar Convention Bureau. Ministry of Environment and Forest, India.

53. Lougheed, V.L., Crosbie, B. and Chow-Fraser, P. 2001. Primary determinants of macrophyte community structure in 62 marshes across the Great Lakes basin: latitude, land use and water quality effects. *Canadian Journal of Fisheries and Aquatic Sciences,* 58, 1603-1612.

54. McGarigal, K., Cushman, S. and Stafford, S. 2000. *Multivariate statistics for wildlife and ecology research*. Springer-Verlag, New York, Inc. USA. 92 p.

55. Mailu, A.M. 2001. Preliminary assessment of the social, economic and environmental impact of water hyacinth in Lake Victoria basin and the status of control, biological and integrated control of water hyacinth (*Eichhornia crassipes*). ACIAR Proceeding No 102.

56. Marnewerk, G., Grundling, P-L. and Miller. 2001. In: South African Peatland Eco-regions. Pre-Congress field trip, 2004. International Mire Conservation Group. 9 p.

57. Maltchik, L., Oliveira, G.R., Rolon, A.S. and Stenert, C. 2005. Diversity and stability of aquatic macrophyte community in three shallow lakes associated to a floodplain system in the south of Brazil. *Interciencia*, 30, 166-170.

58. Mirongo, J.M. 2004. Geograhic information systems (GIS) and remote sensing in the management of shallow tropical lakes. *Applied Ecology Environmental Resources*, 2, 83-103.

59. Malik, A. 2006. Environmental challenge *vis a vis* opportunity: the case of water hyacinth. *Environmental International,* 33 (2007), 122-138.

60. Mensing, D.M., Galatowitsch, S.M. and Tester, J.R. 1998. Anthropogenic effects on the biodiversity of riparian wetlands of a northern temperate landscape. *Journal of Environmental Management*, 53 (4), 349-377.

61. Molles, M. 1999. Ecology: concept and applications. 1st ed. Boston: McGraw Hill Companies. Inc. 403 p.

62. Moser. M., Crowford. P. and Scott, F. 1996. A global review of wetland loss degradation. In: Papers, Technical Session B. Vol. 10/12B, Proc. 6th Meeting of the Conference of Contracting Parties, Brisbane, Australia, 19-27 March 1996. Ramsar Convention bureau, Gland, Switzerland. pp 21-31.

63. Mitsch, W.J. and Gooselink, J.G. 2000. *Wetlands.* Third edition. John Wiley and Sons, Inc. New York.

64. Mitsch, W.J. and Gooselink, J.G. 2002. *Wetlands*. John Wiley and Sons, Inc. New York 25 p.

65. Mooney, H.A, Hamburg, S.P. and Drake, J.A. 1986. The invasion of plants and animals. Pp 250-272. In: Mooney, H.A and Drake, J.A. (eds.). *Ecology of biological invasions of North America and Hawaii*. Springer-verlag. New York.

66. Mueller-Dombois, D. and Ellenberg, H. 1974. *Aims and methods of vegetation ecology*. Wiley New York. 62 p.

67. Mwendera, E.J., Mohamed, S.M.A. and Dibabe, A. 1997a. Effects of livestock grazing on surface run-off and soli erosion from sloping pasture lands in the Ethiopian highlands. *Australian Journal of Experimental Agriculture,* 37, 420-421.

68. Mwendera, E.J., Mohamed, S.M.A. and Zurihun, W. 1997b. Vegetation response to cattle grazing in the Ethiopian highlands. *Agriculture, Ecosystems and Environment*, 64, 43-51.

69. Mooney, H.A., Hamburg, S.P. and Drake, J.A. 1986. The invasion of plants and animals into California. In: H.A. Mooney and J.A. Drakes (eds.), *Ecology of Biological of North America and Hawaii.* Springer-Verlag. pp 250-272.

70. Nalubega, M. and Nakawunde, R. 1995. Phosphorus removal in macrophyte based treatment. 21st WEDC Conference: Sustainability of water and sanitation systems. Kampala, Uganda.

71. Natural Bridge Communications, 2005. Save the wetlands in the Kromme River from extinction. *Working for Wetlands programme. Nelson Mandela Metropolitan Municipality newsletter*.1 pp.

72. Nicholas, J.G. and Colwell, R.K. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparism of species richness. *Ecology Letters*, 4(4), 379-391.

73. Noest, V. and van der Maarel, E. 1989. *A new dissimilarity measure and a new optimality criterion in phytosociological classification. Vegetatio*. In: Kent, M and Coker, P. 1992. *Vegetation description and analysis. A practical approach*. 281 p.

74. OECD/IUNC. 1996. Guidelines for aid agencies for improved conservation and sustainable use of tropical and sub-tropical wetlands. Organization for Economic co-operation and Development .Paris.

75. Oertli, B., Joey, D.A., Castellia, E., Juge, R., Cambin, D. and Lachavanne, J.B. 2002. Does size matter? The relationship between pond area and biodiversity. *Biological Conservation*, 104, 59-70.

76. O'Connell, M.J. 2003. Detecting, measuring and reversing changes in wetlands. *Wetlands Ecology and Management*, 11, 397-401. Kluwer Academic Publishers, Netherlands.

77. O'Connor, T.G. 2005. Influence of land use on plant community composition and diversity in Highland Sourveld grassland in the southern Drakensberg, South Africa. *Journal of Applied Ecology*, 42 (6), 975-988.

78. Palmer, R.W., Turpie, J., Marnewick, G.C. and Batchelor, A.L. 2002. Ecological and economic evaluation of wetlands in the Upper Olifants River Catchment, South Africa. WRC Report No. 1162/1/02. 1 p.

79. Peel, M.J.S., Kruger, J.M. and Zacharias, P.J.K. 2005. Environmental and Management determinants of vegetation state on protected areas in the eastern Lowveld of South Africa. *African Journal of Ecology*, 43, 352-361.

80. Pooley, E. 1998. *A field guide to wild flowers of KmaZulu-Natal and the Eastern Region*. Natal Floral Publication Trust. pp 45-257.

81. Pyšek, P. 1998. Is there a taxonomic pattern to plant invasions? *Oikos*, 82, 282-294.

82. Ramsar Convention. 1996. Third Meeting of the Conference of the Parties to the Convention on Biological Diversity, Buenos Aires, Argentina, 14-15th November, 1996. UNEP/CBD/COP/3/Inf.21.

83. Rejmánek, M. and Randall, J.M. 1994. Invasive alien plants in California: 1993 summary and comparism with other areas in North America. *Madrõno*, 46, 166-171.

84. Richardson, D.M., van Wilgen, B.W., Higgins, S.I., Trinder-Smith, T.H., Cowling, R.M. and Mckell, D.H. 1996. Current and future threats to plant biodiversity on the Cape Peninsula, South Africa. *Journal of Biodiversity and Conservation*, 5 (5), 607-647.

85. Richardson, D.M., Pysek, P., Rejmanek, M. Barbour, M.G. Panetta, F.D. and West, C.J. 2000. Naturalization and invasion of alien plants: Concepts and definitions. *Diversity and Distributions,* 6(2), 93-107.

86. Rouget, M., Richardson, D.M., Cowling, R.M., Lloyd, J.W. and Lombard, A.T. 2003. Current patterns of habitat transformation and future threats to biodiversity in terrestrial ecosystems of the Cape Floristic Region of South Africa. *Biological Conservation*, 112, 63-85.

87. Rolon, S.A. and Maltchik, L. 2005. Environmental factors as predictors of aquatic macrophyte richness and composition in wetlands of souththern Brazil. *Hydrobiologia,* 556, 221-231.

88. Rørslett, P. 1991. Principal determinants of aquatic macrophytes richness in northern European lakes. *Aquatic Botany*, 39, 173-193.

32. Ssegawa, P., Kakudidi, E., Muasya, M. and Kalema, J. 2004. Diversity and distribution of sedges on multivariate environmental gradients. *African Journal of Ecology,* 42 (1), 21-33.

89. Sneath, P.H.A. and Sokal, R.R. 1973. *Numerical taxonomy*. Freeman, San Francisco. In: Kent, M and Coker, P. *Vegetation Description and Analysis. A practical approach*. John Wiley and Sons Ltd. West Sussex- England. 282 p.

90. Smith, L.M. and Haukos, D.A. 2002. Floral diversity in relation to playa wetland area and watershed disturbance. *Conservation Biology*, 16, 964-974.

91. Stanners, D. and Bourdeau, p., 1995. *Europe's environment*: *The Dobris assessment*. European Environment Agency, Copenhagen. 104 p.

92. Symoens, J.J., and Micha, J.C., 1994. *Seminar "The management of integrated freshwater agro-piscicultural ecosystems in tropical areas". Technical Centre for Agricultural and rural Co-operation (CTA).* Royal Academy of Overseas Sciences (Brussels). pp169 –186.

93. Schmid, U.M., and Vincke, M.M.H., 1981. *The technical economic, financial and social feasibility of small -scale rural fish culture development in Rwanda,* - Aquaculture Development and cultural development fisheries Department, FAO, Rome, 117 p. + appendix.

94. Stohlgren, T. J., Falkner, M.B., and Schell, L. D., 1995. A Modified-Whittaker nested vegetation sampling method. *Plant Ecology,* 117 (2), 113-121. Kluwer Academic publishers, Belgium.

95. Stohlgren, T.J., Binkley, D., Chong, G.W., Kalkhan, M., Schell, L.D., Bull, K.A., Otsuki, Y., Newman, G., Bashkin, M., and Son, Y. 1999. Exotic plant species invaded hot spots of native plant diversity. *Ecological Monographs,* 69(1), 25-46. Ecological Society of America.

96. Taylor, R.D., Howard, G.W. and Begg, G.W. 1995. Developing wetland inventories in Southern Africa: a review. *Vegetatio*, 118, 57-79.

97. Tilman, D. 2004. Stochastic theory of resource competition, community assembly and invasions. *Proceedings of the National Academy of Sciences USA,* 101, 10854-10861.

98. Tchamba, M.N. 1995. The impact of elephant browsing on the vegetation in Waza National Park, Cameroon. *Journal of African Ecology*, 33, 184-193.

99. Toerien, D.K. 1979. Geology of the Oudtshoorn area. Department of Mines Geological Survey., Government Printer Pretoria: In International Mires Conservation Group. 2004. Pre-Congress field trip. Southern African Mires and Peatlands.76 p.

100. Tom, K. 1997. Overview of African wetlands. Technical officer for Africa, Ramsar Bureau Switzerland. In Wetlands, biodiversity, and the Ramsar Convention: the role of the Convention on wetlands and the conservation and wise use of biodiversity. Ramsar Bureau. Ministry of Environment and Forest. India. http://www.ramsar.org. 1p.

101. Truswell, K.F. 1977. The geological Evolution of South Africa. Purnell Cape Town. In: International Mire Conservation Group. 76 p.

102. TerBraak, C.J.F. 1986. *Canonical correspondence analysis*: *A new eigenvector technique for multivariate Multivariate Statistics for Wildlife and Ecology Research*. Springer-Verlag, New York Inc. USA. *Direct gradient analysi*s. Ecology. In: McGarigal, K., Cushman, S. and Stafford, S. 2000. 70 p.

103. TerBraak, C.J.F. and Prentice, I.C. 1988. *A theory of gradient analysis*, *Advances in Ecological Research.* In: Kent, M and Coker, P. 1992. *Vegetation description and analysis. A practical approach*. John Wiley and Sons Ltd. West Sussex- England. 229 p.

104. Usher, M.B. (ed.). 1986. *Wildlife conservation evaluation*. Chapman and Hall, London. In: Kent, M. and Coker, P. 1992. *Vegetation description and analysis. A practical approach*. John Wiley and Sons Ltd, West Sussex- England. 103 p.

105. UNESCO, 1994. Convention on Wetlands of International Importance especially as waterfowl habitat. Ramsar 22. UNESCO Office of International Standards and Legal Affairs, Paris, 3 p.

106. Ugolini, F.A., Guiseppe C., Dufey, J.E., Agnelli, A. and Certini, G. 2001. Exchangeable Ca, Mg and K of rock fragmented and fine earth from sandstone and siltstone derived soils and their availability grass. *Journal of Plant nutrition and Soil science*, 164 (3), 309-315.

107. Verhoeven, J.T.A., Kemmers, R.H. and Koerselman, W. 1993. Nutrient enrichment in freshwater wetlands. In: *Landscape ecology* (eds.). Vos, C.C. and Opdam, P. Chapman and Hall. London, UK.

108. Vestigaard, O. and Sand-Jensen, K. 2000. Aquatic macrophyte richness in Danish lakes in relation to alkanity, transparency and lake area. *Canadian Journal of Fisheries and Aquatic Sciences*, 57, 2022- 2031.

109. van der Merwe, A.J., Johnson, J.C. and Ras, L.S.K. 1984. An NH_4CO_3-NH_4F-$(NH_4)_2$ EDTA method for the determination of extractable P, K, Ca, Mg, Cu, Fe, Mn and Zn in soils. *SIRI Inf. Bull*.B2/2.

110. van Oudtshoorn, F. 1999. *Guide to grasses of Southern Africa*. Briza Publications. pp 56-247.

111. van Zuidam, R.A. 1985. *Aerial photo-interpretation in terrain analysis and geomorhologic mapping.* Smits Publishers. 268 p.

112. Walpole, M.J., Nabaala, M. and Matankory, C. 2004. Status of the Mara woodlands in Kenya. *African Journal of Ecology,* 42, 180-188

113. White paper on the conservation and sustainable use of South Africa's biological diversity: draft for discussion. 1997. Government gazette 385 (18163). Department of Environmental Affairs and Tourism. 136 p.

114. Young, J., Halada, L., Kull, T., Kuzniar, A., Tartes, U., Uzunov, Y. and Allen, W (eds.). 2004. *A Report of the BIOFORUM project*. Conflict between human activities and the conservation of biodiversity in agricultural landscapes, grasslands, forests, wetland and uplands in the Acceding and Candidate Countries (ACC). 62 p.

Appendix 1

List of plant species sampled in the $1m^2$ quadrats in the Kromme peatland complex

Scientific names	Common name
Acasia cyclops	-
Acasia longifolia	Brittle willow
*Acasia mearnsii**	Black wattle
Agrostis lachnantha	Bent grass
Arundinella nepalensis	River grass
Athanasia sp	-
Bambusa balcooa	Blue gam
Berkheya sp	-
*Bidens pilosa**	-
Brachiaria brizantha	Common signal grass
Buddeja saligna	-
Salix mucronata	Cape willow
Carpobrotus edulis	-
*Centella asiatica**	Marsh pennywort
Chrysanthemiodes monolifera	-
Cirsium vulgare	Scotch thistle
Clifortia sp	-
*Conyza albida**	-
*Conyza scabrida**	-
Chenopodium album	-
Cynodon dactylon	Couch grass
Cyperus denudatus	Winged sedge/ Water grass
Cyperus textiles	Tall star sedge
Cyperus rotundus	Sedges
Digitaria eriantha	Common finger grass
Eriocephalus sp	-
Eragrostis chloromelas	Curly leaf
Eragrostis curvula	Weeping love grass
*Eucalyptus grandis**	-
Euryops tysonii	-
Freylinia sp	-
Fuirena hirsuta	-
Galenia secunda	-
Helichrysom felinum	-
Hyparrhenia hirta	Common thatching grass
*Hypochaeris radicata**	Hairy wild letuce
Imdigifera hedyantha	Black-bud indigo
Juncus lomotophyllus	Leafy juncus

Leonotis leonorus	-
Lobelia sp	Wild lobelia
Melinis repens	Natal red top
Myrica serratha	-
Nymphaea nouchali	Water lily
Paspalum dilatatum	Dallis grass
Pelargonium luridium	Stalk-flowered pelargonium
Pennisetum llandestinum	-
Pennisetum macrourum	Riverbed grass
Pennisetum setaceum	Fountain grass
*Persicaria lapathifolia**	Spotted knotweed
Phragmites australis	Common reed
Pronium serratum	Palmiet
Pteridium aquilinum	Bracken
Restio zulensis	Zulu restio/Cape reed
Rhus dentata	-
Rhus glauca	-
Rhus rehmanniana	-
Ricinis communis	-
*Rubus rigidus**	Bramble
Salix babylonica	-
Selago c.p. corymbosa	-
Senecio sp	-
Stoebe sp	-
Thelypterus sp	-
Typha capensis	Bulrush/ Cat tail
Xanthum spinosum	-
Zantedeschia albomaculata	Arrow-leaved arum

- = no common name found for the associated plant species
* = Alien invasive species

Appendix 2

List of plant species richness recorded in the subquadrats nestled in Whittaker plots

Plot no				
	10m²	**10m²**	**100m²**	**1000m²**
KA	***Pennisetum macrourum***	***Eragrostis curvula***	***Rhus glauca***	***Leonotis leonorus***
	Conyza scabrida	***Pennisetum macrourum***	***Digitaria eriantha***	***Rhus dentata***
	Digitaria eriantha	***Leonotis leonorus***	***Pennisetum macrourum***	***Selago corymbosa***
	Rhus dentata	***Digitaria eriantha***	***Eragrostis curvula***	***Conyza scabrida***
	Eragrostis curvula	***Selago corymbosa***	***Phragmites australis***	***Pennisetum macrourum***
		Conyza scabrida	***Selago corymbosa***	***Euryops tysonii***
			Rhus dentata	***Eragrostis curvula***
			Euryops tysonii	***Digitaria eriantha***
				Helichrysum felinum
KB	***Senecio sp***	***Conyza scabrida***	***Acasia mearnsii***	***Euryops tysonii***
	Eragrostis curvula	***Pennisetum macrourm***	***Helichrysum felinum***	***Leonotis leonorus***
	Conyza scabrida	***Acasia mearnsii***	***Digitaria eriantha***	***Selago corymbosa***
	Digitaria eriantha	***Digitaria eriantha***	***Phragmites austarlis***	***Conyza scabrida***
	Rhus dentata	***Pennisetum setaceum***	***Rhus glauca***	***Eragrostis curvula***
	Leonotis leonorus	***Eucalyptus camadulensis***	***Eragrostis curvula***	***Eragrostis chloromelas***
	Rhus glauca	***Helichrysum felinum***	***Rhus rehmanniana***	***Rhus rehmanniana***
	Acasia mearnsii		***Senecio sp***	***Phragmites australis***
	Stoebe sp		***Euryops tysonii***	***Digitaria eriantha***
				Rhus dentata
				Rhus glauca
KC	***Phragmites australis***	***Cyperus denudatus***	***Pennisetum marourum***	***Phragmites australis***
	Helichrysum felinum	***Pennisetum marourum***	***Eragrostis curvula***	***Euryops tysonii***
	Rhus rehmanniana	***Conyza scabrida***	***Digitaria eriantha***	***Pronium serratum***
	Acasia mearnsii	***Pronium serratum***	***Acasia mearnsii***	***Pinus sp***
	Eragrostis chloromelas	***Rhus dentata***	***Cyperus denudatus***	***Eucalyptus camadulensis***
	Eriocephalus sp	***Eragrostis curvula***	***Pronium serratum***	***Digitaria eriantha***
		Digitaria eriantha	***Rhus rehmanniana***	***Eriocephalus sp***
				Leonotis leonorus
				Pennisetum macrourum
				Selago corymbosa
				Acasia mearnsii
				Eragrostis curvula
KD	***Phragmites australis***	***Selago corymbosa***	***Phagmites australis***	***Acasia mearnsii***
	Eragrostis	***Pennisetum macrourum***	***Cyperus denudatus***	***Eragrostis curvula***

	chloromelas			
	Pronium serratum	*Rhus glauca*	*Pronium serratum*	*Stoebe sp*
	Pennisetum setaceum	*Acasia mearnsii*	*Digitaria eriantha*	*Conyza scabrida*
	Cyperus denudatus	*Pronium serratum*	*Rhus dentata*	*Euryops tysonii*
	Pinus sp	*Digitaria eriantha*	*Conyza scabrida*	*Leonotis leonorus*
	Euryops tysonii	*Helichrysum felinum*	*Eucalyptus camadulensis*	*Pronium serratum*
	Pennisetum llandestinum	*Eragrostis chloromelas*	*Pinus sp*	*Digitaria eriantha*
		Phragmites australis		
		Eragrostis curvula		
CA	*Leonotis leonorus*	*Conyza scabrida*	*Conyza albida*	*Helichrysum felinum*
	Cynodon dactylon	*Pronium serratum*	*Leonotis leonorus*	*Conyza scabrida*
	Conyza albida	*Cynodon dactylon*	*Cynodon dactylon*	*Senecio sp*
	Acasia mearnsii		*Rubus cuneifolius*	*Eragrostis curvula*
	Eriocephalus sp		*Eriocephalus sp*	*Digitaria eriantha*
			Stoebe sp	*Leonotis leonorus*
CB	*Eriocephalus sp*	*Conyza scabrida*	*Rubus rigidus*	*Conyza scabrida*
	Conyza albida	*Cynodon dactylon*	*Conyza scabrida*	*Cynodon dactylon*
	Leonotis leonorus	*Rubus rigidus*	*Eragrostis chloromelas*	*Acasia mearnsii*
	Cynodon dactylon	*Acasia mearnsii*	*Digitaria eriantha*	*Eriocephalus sp*
		Digitaria eriantha	*Acasia mearnsii*	*Rubus rigidus*
				Eragrostis chloromelas
CC	*Buddeja saligna*	*Conyza scabrida*	*Acasia mearnsii*	*Pennisetum setaceum*
	Galenia secunda	*Helichysum felinum*	*Pinus sp*	*Conyza scabrida*
	Cirsium vulgare	*Eriocephalus sp*	*Buddeja saligna*	*Cynodon dactylon*
	Eragrostis curvula	*pennisetum macrourum*	*Galenia secunda*	*Acasia mearnsii*
	Digitaria eriantha	*Cynodon dactylon*	*Eragrostis chloromelas*	*Helichysum felinum*
	Pennisetum llandestinum		*Helichrysum felinum*	*Galenia secunda*
			Cynodon dactylon	*Digitaria eriantha*
			Eucalyptus camadulensis	
CD	*Buddeja saligna*	*Pennisetum llandestinum*	*Eucalyptus camadulensis*	*Pennisetum macrourum*
	Cynodon dactylon	*Eragrostis curvula*	*Buddeja saligna*	*Buddeja saligna*
	Cirsium vulgare	*Conyza scabrida*	*Cynodon dactylon*	*Cynodon dactylon*
	Acasia mearnsii	*Helichrysum felinum*	*Digitaria eriantha*	*Cirsium vulgare*
	Eriocephalus sp	*Galenia secunda*		*Helichrysum felinum*
	Digitaria eriantha			*Rhus glauca*

				Conyza scabrida
				Galenia secunda
				Acasia mearnsii
HNA	*Leonotis leonorus*	*Pennisetum setaceum*	*Hyparrhenia hirta*	*Melinis nirviglumis*
	Eragrostis curvula	*Cyperus denudatus*	*Acasia mearnsii*	*Leonotis leonorus*
	Cynodon dactylon	*Juncus lomotophyllus*	*Cape willow*	*Cynodon dactylon*
	Stoebe sp	*Melinis nirviglumis*	*Eragrostis curvula*	*Pennisetum setaceum*
	Hyparrhenia hirta	*Cape willow*	*Pennisetum macrourum*	*Hyparrhenia hirta*
			Conyza scabrida	*Digitaria eriantha*
			Stoebe sp	*Restio zulensis*
				Juncus lomotophyllus
HNB	*Pennisetum macrourum*	*Eragrostis chloromelas*	*Acasia mearnsii*	*Eragrostis curvula*
	Pelargonium luridium	*Acacia mearnsii*	*Pennisetum macrourum*	*Cynodon dactylon*
	Cynodon dactylon	*Pronium serratum*	*Melinis repens*	*Conyza scabrida*
	Eragrostis chloromelas	*Restio zulensis*	*Digitaria eriantha*	*Acacia mearnsii*
		Hyparrhenia hirta	*Cynodon dactylon*	*Pelargonium luridium*
			Cyperus denudatus	
HNC	*Senecio sp*	*Pennisetum setaceum*	*Acasia mearnsii*	*Pennisetum macrourum*
	Digitaria eriantha	*Phragmites australis*	*Pronium serratum*	*Cynodon dactylon*
	Pennisetum macrourum	*Eragrostis curvula*	*Stoebe sp*	*Digitaria eriantha*
	Myrica serratha	*Hyparrhenia hirta*	*Senecio sp*	*Acasia mearnsii*
	Pelargonium luridium	*Stoebe sp*	*Pelargonium luridium*	*Restio zulensis*
	Cynodon dactylon	*Cynodon dactylon*	*Melinis repens*	*Myrica serrata*
			Eragrostis curvula	
			Cynodon dactylon	
HND	*Eragrostis curvula*	*Pronium serratum*	*Acasia mearnsii*	*Pronium serratum*
	Pennisetum setaceum	*Restio zulensis*	*Eragrostis curvula*	*Acasia mearnsii*
	Cynodon dactylon	*Pennisetum setaceum*	*Digitaria eriantha*	*Arundinella nepalensis*
	Stoebe sp	*Pelargonium luridium*	*Salix mucronata*	*Digitaria eriantha*
			Arundinella nepalensis	*Cynodon dactylon*
KMA	*Pteridium aquilinum*	*Athanasia sp*	*Acasia mearnsii*	*Eragrostis curvula*
	Eragrostis chloromelas	*Pennisetum setaceum*	*Eragrostis curvula*	*Digitaria eriantha*
	Cynodon dactylon	*Acasia mearnsii*	*Cynodon dactylon*	*Conyza albida*
	Conyza albida	*Stoebe sp*	*Athanasia sp*	*Acasia mearnsii*

		Pteridium aquilinum	*Digitaria eriantha*	*Stoebe sp*
		Carpobrotus eduli	*Peridium aquilinum*	*Pronium serratum*
		Eragrostis chloromelas	*Carpobrotus eduli*	*Freylinia sp*
			Conyza scabrida	*Cynodon dactylon*
				Carpobrotus eduli
				Pteridium aquilinum
				Pennisetum macrourum
KMB	*Phragmites australis*	*Digitaria eriantha*	*Acasia mearnsii*	*Pennisetum macrourum*
	Pronium serratum	*Pronium serratum*	*Pennisetum macrourum*	*Digitaria eriantha*
	Digitaria eriantha	*Eragrostis curvula*	*Pronium serratum*	*Chrysanthemoides monolifera*
	Chrysanthemoides monolifera	*Acasia mearnsii*	*Eragrostis curvula*	*Eragrostis chloromelas*
	Restio zulensis	*Pennisetum setaceum*	*Conyza scabrida*	*Restio zulensis*
		Cyperus rotundus	*Digitaria eriantha*	*Acasia mearnsii*
		Phragmites australis	*Chrysanthemoides monolifera*	
			Restio zulensis	
KMC	*Cynodon dactylon*	*Pennisetum macrourum*	*Pronium serratum*	*Arundinella nepalensis*
	Acasia mearnsii	*Pronium serratum*	*Pteridium aquilinum*	*Cynodon dactylon*
	Pteridium aquilinum	*Arundinella nepalensis*	*Phragmites australis*	*Pronium serratum*
	Conyza albida	*Conyza albida*	*Acasia mearnsii*	*Crysanthemoides monolifera*
	Eragrostis curvula	*Chrysanthemoides monolifera*	*Cyperus denudatus*	*Cyperus denudatus*
	Athanasia sp	*Eragrostis curvula*	*Nymphaea nouchali*	*Phragmites australis*
	Restio zulensis		*Typha capensis*	*Athanasia sp*
KMD	*Acasia mearnsii*	*Rubus rigidus*	*Phragmites australis*	*Pronium serratum*
	Phragmites australis	*Pennisetum setaceum*	*Cyprus rotunudus*	*Arundinella nepalensis*
	Rubus rigidus	*Pronium serratum*	*Nymphaea nouchali*	*Pennisetum macrourum*
	Cirsium vulgare	*Acasia mearnsii*	*Conyza albida*	*Cynodon dactylon*
	Pteridium aquilinum	*Cynodon dactylon*	*Rhus rehmanniana*	*Acasia mearnsii*
			Bidens pilosa	*Pteridium aquilinum*
				Bidens pilosa
HUA	*Pennisetum macrourum*	*Pennisetum setaceum*	*Centella asiatica*	*Acasia mearnsii*
	Bambusa balcooa	*Clifortia sp*	*Persicaria lapathifolia*	*Pennisetum macrourum*
	Nymphaea nouchali	*Typha capensis*	*Stoebe sp*	*Pronium serratum*
	Persicaria lapathifolia	*Senecio sp*	*Chrysanthemoides monolifera*	*Eragrostis curvula*
	Senecio sp	*Stoebe sp*	*Cyperus denudatus*	*Phragmites australis*
		Persicaria lapathifolia	*Phragmites australis*	*Clifortia sp*

			Pennisetum setaceum	*Freylinia sp*
			Persicaria lapathifolia	*Cyperus denudatus*
			Freylinia sp	*Chrysanthemoides monolifera*
				Centella asiatica
				Zanthedeschia albomaculata
HUB	*Typha capensis*	*Acasia mearnsii*	*Acasia mearnsii*	*Acasia longifolia*
	Pronium serratum	*Pennisetum setaceum*	*Pronium serratum*	*Acasia mearnsii*
	Phragmites australis	*Pronium serratum*	*Pinus sp*	*Hypochaeris radicata*
	Cyperus rotundus	*Stoebe sp*	*Pennisetum setaceum*	*Rubus rigidus*
	Pennisetum setaceum		*Clifortia sp*	*Cyperus denudatus*
			Eragrostis curvula	*Juncus lomotophyllus*
			Typha capensis	*Agrostis lachnantha*
				Clifortia sp
HUC	*Cyperus denudatus*	*Eucalyptus camadulensis*	*Pennisetum setaceum*	*Eucalyptus grandis*
	Acasia mearnsii	*Rhus rehmanniana*	*Pteridium aquilinum*	*Acasia mearnsii*
	Pennisetum setaceum	*Cynodon dactylon*	*Eucalyptus grandis*	*Rhus rehmanniana*
	Typha capensis	*Acasia mearnsii*	*Acasia mearnsii*	*Cynodon dactylon*
	Rubus rigidus	*Hypochaeris radicata*	*Hypochaeris radicata*	*Eragrostis curvula*
			Acasia longifolia	*Cyperus denudatus*
				Pennnisetum setaceum
				Rubus rigidus
HUD	*Phragmites australis*	*Pronium serratum*	*Phragmites australis*	*Cynodon dactylon*
	Athanasia sp	*Pennisetum macrourum*	*Pronium serratum*	*Pennisetum macrourum*
	Cyperus denudatus	*Cyperus rotundus*	*Acasia mearnsii*	*Pronium serratum*
	Rubus rigidus	*Stoebe sp*	*Eragrostis curvula*	*Hypochaeris radicata*
	Rhus rehmanniana		*Pennisetum macrourum*	*Digitaria eriantha*
			Juncus lomotophyllus	*Cyperus denudatus*
			Rubus rigidus	*Acasia mearnsii*
			Cynodon dactylon	
KAA	*Pennisetum macrourum*	*Acasia mearnsii*	*Acasia mearnsii*	*Clifortia sp*
	Clifortia sp	*Phragmites australis*	*Clifortia sp*	*Phragmites australis*
	Paspalum dilatatum	*Juncus lomotophyllus*	*Phragmites australis*	*Pennisetum marourum*
	Cynodon dactylon	*Pennisetum setaceum*	*Acasia longifolia*	*Cynodon dactylon*
	Cyperus denudatus		*Athanasia sp*	*Juncus lomotophyllus*
			Cyperus textilis	*Acasia longifolia*
				Paspalum dilatatum

KAB	***Eragrostis chloromelas***	***Pennisetum marourum***	***Pronium serratum***	***Conyza scabrida***
	Ricinus communis	***Clifortia sp***	***Eragrostis curvula***	***Clifortia sp***
	Acasia mearnsii	***Phragmites australis***	***Acasia longifolia***	***Pronium serratum***
	Cynodon dactylon	***Conyza scabrida***	***Ricinus communis***	***Cynodon dactylon***
			Acasia mearnsii	***Acasia mearnsii***
			Cyperus denudatus	***Paspalum dilatatum***
			Cynodon dactylon	***Ricinus communis***
			Conyza scabrida	
KAC	***Acasia mearnsii***	***Acasia mearnsii***	***Eragrostis chloromelas***	***Acasia mearnsii***
	Eragrostis chloromelas	***Pennisetum macrourum***	***Paspalum dilatatum***	***Eragrostis chloromelas***
	Pennisetum macrourum	***Eragrostis chloromelas***	***Acasia mearnsii***	***Xanthum spinosum***
	Berkheya sp		***Salix babylonica***	***Pennisetum setaceum***
	Xanthum spinosum		***Cynodon dactylon***	***Berkheya sp***
	Persicaria lapathifolia		***Cyperus textilis***	***Cynodon dactylon***
			Phragmites australis	***Persicaria lapatifolia***
				Cttenopodium album
				Clifortia sp
KAD	***Clifortia sp***	***Berkheya sp***	***Clifortia sp***	***Pennisetum macrourum***
	Eragrostis curvula	***Acasia mearnsii***	***Phragmites australis***	***Eragrostis curvula***
	Paspalum dilatatum	***Pennisetum macrourum***	***Acasia mearnsii***	***Paspalum dilatatum***
	Cyperus textilis	***Conyza scabrida***	***Cynodon dactylon***	***Centella asiatica***
	Acasia mearnsii	***Paspalum dilatatum***	***Eragrostis curvula***	***Acasia mearnsii***
		Lobelia sp	***Xanthum spinosum***	***Conyza scabrida***
			Conyza scabrida	***Cttenopodium album***
				Berkheya sp

Appendix 3

Results of soil analysis from 24 Whittaker plots across six peat basins in the Kromme peatland complex, expressed in cmol$^{(+)}$/ℓ soil and mg/ℓ soil.

	Ph	Al	P	K	Mg	Ca	Zn	Total cations	%Acid saturation	%Organic carbon	%Total nitrogen
KA	4.3	1.1	17.7	131	741	1195	2.117	13.5	8.15	2.45	0.204
KB	4.9	0.8	10.3	166	667	1276	2.605	13.08	6.12	2 .05	0.181
KC	4.4	1.3	13.2	105	687	1010	1.55	12.26	10.6	1.81	0.140
KD	4.9	0.95	12.6	250	677	1367	3.328	13.89	6.84	2.26	0.171
CA	3.8	1.8	7.9	102	121	443	1.184	5.27	34.16	0.47	0.128
CB	4.4	1.5	9.2	137	349	642	4.451	7.93	18.92	0.63	0.100
CC	4.1	1.2	31.9	161	730	1419	5.351	14.7	8.16	2.29	0.191
CD	4.3	1.25	15.9	395	710	1326	2.565	14.72	8.49	2.82	0.282
HNA	5.2	0.95	10.3	314	605	1092	1.683	12.18	7.8	0.79	0.112
HNB	5.2	0.9	32.8	116	522	1428	1.696	12.62	7.13	0.96	0.178
HNC	4.6	1.1	10.7	191	574	617	1.311	9.66	11.39	0.68	0.213
HND	7.2	0.45	27.3	121	413	14.14	1.645	11.21	4.01	0.56	0.075
KMA	4.6	1.1	11.2	186	432	724	1.467	8.74	12.59	0.71	0.176
KMB	5.5	0.8	5.0	62	227	541	7.448	5.53	14.47	0.42	0.174
KMC	4.5	1.15	32.2	197	589	980	1.819	11.39	10.1	1.83	0.187
KMD	5.1	0.9	10.6	283	506	746	1.915	9.51	9.46	0.92	0.202
HUA	5.0	2.35	24.5	105	814	1200	3.547	15.3	15.36	2.2	0.150

HUB	4.4	3.0	53.1	77	670	1000	6.73	13.7	21.9	1.64	0.133
HUC	5.9	1.45	18.3	156	818	1106	1.8	14.1	10.28	0.98	0.088
HUD	6.7	1.65	25.8	96	491	520	2.864	8.53	19.34	1.28	0.197
KAA	4.6	1.75	77.0	395	60.3	1237	12.27	13.89	12.6	1.53	0.182
KAB	4.3	1.8	15.0	70	213	435	1.974	5.9	30.51	0.43	0.068
KAC	4.8	1.8	33.3	227	643	1063	4.989	12.98	13.87	1.53	0.127
KAD	5.9	1.2	19.0	83	781	909	5.992	12.37	9.7	1.31	0.086

Appendix 4

Water quality variables from 12 sample points across the six peat basins in the Kromme River Peatland, expressed in mg/ℓ. A Merck SQ 118 mass photospectrometre was used to analyse the water samples for the six variables

Sites	Sample points	Variables					
		Nitrite	Ammonium	Nitrate	Phosphate	pH	Elec.cond
Krugersland	Upper extreme	0.05	0.1	0.02	2.2	5.83	224
	Lower extreme	0.01	0.04	0.02	0.6	5.54	109
Compenjesdrift	Upper extreme	0.01	0.02	0.01	1.0	5.59	132.5
	Lower extreme	0.01	0.01	0.02	0.9	5.67	131.3
Hendrikskraal	Upper extreme	0.02	0.02	0.01	1.1	6.11	139.3
	Lower extreme	0.02	0.01	0.05	0.1	6.08	139.4
Kamiesbos	Upper extreme	0.02	0.0	0.02	0.1	6.0	147.1
	Lower extreme	0.01	0.01	0.02	0.2	6.16	147.4
Hudsonvale	Upper extreme	0.02	0.0	0.03	0.3	6.04	118.6
	Lower extreme	0.04	0.02	0.04	0.8	5.75	117.2
Kareedouw	Upper extreme	0.03	0.0	0.03	0.4	5.83	121.8
	Lower extreme	0.03	0.01	0.05	0.4	6.0	129.1