The Use of Wetland Bird Species as Indicators of Land Cover Change within the Mgeni Estuary and Beachwood Mangrove Swamps

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DECLARATION

Submitted in fulfilment / partial fulfilment of the requirements for the degree of .... , in the Graduate Programme in

.... , University of KwaZulu-Natal, South Africa.

I declare that this dissertation is my own unaided work. All citations, references and borrowed ideas have been duly acknowledged. I confirm that an external editor was / was not used (delete whichever is applicable) and that my Supervisor was informed of the identity and details of my editor. It is being submitted for the degree of .... in the Faculty of Humanities, Development and Social Science, University of KwaZulu-Natal, South Africa. None of the present work has been submitted previously for any degree or examination in any other University.

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Abstract

Because of the variety of ecological and economic functions they perform, estuaries and mangrove swamps are recognised as amongst the most valuable habitats on earth. However, estuaries and related mangrove swamps are threatened by human expansion and exploitation which leads to changes in land cover change within and surrounding these sensitive ecosystems. Such land cover changes can either have desirable or undesirable effects on natural ecosystems. Examples of undesirable impacts of land cover change include soil erosion and degradation, the removal of indigenous vegetation for human development, and the pollution of water. Without an effective means of identifying, monitoring and managing land cover changes over time, these sensitive ecosystems face a bleak and uncertain future.

The researcher sought to determine whether wetland bird species could be used as an effective method of monitoring the environmental health of estuaries and mangrove swamps. In particular, the research sought to determine whether analysing fluctuations in the populations of wetland bird indicator species, as evident in the CWAC Bird Census data, could assist in monitoring and assessing undesirable and desirable land cover changes within the Mgeni Estuary and Beachwood Mangrove Swamps.

An examination of the archival aerial imagery of the study area for the years 1991, 1997, 2003 and 2008 provided by the University and private companies, revealed significant changes in land cover over the last two decades. The land cover changes identified represent an actual decline or increase in the suitable foraging, roosting or reproductive habitats of wetland bird indicator species within the study area. The research focused on investigating whether fluctuations in wetland bird populations can be correlated with the recorded changes in land cover over the last two decades. The research discovered a direct and comprehensive link between fluctuations in specific populations of wetland bird indicator species and the land cover changes identified within the study area over a 20 year period.

Declaration

The work described in this dissertation was carried out in the School of Environmental Sciences, University of KwaZulu Natal, from March 2008 to October 2009. This work was undertaken under the supervision of Prof. F. Ahmed

This study represents the original work of the author and has not otherwise been submitted in any form, in part or in whole, for any degree or diploma to any other university. Where use has been made of work by others, this has been duly acknowledged in the text.

Signed ____________________

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Supervisor:

Prof. F. Ahmed

Signed ____________________

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Chapter One

Introduction

1.1 Background and Outline of Research

Estuaries and mangrove swamps are recognised as amongst the most valuable habitats on earth because of the variety of ecological and economic functions they perform. These sensitive ecosystems are, however, threatened by human expansion and exploitation, and now face a bleak and uncertain future (McCarthy and Rubidge, 2006)

The South African coastline is well endowed with estuaries which compromise a dominant component of its coastal geomorphologic elements (Cooper *et al.,* 1989). An estuary is currently defined as semi-closed coastal body of water into which one or more rivers or streams flow. Estuaries are generally freely connected to the open sea where fresh water and the salty sea water eventually meet. Heydorn and Tinley (1980) state that there are 166 estuaries between the Orange River and the Great Kei alone, 60 estuaries in the Eastern Cape and 239 independent river outlets along the KwaZulu -Natal coastline.

This study focuses on the Mgeni Estuary situated north of Durban at approximately 29°48'S and 31°02'E in the South African Province of KwaZulu-Natal. Like the majority of estuaries and mangrove swamps around the world, the Mgeni Estuary and the surrounding Beachwood Mangrove Swamps are an important resource to the local Durban community. However, over utilization of natural resources, and unchecked land use practices (particularly in the vicinity of the Mgeni Estuary) can lead to unsafe water, beach and shellfish bed closings, harmful algal blooms, unproductive fisheries, and loss of habitats which are essential to the survival and propagation of many plant, mammal, fish and invertebrate species.

As the world's population grows, the demands made on the natural resources increase. Land resources are considered a basic natural resource because land meets a variety of human and environmental needs. Humans use land for agriculture, industry, forestry, energy production and settlement. Human population growth along South Africa's coastline is placing tremendous pressure on land resources by stimulating and driving changes in land cover in, especially, estuaries and mangrove swamps. Land resources are showing signs of decline in terms of quantity and quality due to degradation, pollution and competition with different land use demands.

Such a decline in the quantity and quality of land resources and, in particular in land cover within and surrounding the Mgeni Estuary and Beachwood Mangrove Swamps, has been identified as a possible clue to the gradual decline in wetland bird populations within these estuarine ecosystems (Marus, Ealles and Wildschut, 1996). Wetland bird species that inhabit estuarine and mangrove ecosystems are highly sensitive to disturbances and changes taking place within these habitats. This makes birds an ideal tool for monitoring the health and integrity of these ecosystems. To provide for the well-being of existing and future generations, local authorities must develop and implement an effective monitoring system to ensure that a sustainable land management plan can be introduced to protect all natural, economic and aesthetic benefits that estuarine and mangrove ecosystems represent. The use of wetland bird species as an environmental monitoring tool within estuarine, mangrove swamp and other wetland ecosystems has been successfully implemented in the United States and throughout Europe over the last couple of decades. However, the use of wetland bird species as a monitoring tool in any form of environmental assessment is a relatively new concept in Southern Africa. This study seeks to provide greater empathise for the utilisation of wetland birds as an environmental monitoring tool within the South African estuaries, mangrove swamps and wetland ecosystems.

1.2 . Land Cover Change

There are no universally acceptable categories for the classification of land use or cover. However, the most commonly used system of classification are hybrids of land cover and land use (Anderson *et al.,* 1976; Meyer, 1995). Land cover can be described as the actual physical state of the land surface. The land surface may be covered in dense natural or artificial vegetation such as plantations of pine trees, or covered with man-made structures such as bridges, roads or buildings (Longley *et al.*, 2007). Anything that covers the earth's surface can be classified as land cover.

1.3. Land Use Change

Land use defines use by humans. Yemane (2003) defines it as: "*...the purpose for which humans formally, presently, or may in the future change the landscape for the purpose of resource extraction and processing, housing, and transportation*" (Yemane, 2003; 1). Land use can be defined as any activity that alters the earth's surface, and that has been chosen and deliberately implemented by humans for their own benefit. These activities are normally directly related to land, make use of land resources or have a positive or negative impact upon it. "*The purposes for which land is being used, commonly have associated types of cover, whether they are for forests, agricultural, residential, or industrial uses*" (Anderson *et al.,* 1976).

If the users of a particular piece of land decided to utilise its resources for a different purpose, land cover change will occur. The definition of land cover change is the alteration of the actual physical or biotic nature of a piece of land. For example, the transformation of a wetland ecosystem into a man-made golf course (Longley *et al.*, 2007). Land cover change takes two different forms, firstly, the conversions from one land cover class to another; and secondly, the modification within one class (Longley *et al.*, 2007). The change in land cover describes the differences in area occupied by a particular land cover type over time where both the losses and gains are identified and quantified. Land cover change is also used to describe shifts in the spacing of cover types across a landscape over time (Yemane, 2003).

1.4. The Significance of the Study

Land cover change produces both positive and negative consequences. Sensitive ecosystems such as the Mgeni Estuary and Beachwood Mangrove Swamps are threatened by negative land cover change such as a loss in biodiversity, soil erosion and degradation and water flow and quality change. However, it is recognised that not all changes which result from human use of natural ecosystems and their land resources are destined to be detrimental to the natural environment. Some land cover changes have a positive impact on the lives of humans and the economy and improves the natural environment. It is essential that information on land cover patterns, as well as their changing proportions through time, is recorded. This will assist scientists and policy makers to understand, anticipate and possibly prevent the more negative effects of land cover change and to identify and preserve vulnerable land cover types.

This study seeks to identify whether land cover changes have occurred within and surrounding the Mgeni Estuary and Beachwood Mangrove Swamps study area, and to determine if these land cover changes have a negative or positive impact on these natural ecosystems. In addition, the study aims to determine whether land cover change has impacted upon wetland bird populations within these ecosystems. Birds are recognised as an appropriate tool for monitoring the health and integrity of natural ecosystems throughout Europe and the North America (US Environmental Protection Agency, 2007). However, the utilization of birds as an environmental monitoring tool is a relatively new concept in Southern Africa, and the study sought to reinforce the argument that wetland avian species should be appropriately monitored to help assess the health and integrity of ecosystems in terms of the negative impacts of land cover change within mangrove ecosystems, and within the vicinity of water bodies and wetlands.

In order to determine the usefulness of wetland bird species as an effective monitoring tool, the CWAC Wetland Bird Census Database complied by the Animal Demographic Unit, University of Cape Town was assessed, and indicator species for each land cover class identified. Studies indicate that fluctuations in avian populations occurred due to negative or positive land cover changes taking place within an ecosystem (US Environmental Protection Agency, 2007). Fluctuations in avian populations within the study area could be due to changes in land cover identified in archival aerial imagery. This would provide sufficient evidence to conclude that wetland avian populations can be used as an effective tool to help monitor the health and integrity of estuarine and mangrove ecosystems in Southern Africa.

1.5. The Importance of the Mgeni Estuary and Beachwood Mangrove Swamps

Estuaries and mangrove swamps perform various ecological functions as noted above. For example, estuaries may be fringed by wetlands which fulfil a valuable role. By processing water which drains from the uplands carrying sediments, nutrients and sometimes pollutants are then filtered out by wetland habitats, which ensure that the water is clean and clearer and not harmful to the natural environment and humankind. Mangrove swamps help to protect land from soil erosion and the effects of coastal storm surges. They also provide a natural means of controlling pollution by filtering out industrial and human waste. Mangrove swamps perform the same functions as wetlands, acting as a natural buffer between the land and ocean, helping to absorb flood waters and dissipate storm surges and prevent soil erosion. These natural ecosystems provide an opportunity for tourism associated with bird watching and other recreational activities whilst also supporting the fishery industry and other commercial activities which are based on the utilization of natural resources provided by estuaries and mangrove swamps (Christian, 2008).

Researchers in the United States discovered that estuaries offer a habitat for an estimated 75% of America's commercial fish catch, and around 80-90% of the recreational fish catch (US Environmental Protection Agency, 2008). Further research indicates that estuarine-dependent fisheries must be conserved because these ecosystems help maintain sustainable commercial and recreational fisheries, industries which are estimated to be worth billions of dollars. Nationwide, commercial and recreational fishing, boating, tourism, and other coastal industries generated an estimated 30 million jobs with the commercial shipping industry alone employing tens of thousands of people (Christian, 2008).

These estuarine and mangrove ecological and economic functions benefit the natural environment and mankind, and deserve an appropriate level of management and conservation. There is the need for an effective method of monitoring the health and integrity of estuarine and mangrove swamp systems to ensure that these valuable ecosystems are conserved and managed appropriately for future generations to enjoy. To this end, this study investigates the viability of specific wetland bird species as environmental indicators that can be used to monitor the environmental health and integrity of estuarine and mangrove ecosystems in Southern Africa.

1.6. Aim of Study

The aim of this study is to investigate whether changes in wetland avian populations can be meaningfully correlated with land cover changes that have occurred within the Mgeni Estuary and the adjacent Beachwood Mangrove Swamps.

1.7. Objectives of Study

The specific objectives of the study are to:

- Identify and map the various habitats within the study area.
- Identify and record changes in land cover patterns within the study area between 1991 and 2008.
- Identify changes in the populations of indicator bird species within the study area between 1991 and 2008.

- Determine if there is a significant relationship between changes in the populations of indicator bird species, and related changes in the patterns of land cover in the study area.
- Identify the primary human activities that may have influenced estuarine and mangrove habitats in the study area.

1.8. Structure of Thesis

Chapter Two, the Literature Review, examines estuarine and mangrove ecosystems within South Africa, and the ecological and economic benefits they offer both local communities and the natural environment. It explores the role of birds as environmental indicators and bird adaptations to estuarine and mangrove habitats. In addition, this chapter investigates land cover change in relation to estuaries and mangrove swamps in detail.

Chapter Three focuses on discussing the study area of the Mgeni Estuary and Beachwood Mangrove Swamps ecosystem.

Chapter Four describes the Material and Methods, and provides an in-depth view into the various data collection methods and procedures which were employed during the course of the study.

Chapter Five presents the Results and Discussions.

Chapter Six, the final chapter, presents Conclusion and Recommendations.

Chapter Two

Literature Review

2.1. Introduction

Estuaries and mangrove swamps are recognised as some of the most valuable ecosystems on earth due to the variety of ecological and economic functions they perform. However, many of these important ecosystems are now threatened by human expansion and exploitation. Land cover changes around estuarine and mangrove ecosystems as a result of human activities have a negative impact on the economic worth of such sensitive ecosystems and consequently endanger their very existence. Land cover changes within and surrounding the Mgeni Estuary and Beachwood Mangrove Swamps, have contributed to the steady degradation and deterioration of foraging, roosting and reproductive habitats utilised by wetland bird species. The sensitivity of wetland bird populations to habitat transformation disturbances within estuaries and mangrove systems makes them an ideal environmental indicator for monitoring the health and integrity of these valuable ecosystems. Research has indicated that the disappearance of certain estuarine and mangrove habitats has contributed to a decline in populations of wetland bird species within the Mgeni Estuary and Beachwood Mangrove Swamps.

2.2. South African Estuaries and Mangrove Swamps

Day (1980) defined an estuary as, *"...a partially enclosed coastal body of water which is either permanently or periodically open to the sea and within which there is a measurable variation of salinity due to the mixture of sea water with fresh water derived from land drainage"* (Day, 1980; 2). This definition was adjusted by the compilers of the South African National report to the United Nations Conference on Environment and Development which was held in Rio de Janeiro in June 1992 (Day, 1980) and a new definition of an estuary within a South African context was established Estuaries are part of a river system which has, or can from time to time, be in contact with the sea. During periods of flooding, an estuary becomes a river mouth and conditions deny seawater access to the formerly estuarine area. Estuaries can also be periodically isolated from the sea by sandbars and dunes, which over a period of time from a lagoon, which may turn into fresh water or hypersaline body of water, or eventually completely evaporate to form a salt pan (Mornat and Quinn, 1999).

Stretching for thousands of kilometres in a continuous band around most of the world's continents, mangrove swamps are defined as tropical or subtropical marine swamp ecosystems found in the littoral zones, being a narrow coastal strip, neither terrestrial nor marine in nature, where land meets the sea (Berjack *et al.*, 1981). Some zones consist of rocky shorelines that are unprotected and heavily wave beaten, while others are sandy beaches that are washed over by waves without a scouring or gouging effect (McNae, 1963). The mangrove communities are found only on the warmest and most protected shores around the globe, and are dominated by plant life that is adapted to the unique environmental conditions of these dynamic ecosystems (Berjack *et al.*, 1981).

A mangrove community is a colony or grove of trees and shrubs of terrestrial origin, which are termed mangroves regardless of individual type, and which are grouped in stands or groves. Groves of mangrove trees can be of considerable size, and lush in terms of vegetation or small and sparely vegetated (McNae, 1963). In some cases mangrove groves or stands are referred to as coastal woodland or tidal forest. Other species of mangrove plants find shelter and nutrients amongst the mangrove trees which they use for shelter and nutrients (Berjack *et al.*, 1981). Mangrove trees dominate and characterize this habitat by being the only major member of the community that is found permanently within these harsh and constantly changing ecosystems (McNae, 1963). Other plant species are also found in other albeit related habitats. Some organisms rely on mangroves for a part of their life cycle, while others use the mangroves as a permanent environment for feeding, breeding and shelter (Berjack *et al.*, 1981).

2.3. Tidal Influence on Estuarine and Mangrove Ecosystems

The moon travels around the earth and together, they travel around the sun. The gravitational forces that are created generate the rise and fall of the world's ocean, which in turns impacts on the water bodies within the study area. Tides ebb and flood estuarine and mangrove ecosystems on cycles over a 24-hour period. Each day, estuaries can have one or two high tides, plus one or two low tides (Manoj, Unnikrishinan & Sundar, 2009). As water rises along the coastline, seawater is forced into estuary and their adjacent mangrove swamp ecosystems. Eventually the tides ebb and the water flows out to sea once again. The rise and fall of the tides are vital for the health of these sensitive ecosystems because they flush the system and provide valuable nutrients to keep the food web functional (Manoj, Unnikrishinan & Sundar, 2009).

Researchers at the Cape Cod National Seashore discovered at discrepancy between the tides at the local beach and the nearby estuary (National Parks Service, 2005). The tides that were affecting the beach bordering the ocean followed a roughly twelve hour cycle. The beaches adjacent the Mgeni Estuary and Beachwood Mangrove Swamps experience a similar cycle of six hours of high tide and six hours of low tide. However, the tides taking place within the neighbouring estuary at Cape Cod National Seashore, which was connected directly to the ocean by a narrow open channel very similar to that of the Mgeni Estuary mouth, experienced eight hours of high tide and approximately four hours of low tide. Basically water flows out of the estuary, there is a less of a push by the water entering the system and the drainage out of the system is a slow process. However, as the ocean water begins to rise with the high tide, the water surges into the estuary and the estuary is affected by the rising tide (National Parks Service, 2005).

As the tide ebbs and flows within the estuarine and mangrove ecosystem, the intertidal zone is exposed for a period of time to the elements and then inundated once again by the rising tide (Manoj, Unnikrishinan & Sundar, 2009). This cycle of exposure and inundation of the mud flats, sand banks and the shoreline of estuaries and mangrove swamps makes it difficult to assess whether these land cover classes are unmodified or modified through human intervention, natural causes or a combination of both, outside of the actual designated estuarine and mangrove ecosystem or within the actual ecosystems themselves. In addition, the alternating periods of wet and dry conditions impacts upon the life cycles of numerous organisms, which rely on these intertidal zones for foraging, resting and reproductive purposes such as wetland bird species.

2.4. The Ecological and Economic Benefits of Estuaries and Mangrove Swamps

Estuaries and mangrove swamps provide a variety of different ecological and economic functions which benefit the natural environment and mankind, not least of which is their aesthetic and recreational value (US Environmental Protection Agency, 2008).Among others, they provide marine species with important nursery areas supporting inshore fisheries. Consequently estuaries are often referred to by many biologists as the "nurseries of the sea" (Berjack *et al.*, 1981). Estuaries may also be fringed by wetlands which provide a valuable cleansing service. The water which drains from the uplands often carries sediments, nutrients and other pollutants (Christian, 2008). As this water moves through the wetland areas such as swamps and salt marshes, much of the sediment and pollutants are naturally filtered out.

Various characteristics make wetlands suitable for this function, including the lowering of water velocity due to the low gradient of the slope combined with wetland vegetation helping to suspend particles to be deposited. The anaerobic and aerobic processes, such as denitrification and nitrification, the constant contact between water and sediment and, finally the high organic content within wetlands, are ideal for the retention of heavy metals. The wetlands filtration process naturally creates clean and clearer water, which in turn contributes profoundly to the well-being of humans and marine life in general (McNae, 1963; US Environmental Protection Agency, 2008).

Mangrove swamps help protect coastal land from soil erosion and the effects of storm surges. They provide a means of controlling pollution by filtering out industrial and human waste. Scientists also believe that mangrove swamps perform similar functions to wetlands: acting like a natural buffer between the land and ocean, absorbing flood waters and dissipating storm surges. Mangrove tree root systems help remove sediment from run off before it reaches the open water of the ocean, thereby preventing sediment from covering and killing coral reef colonies. The removal of sediment also assists in the protection of inland habitats within the estuary and river systems, as well as protecting valuable real estate from storm and flood damage (McNae, 1963). Estuarine salt marshes and the grass species that colonize these areas also play a vital role in preventing erosion and contribute to the stabilization of the shoreline.

These ecosystems protect the coastal waters of estuaries and provide ideal locations for important public infrastructure, forming natural harbours and ports which are vital for recreation shipping, transportation and industry (US Environmental Protection Agency, 2008). Studies in the United States were undertaken to measure certain aspects of economic activities attributed to estuaries and other coastal waters to help determine their contribution to society. Researchers discovered that estuaries provide habitat for an estimated 75% of America's commercial fish catch, and around 80-90% of the recreational fish catch (US fisheries were vital for maintaining sustainable commercial and recreational fisheries). These industries are estimated to be worth billions of dollars. Studies also indicated that commercial and recreational fishing, boating, tourism, and other coastal industries generated an estimated 30 million jobs nationwide, with the commercial shipping industry alone employing tens of thousands of people (Christian, 2008).

The economic value of South African estuaries and mangrove swamps is currently being investigated by the Percy FitzPatrick Institute of African Ornithology at the University of Cape Town. The researchers considered the subsistence, property, tourism, nursery and existence values of temperate estuaries in South Africa within the context of a Total Economic Value framework (Turpie and MSc Class, 2005). Total subsistence value of estuaries in South Africa ranged from zero to R800 000 per estuary according to the study (Turpie and MSc Class, 2005). The findings concluded that the average total subsistence value of an estuary within South Africa was around R70 000. It was also determined that the total property value around estuaries was estimated to be worth R10.6 billion (a capital value). The study converted these values to an annual value akin to the income that is generated by the South African property sector, and this translated to a total of approximately R320 million per year (Turpie and MSc Class, 2005)

The study indicated that the majority of estuaries within South Africa had a tourism value of between R10 000 and R1 million per annum. Retail and tourism sectors by comparison, generated an estimated R2.08 billion in annual turnover (Turpie and MSc Class, 2005). Estuaries provide nurseries for various commercially or recreationally valuable fish species, valued between R 10 000 and R 1 million per annum (Turpie and MSc Class, 2005). According to researchers, temperate estuaries generated R773 million. Researchers explored the existence value of estuaries and the public's perceptions of such ecosystems, indicating that many people were willing to pay R90 million for South African estuaries simply because of the feeling of satisfaction that their existence generates (Turpie and MSc Class, 2005). Further research revealed that respondents tended to focus on scenic beauty and biodiversity importance when they were asked to rate individual estuaries, but the scores were very well correlated with the scenic value of these locations alone (Turpie and MSc Class, 2005). This allowed researchers to extrapolate the scores of all other estuaries within South Africa simply based on the independent rating of scenic beauty. The scores were then used to disaggregate the overall WTP for all the estuaries within South Africa (Turpie and MSc Class, 2005).

The study indicated that the poorest members of society tend to favour higher levels of development around estuaries (average 48%) compared to the wealthier members (average 25%). However, all respondents felt that at least 50% of these estuaries should remain intact and undeveloped. Other researchers undertook a study to examine the economic value of mangrove ecosystems within South Africa. A project examining the value of the Mngazana Estuary Mangroves was conducted by the Percy FitzPatrick Institute of African Ornithology (Schroenn, de Wet and Turpie, 2005). A partial economic valuation of the benefits that mangrove ecosystems offer local rural communities was undertaken. The researchers gathered data from the local communities surrounding the estuary undertaking household surveys and holding focus group discussions (Schroenn, de Wet. and Turpie, 2005). A market price method was applied to determine the value of mangroves that were harvested for building material, and the subsistence consumption of fish by local communities living in the vicinity of estuaries around South Africa (Schroenn, de Wet and Turpie, 2005). Various other values were estimated such as honey production, canoe trails and finally the local economic impact of expenditure of visitors utilizing local accommodation that is adjacent the estuary. These results were then incorporated into a 20-year valuation model with the net annual benefits, and then these were discounted to present value terms. The sensitivity analysis was undertaken by the researchers to determine lower-bound, upper-bound and most-likely values (Schroenn, de Wet and Turpie, 2005).

The Mngazana Estuary Mangroves had a minimum economic value between R0.5 and R7.0 million, at a most-likely value at a 5% discount rate of R3.4 million (Schroenn, de Wet and Turpie, 2005). This study illustrates the importance of implementing policies for managing environmental goods and services that are ecologically, socially and economically sound. Schroenn, de Wet and Turpie (2005) state that an integrated approach to address the socio-economic needs of local communities has the ability to help protect environmental resources for future generations to enjoy.

Estuaries and mangrove swamps are recognised as sensitive ecosystems that are vulnerable to human development and pollution. The clearance of land for development and agriculture around and within such ecosystems, increases sediment loads (McCally, 2007). This increase in the sediment load impacts on the clarity of the water, as well as the nature of the sediments and the rate of sedimentation taking place within these ecosystems. In addition, the construction of dams and other man-made obstacles within a river's catchment can contribute to a reduction in downstream flow and the sediment load reaching the estuary (McCally, 2007).

Numerous studies have been conducted that examine the annual sediment yields of river catchments before the construction of dams, and following the commencement of the operation of these same dams. The Mgeni River had a sediment yield of approximately l-6x 10* tonnes before the construction of the Inanda Dam (Garland and Moleko, 2000). However, the construction of five dams within the catchment area has gradually reduced the contemporary sediment yield to the coast over a period of time. The catchments area below the four main dams that were completed prior to 1987 is estimated to be around 1700 Km2, and the total sediment yield from this area was calculated to be around 0-5 x 10* tonnes per year (Garland and Moleko, 2000). The completion of the Inanda Dam in 1988 has only exacerbated the situation by altering bed load transportation and deposition. After the completion of the Inanda Dam, the mean annual discharge of the river was significantly reduced (4%). The establishment of a water release policy also had a major impact on the discharge regime which has led to an increase in discharge events (Garland and Moleko, 2000). Sediment continually builds up behind the dam wall, which has led to a notable reduction in available downstream sediment. Whereas the volume of sediment within the estuary has not changed since 1989, the sediment calibre has become much finer (Garland and Moleko, 2000).

Garland and Moleko (2000) also mentioned that without the natural replenishment of downstream sediment from the upper reaches of the Mgeni Catchment area, sand mining operations below the Inanda Dam will eventually cease. Such activities contribute to the reduction in the amount of sediment being transported downstream towards the Mgeni Estuary and the eThekwini beaches. Eventually, the estuary will begin to deepen, and the mudflats and sand banks will gradually disappear as the coarse pre-dam sediment is eventually flushed out into the Indian Ocean and is replaced by new sediment of a finer particle size. Local eThekwini beaches will also be affected as their sediment supply is curtailed. This process would have a considerable impact on the overall environmental conditions of the estuary. Scientists have found that many different invertebrates, plants, fish, birds and mammals prefer certain sediment particle sizes. Consequently, some might be affected by even minor changes in the rate of sedimentation, and the level of turbidity and either die out or relocate to more suitable habitats (EW Environment Waikato Regional Council, 2007).

In some instances, other man-made disturbances can also result in greater sediment runoff into estuarine ecosystems which can then increase the rate of estuary infill. The consequent reduction in water depth can affect the distribution of plants, animals and their habitats, while at the same time decreasing natural, recreational and amenity values (EW Environment Waikato Regional Council, 2007). Fertilizers, pesticides and other toxic materials which are washed into estuaries and mangrove swamps are also harmful to the balance of the natural environment. Oil pollution can smother mangrove root systems and suffocate trees. The development of infrastructure such as roads, railways and bridges increases the surface runoff which carries sediment and pollutants into the estuary and mangrove ecosystems. As coastal regions become more heavily populated, and the rate of development increases, additional strain is put on ecosystems. Land is cleared for more housing and infrastructure. Littering, results in increased incidents of resultant rubbish which washes into the estuarine and mangrove ecosystem and damages vegetation (EW Environment Waikato, 2008). Mangrove trees are sometimes cleared to supply timber, fuel or pulp. The World Wildlife Fund has found that more than 35% of the world's mangrove swamps have already disappeared. In some countries such as India, the Philippines, and Vietnam this figure is estimated to be around 50% (World Wildlife Fund, 2009). As such, it is clear that natural estuarine and mangrove ecosystems are under threat.

2.5. Birds within Estuarine and Mangrove Ecosystems

Studies indicate that one hundred and sixty-two different species of birds are found within estuarine and mangrove habitats around South Africa. As already stated, these bird species are taxonomically, functionally and morphologically diverse. They range from *piscivores,* such as White-Backed Pelicans which can weight several kilograms, to small insectivores like Sandpipers. Representatives of 13 of the 26 Orders of birds are found within South African estuaries (Hockey *et al.,* 1992). The high taxonomic diversity of bird species in estuaries can be attributed to the variety of diverse habitats which are found within the estuarine ecosystems.

Several different habitat systems have been identified. These include shallow water, deep open water, intertidal mud and sand flats, reed beds and mangroves, all of which are further diversified by the existence of a strong salinity gradient which has a significant influence on the spatial occurrence of plant and invertebrates (Kalejta and Hockey, 1991). Tthis habitat diversity exists within restricted areas. Estuaries attract various bird species with their wide range of habitat requirements for breeding, feeding and roosting. In six of the avian Orders, more than two-thirds of the species are found regularly in estuaries. Whilst these Orders are normally closely associated with aquatic habitats, they are not necessarily exclusively or predominantly within estuaries (Kalejta and Hockey, 1991).

Table 1: The Number of Bird Species of each Avian Order Represented in South Africa, Compared with the Number of Species of each of these Orders which are found in South African Estuaries

South African Bird Species and Distribution in Estuary and Mangrove Ecosystems			
Orders	**South Africa**	**Estuaries**	**%**
Struthionifromes	1	0	0
Sphenisciformes	1	0	0
Podicipediformes	3	3	100
Pelecaniformes	9	7	78
Procellariiformes	19	0	0
Phoenicopteriformes	2	2	100
Ciconiiformes	31	26	84
Falconiformes	58	8	14
Anseriformes	17	12	71
Galliformes	17	0	0
Gruiformes	29	8	28
Columbiformes	14	0	0
Charadriiformes	66	45	68
Pterocliformes	4	0	0
Musophagiformes	4	0	0
Psittaciformes	5	0	0
Cuculiformes	15	1	7
Strigiformes	12	1	8
Caprimulgiformes	7	2	29
Apodiformes	10	0	0
Coliiformes	3	0	0
Trogoniformes	1	0	0
Alcedrinformes	16	5	31
Coraciiformes	14	0	0
Piciformes	20	0	0
Passerifiormes	316	41	13

Source: Kalejta and Hockey, 1991

Orders which have been identified in South African estuaries include the *Podicipediformes* (grebes), *Pelecaniformes (*pelican species), *Ciconiiformes* (herons and stork species), *Phoenicopteriformes* (flamingo species), *Anseriformes* (duck species) and finally the *Charadriiformes* (waders, gulls and tern species) (Kalejta *and Hockey*, 1991).Three of the bird species listed in Table 1 do not feed in estuaries. Of the 162 estuarine bird species, 96

(59%) actually breed in estuaries. However, a few species migrate to the tropics during the non-breeding season. Studies indicate that 66 species only visit estuaries to forage and roost. Some of these visitors are long-distance migrants from Palaearctic breeding grounds in the northern hemisphere (Kalejta and Hockey, 1991). Some species such as Flamingos and Mangrove Kingfishers are intra-African migrants. Several researchers have shown that it is not possible to give an accurate assessment of the total number of birds that actually utilise South African estuaries because the abundance and composition of bird populations are dynamic over time scales as short as hours, causing inaccuracies in counts. Secondly, skulking species such as bitterns, rails and crakes, and nocturnal species such as owls, night herons and nightjars are not easily seen during surveys. Such species spend much of their existence in structurally complex habitats such as reed beds.

The number of birds in estuaries fluctuates all year round; however, the most significant changes in avifauna are seasonal. During the austral summer, hundreds of thousands Palaearctic-breeding waders take up residence in South African estuaries. The first birds arrive in August, and most have left by the end of May to return to northern breeding grounds. Juveniles of most of the migrating wader species take up residence in South African estuaries during their first year and remain throughout the Southern winter; finally migrating north to their breeding ground at two years of age (Martin and Baird, 1988). The number of juvenile birds present in South African estuaries varies from year to year. As the Palaearctic-breeding migrants leave the South African estuaries, other groups of birds begin to arrive. Researchers indicate that for example that the Berg River Estuary is dominated by migrant wading bird species during the summer. However, when these bird species migrate north during the autumn, they are replaced by resident waders and waterfowl which remain in the estuary throughout the winter

2.6. Diet and Foraging Behaviour of Estuarine Bird Species

Estuarine bird species are specially adapted to the location and consumption of specific food types. There are six major dietary categories have been identified amongst estuarine bird species in South Africa. This diversity of dietary categories is due to the wide range of habitats systems found within estuaries (Kalejta and Hockey, 1994). The aquatic and terrestrial habitats of estuaries are rich with various different invertebrates, vertebrates and plant types consumed by resident bird species. Within each of the thirteen estuarine bird Orders, the species normally fall within one or two categories in terms of the main components of their diet. Findings indicate that invertebrate feeders dominate in all estuarine ecosystems within South Africa (Kalejta and Hockey, 1994)

There are ninety species in the eleven different Orders. In eight of the Orders, forty-eight species feed on vertebrates such as amphibians, fish and small mammals. In a further five Orders, twenty-two species are herbivores. Aquatic and Terrestrial feeders both have representatives from the nine Orders (Kalejta and Hockey, 1994). The former group has a total of ninety-four species, while the Terrestrial group consists of sixty-five species. Generally the Aquatic feeders, which consume invertebrates, belong to the *Charadriiformes;* while the vertebrate feeders are associated with the *Ciconiiformes* (Kalejta and Hockey, 1994). Herbivores belong to the *Anseriformes* and *Gruiformes*. Terrestrial feeding bird species are generally Passeriformes. A high number of partially and highly estuarine dependent species are aquatic foragers. Generally, Terrestrial feeding bird species are considered to be low estuarine-dependent species because of their ability to forage in other aquatic habitats like rivers, lakes and lagoons. Ten of the forty-four Aquatic herbivore feeders are highly dependent on the estuarine habitats in South Africa.

Kalejta and Hockey (1994) and others have done extensive research on estuarine bird foraging behaviour, and state that in terms of energy flow and the role of birds within a functioning estuarine ecosystem, there are three different dietary categories that are of particular importance and include birds that consume aquatic vegetation, invertebrates, fish and amphibians (Kalejta and Hockey, 1994). Such species exhibit a higher degree of estuarine dependence than other species and this makes them ideal indicators for this study.

Table 2: Number of Estuarine Bird Species Offering Three of Three Degrees of Estuarine Dependence (1=Low, 2=Moderate and 3= High) in Each of the Six Different Dietary Categories

Main Dietary Categories	Degree of estuarine dependence					
	1	%	2	%	3	%
Aquatic vegetation	5	63	2	25	1	13
Aquatic invertebrates	25	57	10	23	9	20
Aquatic vertebrates	20	48	19	45	3	7
Terrestrial vegetation	12	86	1	7	1	7
Terrestrial invertebrates	40	87	4	9	2	4
Terrestrial vertebrates	5	83	1	2	0	0

Source: Kalejta and Hockey, 1991

Within dietary categories, there are variations in bird species' foraging behaviour, and methods of obtaining their prey (Kalejta and Hockey, 1994). Some estuarine bird species like the Yellowbilled Duck and Redknobbed Coot, focus on obtaining food from the water surface while swimming while some species prefer diving to find food on the estuary bed. Waders generally prey on aquatic invertebrates found close to the surface of inter-tidal mudflats by pecking or shallow probing once the prey has been visually identified by the bird. However, waders can also locate prey by secondary clues such as surface casts of poychaetete worms and the movement of prawns as they irrigate their burrows (Smith, 1981). The range of foraging habitats is limited by their morphology, as well as the range of prey they locate and consume.

The Little Stint which is the smallest wading bird in South Africa has adapted to foraging for its prey on exposed mudflats, salt marshes and along the water. Its legs are small and not adapted to wading in deep water, and its beak is too short to probe very far beneath the surface of the mud. Their small size allows Little Stints to forge on floating mats of algae and other material. Scolopacid waders such as Curlews and Sandpipers have a larger body size correlating with a larger beak and longer legs adapted to wading into deeper water (Kalejta and Hockey, 1994). Longer bills allow these waders to probe deeper into the mud to catch their prey. Like smaller waders, the scolopacid waders use their eyesight to visually identify their prey, as well as using secondary clues

Black-Smith and Crowned-Plovers are exclusively visual foraging bird species with short bills and legs which are not adapted to wading into water. The Pied, Giant and Mangrove Kingfisher species either hover in the air above open water or the shallows trying to locate a fish, before plunging at great speed into the water to catch their prey. The only filter-feeder found in estuaries is the Greater-Flamingo which consumes crustaceans. Above the estuary, swarms of mosquitoes, dragonflies and other invertebrates become the prey of Swallows, Swifts, Martins and other bird species. The majority of the *piscivores* use one of three techniques. Herons and Storks wade steadily through the shallows or deeper water, moving their feet in the mud and vegetation on the estuary bottom to scare fish, amphibians and other prey species out into the open. These species also practice a 'sit-and-wait' strategy to catch unsuspecting prey along the water's edge (Hockey & Turpie, 1999). Generally when the Heron spots movement of its prey below the surface, it plunges its beak into the water to grab its victim. Cormorants and Darters dive beneath the water's surface and hunt for fish amongst submerged logs and other obstacles below the surface. Pelicans swim along and catch prey close to the water's surface.

Ecological segregation of bird species within estuarine environments has been researched extensively around the world. The wide diversity of bird species that exist within many estuarine ecosystems has the potential for inter-species competition for food. Kalejta and

Hockey (1994) state that there are several different mechanisms which can be employed by different bird species to avoid competition with other species within the estuarine ecosystem. These range from changes in bird behaviour, physical characteristics and possibly prey types. Kalejta and Hockey (1994) states that birds have options which include where to feed, when to feed and how to feed, what to actually eat.

Velásquez and Hockey (1992) state that there are even differences in foraging habitats at the macro scale between species within a particular diet category. Studies which were conducted at various different estuaries around South Africa during the 1980s and 1990s examined the competition between different estuarine species. For example, at the Berg River estuaries, the majority of waders forage on the exposed mudflats of the estuary, where as Ruffs tend to favour salt marshes, as do the herbivorous Redbilled Teals (Velásquez, Kalejta and Hockey, 1991). There are also differences between the foraging habits at the meso-scale between different types of mudflats within the estuary systems.

An interesting example is the Ringed and Whitefronted Plovers which both inhabit the Berg River Estuary. The Ringed Plovers tend to be found foraging in the areas of the estuary with soft, fine mud while the Whitefronted Plovers tend to prefer the more sandy areas. Velásquez and Hockey (1992) continue by discussing how wading piscivores, which inhabit the St Lucia Estuary tend to avoid other species by segregating themselves spatially. This is done by foraging in water of differing depths. For example, whilst White Egret tends to forage in shallow water of an average depth of 100mm, the larger Greater White Egret will wade into water with an average depth of 160mm. The world's largest heron, the Goliath Heron, can be found foraging in water of a depth of 325mm (Velásquez and Hockey, 1992). The intertribal mudflats are also exploited in three different dimensions by estuarine bird species. The short-billed species tend to forage for food on the surface of mudflats, or probe just below the surface of the mud, whereas longer billed species tend to obtain their prey from a couple of centimetres below the surface (Hockey & Turpie, 1999). Evidence suggests that the temporal segregation of the foraging activities of bird species in estuaries can reduce interference competition; it will not reduce exploitative competition. Kalejta and Hockey (1994) define exploitative competition as follows:

> *Exploitative competition occurs when the numbers of birds results in the depletion of prey resources available to individuals to the point where availability is limited. Interference competition occurs when birds directly hinder one another's access to food, either by affecting prey behaviour or by restricting their space available in which to gain access to resources* (Kalejta and Hockey, 1994; 242).

The tidal rise and fall that occurs within open estuaries puts severe restrictions on the time available for bird species to access their food source inter-tidally. Tidal variation expands and contracts foraging habitats and has a significant influence on predation dynamics in the estuary itself. This has an impact on the extent to which temporal segregation of foraging can be employed by birds (Hockey *et al.*, 1992). Some bird species are forced to forage both day and night because of a restricted day-light foraging time.

The wading *piscivorous* species are not affected by tidal variations and the limited time available to forage in the estuarine environment. The Herons, Egrets and Storks are able to forage at both high and low tide because of their longer legs. The majority of wading *piscivorous* species are daytime foragers, returning to communal roosting sites during the evening. Ornithologists have seen Goliath and Grey Herons foraging both night and day along the shores of Lake Turkana, Kenya (Hockey *et al.*, 1992).

2.7. Birds as Indicators of Environmental Change

Ornithologists and scientists have begun to recognize the importance of using birds as environmental indicators. Birdlife International, a global partnership of conservation organisations which strive to conserve birds, their habitats and global biodiversity, stress that birds must be recognised as valuable indicator species for biodiversity conservation.

Birdlife International state that birds are ideal indicators because they have widespread popular appeal, and they make ideal flagship species for rallying and mobilizing volunteer-based monitoring networks and programmes, as well as for education and advocacy within civil society (Birdlife International, 2008). Furthermore, birds are highly sensitive to many environmental disturbances. Scientists can monitor the environmental health and integrity of an area and identify potentially harmful changes within the environment by using birds as indicators. Birds are found in a broad range of ecosystems, have varied natural histories, and are found in all regions and countries around the world. Biologists state that birds are high up the food chain, thus integrating changes at lower tropic levels and they are the best-known and best-documented major taxonomic group. This is true in terms of the sizes and trends of populations and their distribution, and the number of species (c.10 000) is manageable. This allows for comprehensive and rigorous analyses (Birdlife International, 2008).

The US Environmental Protection Agency has utilized birds as indicators of environmental health and integrity over the last two decades. In the early 1990s a study was undertaken by the US Environmental Protection Agency to determine whether birds could be utilized as indicators of prairie wetland integrity. The researchers believed the following factors made birds ideal for monitoring wetland integrity and health. Firstly, birds are easy to monitor (usually no samples to process) and secondly, identifying birds is a simple task and can be undertaken by capable non-scientists who are willing to assist with surveys (Crewe and Timmermans, 2005). In addition, established survey protocols are readily available. Some species have the tendency to accumulate toxic substances within their bodies because of their position at the right end of the food chain. Birds are also useful for situ assessments (confined or behaviourally imprinted individuals) (Morrison, 1986). Many bird species have a longer lifespan than other bio-indicators which make them far more sensitive to cumulative impacts and more able than other groups to integrate the effects of episodic events (Morrison, 1986). Researchers all indicate that the ease of access to a relatively extensive nationwide database on avian trends, habitat needs and distribution and finally the availability of moderately extensive bioassay data base, all combine to make them favourable environmental indicators (Crewe and Timmermans, 2005). Some species of birds will leave an area, or modify their behaviour within an area, to avoid the presence of humans. Human over-utilization of an area elicits a variety of responses from the birds in the area. These include bird communities changing in terms of species composition and density as pastures are replaced by natural forests, and again as the pastures are replaced by suburbs (Conway and Timmermans, 2005). Birds are influenced by natural phenomena as well as human activities, and serve as useful gauges of habitat quality.

Several studies have been conducted using birds as indicators of environmental health and integrity. Ornithologists in the United States indicate that half of the 700 species of birds which have been recorded within the United States spend two-thirds of the year in the tropical forests of Central, South America or the Caribbean islands (Miller, 2004). During the warm summer months, when insects are plentiful, they return to North America to breed. A United States Fish and Wildlife study, which was conducted between 1978 and 1987, indicated that populations of 44 of the 62 surveyed species of insect-eating, migratory songbirds in North America were declining. Figures indicated that 20 of the bird species surveyed showed a decline of 25-45% (Miller, 2004). Further research indicated that habitat destruction and fragmentation were the main reasons for this drastic decline in bird populations. The destruction of the rain forests of South America for timber and agricultural land was identified as one major problem. As a result, migrating bird species were losing their winter habitats.

Secondly, the fragmentation of migrating birds' summer forests and grassland habitats in North America due to the expansion of urban areas and agricultural activities has fragmented once pristine forests and grasslands (Miller, 2004). A study was undertaken to examine the shifting seabird distribution which was directly linked to the rapidly changing marine environment in the Western Arctic (Divoky, 1998). According to marine ornithologists there are ten different ways that seabirds can serve as indicators: Indicators of meso- and large-scale marine habitat characteristics; ecosystem controls; temporal environmental variation and climate change; zooplankton and fish stocks; fish and zooplankton communities; contaminants; harmful algal blooms; fisheries and other human impacts on marine ecosystems; and finally of fisheries management and ecosystem-based management in general. The Bering Land Bridge acted as an impassable barrier to the dispersal of seabirds on the Bering/Chukchi Shelf until approximately ten thousand years ago (Divoky, 1998). In the last four decades significant changes have occurred in the Arctic Basin, which have resulted in a decrease in the latitudinal environmental gradient in the entire region. The Chukchi Sea does not have an active commercial fishery and systematic biological sampling, which means that the changes in seabird distribution and abundances in the area are the most effective means of measuring the timing and magnitude of ongoing climate change (Divoky, 1998).

Researchers indicated that three different species of seabirds have shown significant signs of range expansion and population increase. These are both species of Puffin which are now occupying vast colonies throughout northern Alaska where they previously never existed; and the population explosion of Bering Sea Alcids on the northern shelf (Divoky, 1998). However, research has also revealed that cold water species of seabirds such as Black Guillemots (*Cepphus grille*) and Kittlitz's Murrelet (*Brachyramphus brevirostris*) appeared to be decreasing in number due to the melting of the pack ice due to the rapid warming of the ocean in the region (Divoky, 1998). The findings of the research clearly indicate a link between the warming of the Arctic Ocean and the distribution and abundance of different species of seabirds in the Arctic.

For many decades marine ornithologists have argued that seabirds are good indicators of the environmental health of ecosystem constituents (Furness & Tasker, 2000). Researchers state that as the interest in the development of different approaches to marine conservation, such as ecosystem management and ecosystem based approaches to fisheries conservation grows, there has been an awakening interest in using seabirds as environmental indicators, and their potential application to management sciences has been recognised.

2.8. Avian Census Data and its Contribution to Environmental Monitoring

As already noted, avian indicators provide environmental agencies and organizations with an effective tool to monitor diverse and sensitive ecosystems in an unobtrusive manner. One such approach pioneered in the United States of America and Europe, is the identification and examination of the fluctuations in wetland avian populations found within readily available archival avian census data.

The avian census databases of the British Trust for Ornithology is regularly utilised during environmental assessments throughout the British Isles (Hill *et al.*, 1993). This data is collected through annual surveys conducted by birders, volunteers and government officials (Peakall, 2004). Avian census data provides conservation organisations and government departments with an effective monitoring tool to manage agricultural production and industry and its effects on avian populations. Surveys such as the Ringing Scheme provide valuable information about the annual mortality rate of birds throughout the British Isles, the Common Birds Census coordinate surveys and compiles field data about bird numbers into a comprehensive and easily assessable index and the Constant Effort Sites monitors the productivity and survival rate of specific bird species (Peakall, 2004). British scientists have also begun to monitor these databases in an attempt to help monitor global warming.

Avian census data is collected on an annual basis in several states around the United States for lagoons, estuaries, lakes and river systems by NGOs, government agencies and private groups and individuals to gauge the health of bird populations, as well as the overall health of these ecosystems (Canterbury *et al.*, 2000). The archival avian census data that is currently available for estuarine ecosystems is extensive and regularly up-dated. The importance of such census databases has been recognised by several government agencies such as the United States Environmental Protection Agency (Wheeler, 2008). These organisations regularly utilise this data when assessing the health and integrity of water bodies throughout the United States. The examination of avian census data contributes to the overall assessment of the health and integrity of a wetland or estuarine ecosystems.

Meanwhile, in South Africa the collection of wetland avian census data is a recent phenomenon. Prior to the establishment of the Coordinated Waterbird Counts (CWAC) project in 1992 by the Animal Demography Unit (ADU) of the University of Cape Town, wetland avian data was collected in an *ad hoc* and unregulated manner by random individuals and bird clubs (Wheeler, 2008). Some data was compiled into a useable database and much of it was lost. The Coordinated Waterbird Counts (CWAC) project coordinates, prioritise and continues to expand waterbird surveys on a national level with a focus on the establishment of an effective long term waterbird monitoring tool that can benefit conservation efforts at a local and global level. The project ensures that data is effectively and efficiently compiled, managed and shared amongst conservation bodies and the general public (Allen, 2008).

Since 1992, regular six monthly counts of all major water bodies have been undertaken by volunteers and several organisations with a passion for waterbird conservation. This has assisted in the creation of a concise wetland avian census database. The Coordinated Waterbird Counts (CWAC) project is currently one of the largest and most successful citizen science programmes on the African continent (Wheeler, 2008). The project is responsible for the monitoring of over 400 wetland ecosystems from all over South Africa, and also curates waterbird data for over 600 different sites (Wheeler, 2008).

Local ornithologists indicate that the collection of waterbird data from around South African is vital because it provides an indication of the seasonal movements and the relative importance of sites for the protection of different species through the comparison of counts from different locations. Wheeler (2008) states that the long term monitoring of the numbers of wetland birds utilising a particular location allows for the development of an annual population indices which can be used to trace fluctuations of these populations over a period of time. These counts provide a better understanding of how wetland bird species actually use wetland habitats. It helps identify which locations are of particular importance to the survival of wetland bird populations, and it helps in the provision of information support for the development and implementation of management policies and it also provides an effective means of monitoring the health and integrity of the wetland ecosystem as a whole (Allen, 2008).

The emphasis of this study is to assess and process all the bird count data collected by volunteers and birders during their six-monthly visits to the Mgeni Estuary and Beachwood Mangrove Swamps since 1992, as compiled and published by the Coordinated Waterbird Counts (CWAC) project for utilisation by government organisations and private individuals for studies such as this. The fluctuations in wetland bird populations since the beginning of official bird counts was statistically correlated with land cover changes identified through the analysis of aerial imagery in order to determine if fluctuations in the number of birds recorded within the study area could be directly linked to alterations in land cover within a predetermined time period.

2.9. Using Birds as Environmental Indicators in Estuaries

As ecosystems around the globe become increasingly affected by human activity, the need to monitor, evaluate, manage and remediate the ecological impacts of these changes becomes even more vital. Because of the complexity of these ecosystems, such as estuaries and mangrove swamps, it is likely that the use of biological indicators will also increase. The use of bioindicators has dramatically increased over the last couple of decades, and several environmental agencies in the United States have adopted colonial waterbirds as a tool for helping to monitor water bodies such as estuaries, lagoons and river systems (Kushlan, 1993).

Colonial waterbirds are recognised as the best documented and most reliable bioindicators for the monitoring of the health and integrity of estuarine and mangrove ecosystems because of the following:

- Aspects of colonial waterbird biology.
- The extent of biological understanding of that biology.
- The interest of humans in colonial waterbirds.
- Historical Precedent.

As already stated above, water birds are highly visible, sensitive to environmental changes in both nesting and feeding habitats, and are positioned high up on the food chain (Kushlan, 1993).For example, if scientists noticed a decline in the numbers of water birds species which feed at the marsh-bay interface, this may indicate a reduction in tidal marsh habitat due to sand mining and the reduction in the quality of the habitat by the spillage of crude oil or the decline or disappearance of prey species (Slack, 1992). The decline of Northern Pintails and Green-Winged Teals in the Galveston Estuary area of Texas could be closely linked to environmental degradation that was occurring beyond the estuary itself. However, research has indicated a sharp decline in non-migratory bird species such as the Mottled Duck. Slack (1992) stated that this was probably due to salt water moving into the duck nesting habitats.

A study entitled, *"Status and Trends of Selected Vertebrate Resources in the Galveston Estuary: Birds and Alligators"* indicated a decline in the total number of several water bird species which inhabit and visit the Galveston Estuary during migration (Slack, 1992). The findings also revealed a steady decrease in the number of birds per colony within the same species. The data used to generate the visual representation of this decline was provided by the Texas Colonial Waterbird Survey (Slack, 1992). Certain species of waterfowl such as the Mottled Duck (*Anas fulvigula*), Northern Pintail (A*anas acuta*) and Blue-Winged Teal (*Anas discors*) also showed a steady decline in abundance in the Galveston Estuary area as indicated by the Mid-Winter Waterfowl Transects. These transects reflected a widespread trend which has caused serious concern amongst conservationists and ornithologists alike on a national level (Hill *et al.*, 1993).

Slack *(*1992) undertook another study which focused on the Texas Colonial Waterbird Survey. This data was considered the most robust data set available on estuarine bird species in the United States (Slack, 1992). Furthermore, this data did not indicate any significant trend in the total number of water birds and no mention was made of a trend in species richness from 1973 to 1990. As Slack (1992) stated, *"... a detrended correspondence analysis (using the methodology of Spendelow et al. 1989) revealed significant changes in species and habitat associations*" (Slack, 1992; 2). All the birds which showed similar population trends were selected and allocated into three different groups, each group with its similar feeding habitats. These three groups were as follows:

Inland Group (little Blue Herons, White Ibises, Cattle Egrets, White-Faced Ibises and Great Blue Herons) consists of freshwater marsh feeders and generalists. There was no evidence provided by the study to indicate a decline in the number of individuals or the percentage of them in the community over all (Slack, 1992). However, the study clearly showed that the number of bird colonies in the estuary had increased, but those colonies where these species were present showed that their proportion in the colony had decreased.

The Open Water Group (Royal Terns, Cormorants, and Sandwich Terns) is basically made up of open-bay fish eating bird species. According to the study these species showed a remarkable increase in numbers of individuals, the number of colonies and the number of them in the overall estuarine community (Slack, 1992).

The Marsh Group (Snowy Egrets, Black Skimmers, Spoonbills and Great Egrets) which are all species of water birds which consume small fish and other organisms at the marsh-bay interface. This group showed a steady decline in total numbers and the proportion that they composed in these colonies where they occurred. The number of colonies which contained these species increased but the mean colony size decreased. Slack (1992) mentioned that certain species of water birds were outliers in this analysis. For example, the Least Terns were considered as opportunistic nesters and strictly colonial. The researchers also classified laughing gulls as generalists. According to the survey data, the gulls showed no population trend and no decline in their population.

After carefully analysing the findings of the study, it was concluded that feeding habitat, and not nesting habitat, was the main controlling factor in the trends observed, because most of the water birds species actually nested together in the same colonies (Kushlan, 1993). The steady decline in the numbers of marsh-feeding birds in the estuary correlated with the loss of wetland habitat. Although the nesting habitat was not considered the controlling factor in the estuary it is more important on a local scale. There is plenty of documented evidence of entire rookeries being lost to subsidence or erosion. Human activities in the estuary have caused birds to desert their nests, leaving their eggs and chicks exposed to predators and the elements. Invasions of fire ants have also been observed. The findings of the study indicated that nesting habitats are important, but are not the driving force of the estuary-wide trend (Kushlan, 1993).

Several possible causes for the decline in the estuarine bird species in the Galveston Estuary were listed by Slack (1992). The first suggestion presented by the researchers was the decrease in the quality of the feeding habitat. Other possibilities could be the existence of pollutants which are concentrated in the water of the estuary, sediments or the prey species which are consumed by the wetland bird species. Water birds are very effective bioaccumulators of a wide variety of contaminants. Buoyant materials such as oil and grease, tend to concentrate within the intertidal areas of estuaries and lagoons and this can be detrimental to wading birds and skimmers. Oil spills are a serious problem around the world and have a tremendous negative impact on an estuarine or mangrove ecosystem. Oil and grease also form part of the non-point source pollution, and are often accidentally released during activities relating to the movement of oil products (Kushlan, 1993). In addition, effluent released by local factories can also lead to estuarine and mangrove contamination (Berjack *et al.*, 1981).

A decline in the food supply also had a negative impact on bird populations. Researchers found that an increase in death rate/morbidity could also threaten wetland bird species because of disease or increased predation. This could be a natural occurrence or it could be aggravated by human activity in the estuary (Conway and Timmermans, 2005). Another problem is the decrease in the quality or quantity of nesting habitats. A colony could be affected by inundation and erosion because of rising sea levels, wetland drainage or sedimentation could create a land bridge between island colonies and the main land allowing easy access to people and land-based predators (Kushlan, 1993). A build up of guano on plants in an area which is harbouring more birds than is can cope with, gradually kills off island vegetation. Normal succession could also deny bird species nesting sites. Increased predator density with the introduction of dogs, cats, rats and other vermin also have an impact. Direct disturbance by humans of nest sites could also lead to a decline in the number or size of bird colonies. All these factors have an impact at local level. These would all be expected to affect all water birds that nest together, not just those with similar feeding habitats.

2.10. Assessment of Land Cover Changes

As already mentioned, estuaries and mangrove swamps are recognised as some of the most valuable habitats on earth because of the variety of ecological and economic functions they perform. However, estuaries and mangrove swamps are threatened by human expansion and exploitation as manifested by land cover changes within and surrounding these ecosystems. Land cover changes can either have a desirable or undesirable effect on natural ecosystems. These sensitive ecosystems face a bleak and uncertain future without an effective means of identifying, monitoring and managing land cover changes. The assessment of land cover changes and correlating such changes against fluctuations in wetland bird populations could be a useful environmental management tool to help assess the environmental health and integrity of these estuarine and mangrove ecosystems.

The objective of a land cover change assessment is to record and portray changes that have occurred over time. Langran (1993) indicated that change implies that there is a difference in the land surface of a site between two dates, but also that this difference is uncharacteristic of the normal circumstances that would be found from one time period to the next. Assessments are undertaken by comparing the visible changes within an image of a particular location, captured at a particular moment in time, against another image of that same location at a completely different moment in time (Longley *et al.*, 2007).

Academics refer to land cover changes observed as the change in the state of one or several locations, entities, or both (Peuquet, 1999). Land cover changes occur at different rates for various different locations and entities. Changes in land cover are not easy to detect and measure. In some cases these differences are readily measured, the substantial issue being that true change from what is perceived to be the normal environmental variability and the artefacts of the processes of measurement (Longley *et al.*, 2007; Eastman, McKendy and Michele, 1995).

Time series analysis is a process of examining changes over a sequence of images and maps that represent land cover. This does not only focus on the perception of trends in terms of changes but also describes the characteristic values and the abstraction of anomalies from the series of imagery and maps (Longley *et al.*, 2007). According to Peuquet (1999) and Veldkemp and Lambin (2001) there are no standards that are appropriate for change and time series analysis. Some techniques focus on assessing the rate at which change occurs, while others might put more emphasis on the spatial patterns (Peuquet, 1999, Veldkemp and Lambin, 2001).

Any assessment involving changes in land cover will require the enhancement of remotely sensed data quality and other ancillary data to ensure that the desired land cover information is obtained. Data collected through remote sensing has no purpose by itself, because it cannot be used to identify land cover types correctly. It is essential that a range of other data be collected by the researcher, and this data should be combined with remote sensing data to enhance the quality of this set data through the application of technologies such as GIS in land cover change studies (Longley *et al.*, 2007).

GIS is defined as a computer-based technology and methodology that is used to collect, manage, analyze, model and present geographic data for a variety of applications such as land cover assessments (Davis, 2001). This consists of three integrated elements which are described as

- *Geography*: This is the real world or spatial realities.
- *Information*: The data that is collected and the information that is produced, their interpretation and various uses.
- *Systems*: The computer technology and the supporting infrastructure.

GIS has numerous functions such as the collection of data from various sources, including the global communications media. Data can be collected by remote sensing satellites, collecting GPS coordinates in the field and via the internet (Longley *et al.*, 2007). It can be easily retrieved simply by selecting and viewing the data on a computer screen, printed maps, and the internet. It can be used to change and alter data from one form to another or one map format to match another and can be an efficient digital storage system which allows for administration and keeping track of data. GIS technology analyzes data to produce better insight and new information using various different techniques such as data investigations, statistical analysis procedures and other methods and finally it presents the data in maps, graphs or reports that are easy to understand and reproduce (Longley *et al.*, 2007). GIS assists with land management throughout South Africa because of its use as a decision supporting tool and it has been used to map land use patterns throughout the region (Rivers-Moore, 1997). GIS is a vital asset because it enables many different role players to have the opportunity to make better-informed decisions on the management and use of geographic resources at their disposal (Yemane, 2003). Most land cover change studies in South Africa utilise GIS technology as the tool to map and manipulate land cover databases (Yemane, 2003). GIS technology provides scale-free registration procedures and a wide variety of analytical features that can assist researchers with the tools that are required to identify, map and analyse the gradual disappearance of a particular land cover type within a specific study area.

GIS can play a critical role in assessing land cover changes that are taking place within and surrounding the Mgeni Estuary and Beachwood Mangrove Ecosystems. These ecosystems are already showing visible signs of stress due to human expansion and exploitation that is causing land cover change within and surrounding the study area. GIS technology provided the researcher with a modern, efficient and reliable system to compile and manage field data, aerial imagery and other data relating to land cover changes that are being identified and investigated, retrieve and manipulate the data when necessary. Careful analysis of the data will eventually allow for the presentation of the data of the study area in graphic and tabular forms. This process will assist in a better informed decision making process regarding land management within and in the vicinity of delicate ecosystems such as estuaries and mangrove swamps. The findings of the research will be compared against the findings of the analysis of the fluctuations of wetland bird populations identified in the CWAC Bird Census data.

2.11. Summary

Land cover change within and surrounding estuarine and mangrove ecosystems can produce both desirable and undesirable impacts. Sensitive ecosystems such as the Mgeni Estuary and Beachwood Mangrove Swamps that provide the local community and the natural environment with numerous ecological and economic benefits are threatened by undesirable land cover changes and require rigid preservation and appropriate land management. It has been proposed that the decline in the quantity and quality land covers (habitats) within and surrounding the Mgeni Estuary and Beachwood Mangrove Swamps due to human and natural causes, has had a negative impact on wetland bird populations. According to numerous ornithologists, birds are highly sensitive to environmental disturbances. Such disturbances include human induced land cover changes within estuarine or mangrove habitats. Scientists around the globe have successfully used bird species to monitor the health and integrity of the natural habitats, and have used bird species to identify potential harmful changes. The assumption is that as the quantity and quality of specific land cover types (e.g. mudflats, grassland) decline, then the populations of wetland bird species that are adapted to foraging, nesting and roosting in these land cover types will also show signs of decline.

Chapter Three

Background to Study Area

3.1. Introduction

Durban is a sub-tropical city on the east coast of South Africa. The Mgeni River flows through the northern half of the city into the warm Indian Ocean. The study area comprises the last 3 km of the river estuary and the adjacent mangrove swamps.

3.2. Background

The indigenous Zulu people, who inhabit the South African province of KwaZulu-Natal named the river that flowed from the Drakensberg Mountains through the hills of the hinterland through the estuary into the Indian Ocean, the Mgeni. Mgeni means "the river, which flows through the thorn trees or Acacia" (Gillard, 2008). The Mgeni River flows into the Indian Ocean approximately 5 km north of Durban City centre at 29°48'S and 31°02'E. The river and the estuary that form the Mgeni River mouth are surrounded by the northern suburbs of Durban.

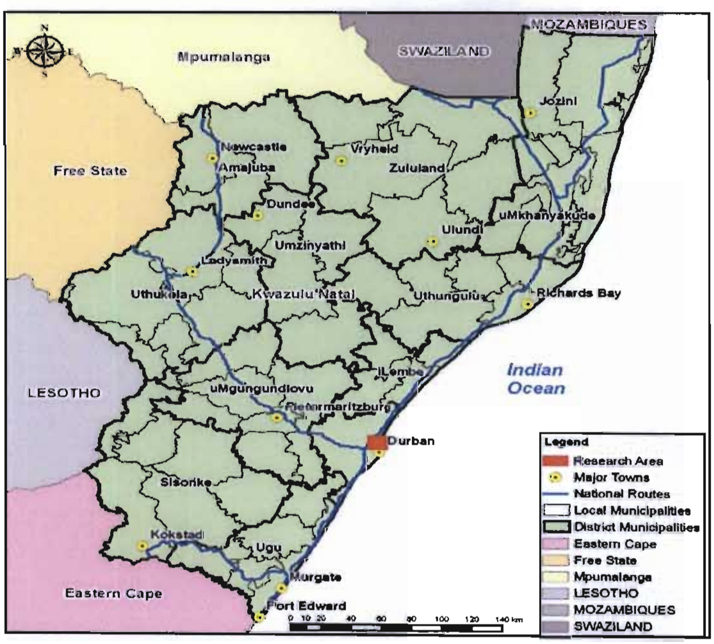


Plate 1: The Study Area in Relation to KwaZulu-Natal (See Appendix A)

The Mgeni Estuary and Beachwood Mangrove Swamps are situated on the wave dominated coastline and they occupy a narrow bedrock confined alluvial valley. The estuary is referred to as a river dominated system due to the closing of the outlet by an elongated sand barrier. The south bank of the estuary is protected from wave action by a groyne, which also acts as a buffer to disrupt the deposition of long-short drift transported by the north-bound longshore current (Begg, 1978). This prevents the estuary outlet closing permanently. Before the construction of the Inanda Dam in 1985, the estuary mouth was permanently open because the river flushed out any material which settled in this area (Plate 2). Garland and Moleko (2000) indicated that the Inanda dam is holding back large quantities of water and sediment which has now caused the river mouth to be a temporarily open-closed estuary. The reduction in water volume and the progressive elongation of the barrier at the mouth of the estuary have been identified as the primary causes of the temporary blockages at the estuary mouth (Gillard, 2008). The study area which forms the basis of this study stretches from the Connaught Railway Bridge to the estuary mouth which enters the Indian Ocean as seen in Plate 2 (Gillard, 2008).

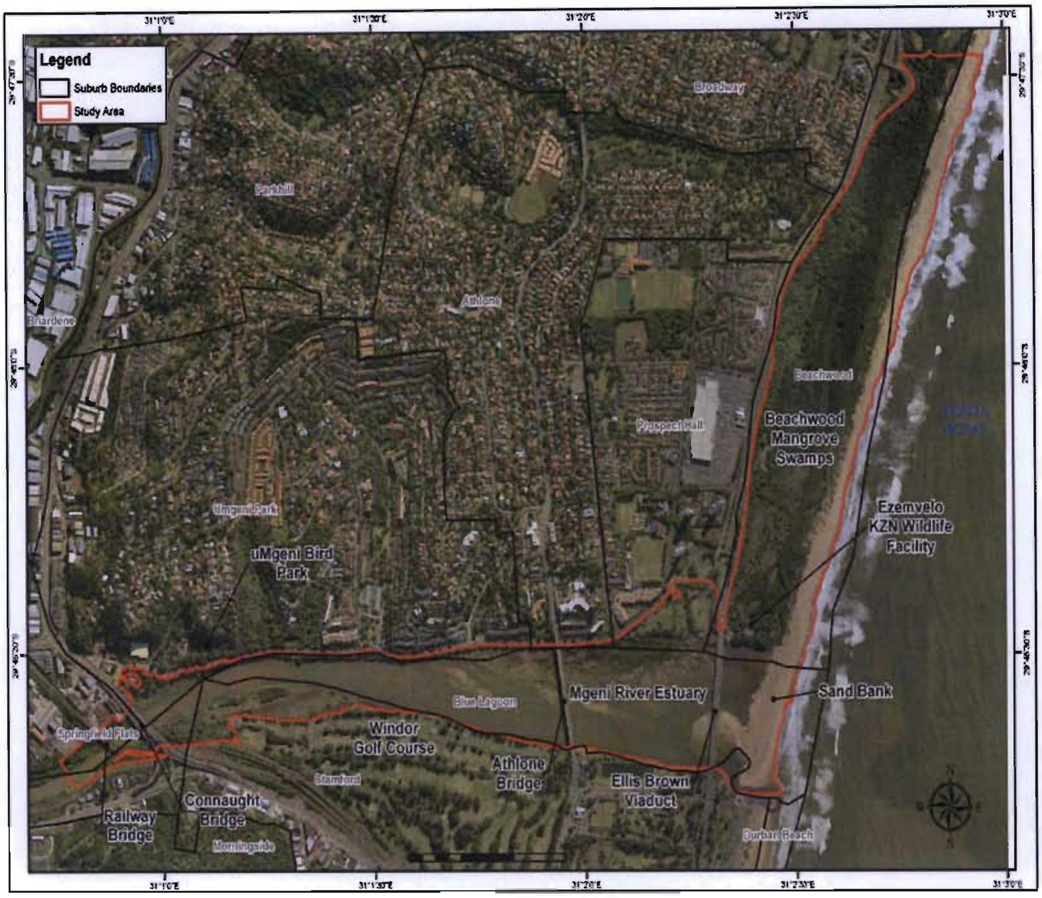
Plate 2: Mgeni Estuary Mouth

3.3. Mgeni Catchment and Estuary

The Mgeni Catchment area covers an estimated 4871 km² (DEAT, 2001). The mean winter and summer flows are 6.5 ms^{-1} and 18.4 ms^{-1} respectively. The lowest flow ever recorded was 4, 5 ms^{-1} while the highest recorded flow was 532 ms^{-1} (Begg, 1978). Studies indicate that 37% of the river catchment area is under agriculture, made up mainly of commercial forestry, sugar cane and subsistence practices. There is also some temporary commercial dryland agriculture taking place. About 3% of the catchment area is covered by degraded bushland and scrubland (DEAT, 2001). Approximately 52% of the catchment was natural and made up of grassland, bush land and forest (DEAT, 2001). Roughly 8% of the land cover in the catchment was urbanised, being made up of residential, industrial and commercial use types (Gillard, 2008).

The river itself has a number of impoundments along its length such as the Inanda, Nagle, Midmar and Albert Falls Dams (Gillard, 2008). Several bridges cross the Mgeni system, starting from the mouth of the Beachwood Creek. Approximately 450 m from the estuary mouth is the Ellis Brown Viaduct. Further up the river, approximately 1.4 km from the estuary mouth is another bridge called the Athlone Bridge. This bridge was officially opened in 1927 (Begg, 1978). The Connaught Bridge is located 2.5 km from the mouth of the estuary, at the head of the estuary. The Connaught Railway Bridge is situated 150 m and to the west of above the Connaught Bridge.

Plate 3: River through Beachwood Mangrove Swamps



Source: Botes (2009)

Plate 4: Map of Mgeni Estuary and Beachwood Mangrove Swamps

The Mgeni Estuary is a popular recreational zone used for bait collection, angling, water sports and bird watching. The world famous Duzi Canoe Marathon actually finishes within the Mgeni Estuary study area. Effluent and storm water is disposed into the Mgeni River and this works its way down into the estuary. Another recreational area is the Beachwood Mangrove Nature Reserve that covers approximately 76 hectares to the north of the study area and has the largest mangrove trees in the entire Durban area (Plate 4). The mangrove swamps contain several species of mangrove trees such as the pioneering white mangrove (*Laguncularia racemosa),* black mangroves *(Avicennia germinans)* and the rarer red mangrove (*Rhizophora mangle)* (McNae, 1963).

Along the shoreline east of the mangrove swamps, there are sand dunes where creeping plant species and pioneer bushes and grasses can be found. Further inland from the swamps are salt marshes, grasslands, thornveld and coastal forest areas (Berjack *et al.*, 1981). The Beachwood Mangrove Reserve is rich in birdlife and numerous natural trails and boardwalks traverse the reserve giving birders the perfect opportunity to explore the natural habitat. Birdwatchers regularly see Goliath Herons, Little Egrets and other bird species wading through the channels hunting fish and amphibians. The reserve is home to the critically endangered Mangrove Kingfisher and the more common Pied Kingfisher. Visitors often witness these amazing birds plummeting into the water ways to catch their prey. The grasslands and salt marshes are the habitat of Water Dikkops that can often be seen trying to conceal themselves in the dense vegetation along the walk ways or scurrying across open ground (Gillard, 2008). These boardwalk platforms allow visitors to have close encounters with mudskippers and the various mangrove crab species such as fiddler crabs.

Plate 5: Beachwood Mangrove Swamps

3.4. Climate

The Mgeni Estuary and Beachwood Mangrove Swamps fall within the regional climatic type of KwaZulu-Natal. This is defined as being subtropical with warm moist summers and cool dry winters (Cooper *et al.*, 1989). The annual average rainfall is approximately 900-1000 mm with the vast majority of the rainfall during the southern hemisphere summer months from December to March. Some estimates state that 80% of the rainfall falls during summer (Cooper, 1999). There are occasional extremes which cause seasonal flood events especially during the summer months. These flood events cause severe scouring of the channel and play a role in the alteration of sediment patterns within the Mgeni Estuary.

The table below illustrates the highest and lowest temperatures for all months of the year. The average daily maximum and minimum temperature are also recorded. The table also illustrates fluctuations and variations in precipitation within the study area. It provides the average monthly precipitation that can be expected, the average number of days with above or equal to 1 mm of rain and the highest 24 hour rainfall that can be expected.

Table 3: Temperature and Precipitation of the Study Area

	Temperature (° C)				Precipitation		
Month	**Highest Recorded**	**Average Daily Maximum**	**Average Daily Minimum**	**Lowest Recorded**	**Average Monthly (mm)**	**Average Number of days with >= 1mm**	**Highest 24 Hour Rainfall (mm)**
January	36	28	21	14	134	15	110
February	34	28	21	13	113	13	197
March	35	28	20	12	120	13	160
April	36	26	17	9	73	9	106
May	34	25	14	5	59	7	111
June	36	23	11	4	28	5	109
July	34	23	11	3	39	5	69
August	36	23	13	3	62	7	91
September	37	23	15	5	73	11	132
October	40	24	17	8	98	15	105
November	34	25	18	10	108	16	94
December	36	27	20	12	102	15	163
Year	**40**	**25**	**17**	**3**	**1009**	**130**	**197**

Source: *South African Weather Bureau*

3.5. Soil and Topology

The northern bank of the upper estuarine channel consists of Dwyka Tillite and Pietermaritzburg Shale, and the slope is considered to be rather steep (Cooper *et al.,* 1989). The southern bank is flatter and low lying and studies over the years have indicated that it is an alluvial formation. A closer examination of the Mgeni Estuary indicates that the channel exhibits a tendency towards braiding over an estimated distance of 1.5 km downstream, practically to the northern bank which stretches from the Connaught Bridge to the Ellis

Brown Viaduct (Gillard, 2008). Meanwhile, the southern bank has a fairly continuous stream of flow. A groyne was installed to prevent tidal scouring and this structure has assisted in stabilizing the southern part of the estuary mouth and managed to control the southward movement of sand spits or long shore drift (Cooper *et al.*, 1989). Cooper *et al.* (1989) found that the, *"Activity of the wave tides producing long-near-shore drift extending southwards, constricts the channel outlet causing periodic closure of the channel, hence flooding the lagoon….."* (Cooper *et al.*, 1989; 5).

3.6. Sediment

Soil erosion within the Mgeni catchment is significant, and as a result the river carries a considerable silt load. Studies have shown that an estimated 70 000 tons of silt per year was carried out into the Indian Ocean between 1958 and 1961 (Begg, 1978). As outlined above, the construction of the Inanda Dam in the mid 80s has reduced the mean annual discharge of the Mgeni River by an estimated 4%. This is due to the introduction of the water release policy which has contributed to the increase in discharge events (Garland and Moleko, 2000). As a result of a controlled outflow, the sediment is being held back behind the dam wall which has led to a reduction in the sediment flow downstream. However, despite the fact that sediment within the estuary had not changed significantly since 1989, the sediment texture has gradual become finer. This study found that sand mining operations in the Mgeni River would probably cease within the next couple of decades and the estuary would then probably begin to deepen as the residual pre-dam sediment is washed out into the Indian Ocean without being replaced by new sedimentary material from upstream (Garland and Moleko, 2000). Mgeni sediment is vital for natural beach nourishment, and the cutting off of this sediment delivery system will have a long term detrimental effect on adjacent beaches (Garland and Moleko, 2000).

3.7. Area and Extent of the Estuary and Mangroves

The total area covered by the Mgeni Estuary and Beachwood is approximately 48 ha on a spring tide (Begg, 1978). The axial length of the estuary is less than 1. 6 km. However, a salinity survey which was conducted on the incoming spring tide during 1972 established that it was in reality approximately 2.5 km. The shoreline length of the estuary is 8.2 km while Beachwood Mangroves cover around 6 km². The total shoreline length is 14. 2 km and the estuary estimated to be 600 m wide near the mouth at the spring tide (Begg, 1978). The actual entrance to the Beachwood Creek Channel is around 20 m wide as seen in the

Plates. However, the channel can reach an overall width of 30-40 m where it splits into a series of different channels (Gillard, 2008). The channel is approximately 100 m wide and the floodplain can reach an estimated 1 km in places (Begg, 1987). The main channel of the estuary splits into a large island. The island is 300 m broad in certain places and almost 3 km in length (Plate 4). The estuary is approximately 2.5 m deep during a spring tide. The depth of the estuary varies from 0. 75 m to around 2 m on an outgoing neap tide. The Beachwood Creek is 0,5m deep depending on the tide. The depth of the entrance of the creek can range from 0.15 m to 1.25 m (Begg, 1978).

Plate 6: Island and Vegetation

3.8. Current Health of Mgeni River and Estuary

The Mgeni River and Estuary ecosystem are impacted upon by surrounding intense, large scale urbanization, and the modification of the river course. The uMgeni, uMbilo and uMhlauzana Rivers have been stripped of their natural habitats (South African River Health Programme, 2002). There is a serious threat to the entire ecosystem due to high population densities and periodic effluent discharge, excessive nutrients and polluted run-off from roads, factory yards and the growing number of informal settlements which have sprung up along the river course post-1994. The existence of up-stream dams and other activities alter water quality; sediment dynamics alter the river's natural flow, and reduce flow in general as shown in Table 4 (South African River Health Programme, 2002).

Table 4: Current Health of Lower Mgeni River and Estuary

Environmental Indicators	Rating	General Comments
Water Quality	Fair	Due to purification of water in the Inanda Dam. However, when river water enters the sea, the water quality is classified as poor due to city pollutants.
Riparian Health	Fair	Not subjected to frequent flood events which has led to excessive reed growth and the invasion of terrestrial weeds.
In stream Habitat	Fair	Impacted upon by dam-regulated flows and cutting off of supply of sand to river. This cause silting and the closure of the estuary mouth.
Invertebrates	Good	Species composition would not resemble the natural diversity. This is due to the unnatural water quality.
Fish Species	Fair	Urban impacts affecting all river systems.

Source: South African River Health Programme, 2002

Chapter Four

Materials and Methods

4.1. Introduction

This study focuses on establishing whether wetland bird species can be used as environmental indictors to monitor changes within and surrounding estuarine and mangrove ecosystems. In order to determine whether wetland birds have the potential to become meaningful environmental indicators, several objectives must be achieved through a systematic and rigorous process using various research methods. This will involve the examination of all available wetland bird census data provided by the Total CWAC Report-Coordinated Water bird Count in South Africa, and the analysis of aerial imagery to identify land cover changes within and surrounding the study area, from year to year, and to see whether such changes impacted on wetland bird populations.

4.2. Materials Used in the Study

4.2.1. Data on Wetland Bird Species

4.2.1.1 The Total CWAC Report-Coordinated Waterbird Counts in South Africa

During the course of the study a review of all available bird census data was undertaken. *The Total CWAC Report-Coordinated Waterbird Counts in South Africa* is a detailed publication, produced by the University of Cape Town's Avian Demography Unit, which summarizes all the results of co-ordinated bird wetland and estuary counts throughout the whole of Southern Africa (Wheeler, 2008). CWAC counts focus on wetland and estuary ecosystems and take place biannually, during both winter and summer. Each individual site is visited and a bird count is undertaken six times within each season. Data collected in the field is subjected to statistical analysis to determine the correlation between two different variables. Basically these produce a series of trend graphs indicating annual variations in observed numbers of key species over the period covered (Wheeler, 2008).

The CWAC Report was reviewed, and the historical records of bird sightings in the Mgeni Estuary and Beachwood Mangrove study area were analysed to determine whether fluctuations in wetland bird populations over the study period could be correlated with land cover changes within the same period. If a direct relationship between variations in bird populations and land cover change could be established within the study period, this would signify that wetland bird species could be used to effectively monitor land cover change within and surrounding estuarine and mangrove ecosystems within South Africa.

4.2.1.2. Interviews with Local Ornithological Experts

Direct interaction in the form of unstructured interviews with the ornithologists was essential to help build trust and develop a working relationship. This research method was used to confirm the findings uncovered by the analysis of the avian literature material and secure additional data on wetland bird behaviour and habitat requirements. Conducting interviews is the most obvious means of gathering essential data 'straight from the horse's mouth'.

4.2.1.3. Archival Aerial Imagery

Aerial imagery is the original form of remote sensing used in topographic mapping and environmental studies and allows for rapid acquisition of accurate, up-to date information about the size, location and the character of objects on the surface of the earth (Carver, 1981; Campbell, 19983. Aerial remote sensing assists in the completion of maps because of their concise representation of the patterns found on the ground (Longley *et al*, 2007).

Vertical aerial imagery is used in the mapping process and will assist in the identification of land cover changes that occurred within and surrounding the Mgeni Estuary and Beachwood Mangrove ecosystems over time. Vertical imagery makes it easier to locate and measure the distance between different objects and features. These measurements can then be compared against older images to determine changes over time (Mitchel, 1981, Campbell, 1983). Secondly, because historical land cover change databases were required for this study, and relevant aerial imagery of the Mgeni Estuary and Beachwood Mangrove Swamps was available, it was more cost effective to use these images than undertake field surveys, although ground truthing was a necessary component of the study (Longley *et al*, 2007).

Because of these advantages, this study obtained vertical aerial imagery of the study area from the *Map Centre CC* and from the eThekwini Municipality, who provided a series of rectified aerial photographs of the study area. Additional images were found in the aerial photograph archives stored in the *University of KwaZulu-Natal's Environmental Science Department* campus library on the Westville Campus. Based on the information available, it was decided to only examine and analyse aerial imagery taken over intervals of five to seven years. The set of 1991 and 1997 images, provided by the eThekwini Municipality, was selected along with the rectified 2002 and 2008 images provided by the *Map Centre CC*. Table 5 outlines the aerial imagery obtained from the *Map Centre CC, eThekwini* Municipality and the library aerial photograph archives of *Environmental Science Department's Westville Campus*.

Table 5: Aerial Imagery of the Mgeni Estuary and Beachwood Mangrove Swamps forming the Basis of this Study

Map	Year	Scale	Job Number	Type	Photographs	Quantity
Map Centre CC	2008	1:50 000	-	Contact Print	-	5
Map Centre CC	2007	1:50 000	-	Contact Print	-	6
eThekwini Municipality	2003	1:30 000	32	Contact Print	4,8,9	3
UKZN Lib	1999	1:10 000	242	Contact Print	13,14	2
eThekwini Municipality	1997	1:11 000	230	Contact Print	29,30	2
eThekwini Municipality	1991	1:30 000	11	Contact Print	140,141	2

4.2.1.4. Discounted Material

As mentioned above, this study focused on the identification and mapping of land cover class changes within the Mgeni Estuary and Beachwood Mangrove Swamps during the study period, the analysis and recording of changes in land cover classes over time within this defined study area, the review and assessment of changes in avian indicator populations; and finally to determine if there is a significant relationship between changes in the populations of indicator bird species, and related changes in the patterns of land cover classes within the estuarine and mangrove swamp study area.

The researcher critically assessed and reviewed various scientific and non-scientific research methods and approaches that were deemed as potentially beneficial to this study. However, after examination and consultation with prominent academics, it was decided that any method considered on the periphery of the study, or not considered necessary for formulating accurate conclusions relative to study objectives would be discounted or excluded. Examples would include the measurement of stream flow and the assessment of river water quality.

4.3. Methods Used in the Study

4.3.1. Evaluating Land Cover Change

4.3.1.1. Land Cover Classification System

After several field visits to the study area and examining the aerial imagery, each land cover class was identified. The Mgeni Estuary and Beachwood Mangrove Swamps was found to comprise mainly open water, mudflats, mangrove forest, marsh and coastal forest as shown in Table 6 below. Satellite and aerial imagery remote sensing techniques have been developed to provide an effective tool for assessing land cover classification and land use acquisition (Thompson, 1996).

In most instances the majority of land cover classification schemes have been developed around the specific user's objectives. As such, these are often influenced by the geographical location of the study area and the data capabilities that are at the disposal of that user (Thompson, 1996). As a result, not many land use classification systems are comparable for directly relevant to the Mgeni Estuary and Beachwood Mangrove Swamp study area.

A standard hierarchical framework that can be used for the classification of remotely sensed data has been developed for the South African environment (Thompson, 1996). The researcher adopted this land classification system as it provided the widest range of recognised land cover types which could be applied successfully to the Mgeni study area. In particular, the hierarchal classification for both water bodies and wetlands has been specifically developed to be broad, because wetland nomenclature and classification schemes are normally formulated and applied to specific mapping or management requirements. To provide an extensive set of subclasses within this land use classification fields would be impractical (Thompson, 1996).

However, the researcher developed and applied subclasses within these fields due to the diversity of land cover types within the Mgeni Estuary and Beachwood Mangrove Swamps. Secondly, the selected avian indicator species are adapted to foraging, roosting and breeding within specific habitat types i.e. land cover subclasses. The specific subclasses developed for this study were based upon a particular classification system used during a land classification study in Maputaland, South Africa (Lubbe, 1996). The vegetation and soil types of Maputaland mirror those found within the study area and, therefore, specific land cover subclasses were selected and adopted for this study.

Table 6: Thompson and Lubbe (1996) Land Cover Classes and Subclasses

Level1	**Level 2**	**Level 3**
Forest and Woodland	Forest Woodland Wooded Grassland Mangrove	Coastal Forest Island Mangrove Vegetation
Thicket, Bushland, Scrub Forest and High Fynbos	Thicket Scrub Forest Bush Clumps High Heathland	None
Scrubland and Low Fynbos	Scrubland Low Fynbos	None

Grassland	Unimproved Grassland Improved Grassland	Grass Area Grassland and Scrub
Waterbodies	Lagoon Estuary Lake Dam Pan Stream River	Shallow (Under 0,5 m) Open (Between 0,5 and 1,5 m)
Wetlands	Reed Beds and Marsh Reed Beds and Grassland	None
Urban/ Built Up Area	Residential Commercial Industrial Recreational Conservation	None
Other Land Cover Classes	Beach Mudflats Sandbanks Salt Marsh	None

Sources: Thompson (1996) and Lubbe (1996)

4.3.1.2. The Impacts of Tidal Fluctuations on Study Area

The moon travels around the earth and together, they travel around the sun. The gravitational forces that are created generate the rise and fall of the world's oceans, which in turn impacts upon water bodies within the study area. Twice daily the study area experiences the ebb and flow of the tide. This is of particular importance to the local mangrove community.

Although limited somewhat by the condition of the sandbar at the estuary mouth, the study area is influenced by tidal fluctuations, and as such the impact of natural tidal movements will need to be addressed by the researcher. In order to assess tidal impact within the study area, the date and times recorded on the aerial imagery were compared to historical records of tidal movements in the Durban area. Below in Table 7, the researcher has identified and recorded the tidal conditions on the days the selected aerial surveys were undertaken.

Tables 7: Relevant Tidal Conditions Correlated with Aerial Surveys (1991-2008)

Date	Time	Tide	High Tide Height (M)	Low Tide Height (M)
13/04/1991	09:02 AM	Low	-	0.33
	03:02 PM	High	1.81	-
25/01/1997	10:41 PM	Low	-	0.43
	04:51 PM	High	1.86	-
15/03/2003	08:16 AM	Low	-	0.65
	02:20 AM	High	1.65	-
18/01/2008	12:12 PM	High	1.53	-
	06:51 PM	Low	-	0.75

An ideal scenario would see controlled conditions whereby the researcher would undertake aerial surveys at the same time, and date within a specific tidal range to ensure that the optimum conditions prevailed, this would allow accurate comparisons between aerial survey photos. However, such an approach was just not feasible within the constraints of this study, and an alternative approach of somehow levelling the playing fields had to be found. The four primary aerial survey images used as the basis of the land cover comparisons were all taken at different times within a 6 hour tidal cycle. As such it was necessary to establish when each image was captured relative to the tidal conditions of any given day.

For the purpose of this study, mudflats were defined as areas of exposed river or mangrove banks which are covered by water twice within a 24 hour cycle due to tidal fluctuation. The influence of river inflows on tidal conditions has been ignored by the study on the basis of the relative infrequency of such occurrences.

Automatically date and time are stamped onto each aerial survey image after it is captured. Where no date or time of capture is provided, the researcher contacted the eThekweni municipality to obtain the flight plans of that particular aerial survey.

Durban tidal conditions are recorded twice daily in the form of the exact time of both low and high tide, together with the water level variance in meters. The table below compares the tidal conditions at the recorded time each aerial survey image was captured.

Table 8: Area Correction Factor

Image Capture		Tidal Conditions		% Above Low Tide	Area Correction Factor
Date	**Time**	**Low**	**High**	**Low Tide -> High Tide**	
13/04/91	13:00	09:02	15:02	70%	**-20%**
25/01/97	11:45	10:41	16:51	20%	**+30%**
15/03/03	11:30	08:16	14:20	50%	**0%**
18/01/08	10:15	05:29	12:12	80%	**-30%**

The date and time of the image captured was compared to the times of tidal cycle, and the time variance above low tide was recorded and converted into a percentile. Using the 2003 aerial image as a datum (representing +/- 50% of the mudflats by area under water) a conversion factor was developed to enable the other areas of exposed mudflats to be adjusted for scientific comparison purposes. For of this study, the areas of shallow and open water will be regarded as relative constant and, therefore, no area adjustments were made as they were not seen to be particularly relevant to the study.

Finally, the digitised areas (Ha) of exposed mudflats were then adjusted by the conversion factor calculated in Table 8 above as outlined in the table below. Whilst not precise, the above data correction methodology offers a simple method of adjusting a significant land cover type, tidal fluctuations such that reasonable comparisons can be made between the various aerial survey images.

Table 9: Corrected Mudflat Area (Ha) Values

Year	Digitised Mudflat Area (Ha)	Corrective Factor (%) See Table 8	Corrected Area (Ha)
1991	20.64	-20%	16.51
1997	10.77	+30%	14.00
2003	11.54	00%	11.54
2008	6.06	-30%	4.24

4.3.1.3. Scanning of Aerial Imagery

Because aerial imagery can be distorted by variations in ground relief, the curvature of the camera lens or the tilt of the plane, there is the possibility that such imagery might be an inaccurate representation of the earth's surface (Carver, 1981; Mitchel 1981; Campbell; 1983). The resolution of images might also present as a problem in terms of contrast, colour and tone of the aerial images.

The first step is to minimise inaccuracies due to distortion and resolution is to scan imagery into an electronic format. A Hewlett-Packard Scanjet 5370C Scanner was used for this purpose. Initially, it was felt that the images should be scanned at 400 dpi. However, the poor resolution of the images in terms of contrast and colour made visually identifying the differences between land covers difficult during digitizing. To ensure a greater level of accuracy, it was decided that the images would be rescanned at 1200 dpi to ensure optimal resolution. This process is referred to as scanning data entry. The process involved the initial raster scanning for the next step of on-screen digitizing (Davis, 2001). The aerial imagery was edited once the process was completed. The scanner produces raster files forming the background images for the on-screen digitizing process, or as a raster image to be combined with remote sensing data obtained for the study (Longley *et al*, 2007).

4.3.1.4. Georeferencing

The next step after the scanning of the aerial imagery is referred to as georeferencing. It was decided that the georeferncing process would be conducted by the Pietermaritzburg–based company *Map Centre CC*. The series of scanned images were emailed to the company and their technicians examined the images and georefernced them. Basically, all GIS data files have real-world coordinate systems that make them suitable for use as geographic data (Longley *et al*, 2007). This process involved data being fixed to a standard coordinate system, geographically linking the aerial images of the Mgeni Estuary or Beachwood Mangrove Swamp, to the earth.

After rigorous examination of the images, four separate points or reference features were identified in each aerial image. Field surveys were conducted within the study area and the GPS coordinates of these points/features were recorded using a portable GPS device. All real world coordinate positions of key features found within all the aerial photographs were collected during these field surveys. The features or points selected included bridges, buildings and road intersections. This data will then be incorporated into Microsoft's Excel spreadsheet to assist in merging field attributes with GPS data.

4.3.1.5. On-Screen Digitizing

The digitizing process is completed on a computer monitor. The scanned aerial images of the study area are displayed on the desktop computer screen and the features that are displayed are traced using a mouse. The latest aerial images would be digitized first. A feature type is selected by the tracer as a point, line or polygon. These features are then traced by the mouse in a similar fashion to the puck on a digitizing table. The GIS data files are specific to either point, line or polygon features. Each different type will be digitized separately by the tracer during the digitizing process.

The digitizing process is organised to ensure that features of all types within the images are digitized and their locations are noted. Every feature within the database is then classified and each receives a label system assigned before the digitizing process begins (Longley *et al*, 2007). Magnification and the moving view are basic functions that require a few clicks on the mouse buttons on the screen to allow the tracer to zoom into aerial images to help ensure that greater accuracy is achieved while tracing features.

The aerial imagery obtained from the university library was not 'rectified'. This means that these images were not corrected to a georeferenced location, and were nothing more than 'uncorrected' pictures that could not be used (Davis, 2001). In order to correct this fault, the tracer used an option that splits the computer screen with the georeferenced aerial photographs on one side, and the unreferenced aerial photographs are on the other. The features and points that are displayed on the screen are related by coordinates.

The next step is to select thirty-two common points on the images, each represented by a coloured dot that is positioned at each of these chosen locations. The aerial photographs are adjusted using the affine transformation program which basically stretches and deforms the aerial images according to these identified coordinate points (Davis, 2001). This program transforms the digitizer table coordinates to real-world coordinates for the digitized aerial photographs, using all the reference points and projection information that is available (Davis, 2001).

4.3.1.6. Projecting Land Cover Maps

Map projections are the representation of the spherical earth onto a piece of paper as a map, or a digital image on a computer monitor. To assess changes in land cover patterns within the study area and to facilitate the comparison between different years, all images had to have the same map projection (Longley *et al*, 2007). Therefore, it was essential to select the ideal map projection required to assess the land cover change patterns, in terms of area covered, in the Mgeni Estuary and Beachwood Mangrove Swamps.

It is vital that from the beginning of this process that there needs to be an understanding of the map projection and coordinate system that is required. The coordinate system that will be adopted is largely determined by eth extent of the area that will be covered during the study. There are two types of coordinate systems that are applicable for working in 2D data: Projected and Geographic Coordinate Systems (Longley *et al*, 2007).

Projected Coordinate systems are ideal for working over a small study areas. The Gauss Conform Projected Coordinate System that is used in South Africa is simply a Transverse Mercator Map that has been turned upside down and limited to an area of approximately 2° of longitude. This means that it will not extend beyond 1° on either side of the Central Meridian (Longley *et al*, 2007). This system is often referred to as LO or Longitude Zero which is based on the Cape Datum. The central meridians are denoted to the LO, followed by the number of line of longitude. The City of Durban falls within the Map Zone where the central meridian is denoted as LO31. The datum that has been adopted by South Africa since 1999 is known as the Hartesbeehoek94 (Hart94) which has been based on WGS84 for a global ellipsoid (Botes, 2009). Therefore, all central meridians are being preceded with WG. Therefore, the Map Zone in which the City of Durban is found has its central meridian is denoted as WG31.

As the study area covers a small portion of the Durban area, it was essential to define the spatial reference system used in South Africa with the parameters of the Map Zone in which the Durban is found (Botes, 2009). Therefore, is defined as WG31.

4.3.1.7. Assessing Changes in Land Cover

The mapping of the land cover of the Mgeni Estuary and Beachwood Mangrove Swamps was completed. The total area of each land cover class was calculated by using the summary function of ArcMap. The land cover class's attribute table is opened and the field titled area is selected. The 'Calculate Values' option is clicked and this generates a summary table which is exported to Microsoft Excel 2007 to be analysed in order to quantify the land cover changes over the study period.

4. 3.1.8. Positional Error

The National Map Accuracy Standard prescribes positional errors that are allowed to occur within a database (Longley *et al.*, 2007). The 1947 US National Map Accuracy Standard indicates that 95% of all errors should fall below 1/30 inches (Approximately 0.85mm) for all maps that are of a scale 1: 20 000. While 1/50 inch (0.51mm) would be acceptable for all other maps (Longley *et al.*, 2007). However, it is advisable that positions that are measured on a map should be subjected to errors of up to 0.5mm at the scale of the map in question. The researcher applied this approach during the cause of this study.

Table 10: below represents the distance on the ground that corresponds with 0.5mm for the common map scale.

Map Scale	Ground distance corresponding to 0.5mm map distance
1:10 000	5 m
1:24 000	12 m
1:50 000	25 m

Source: Longley et al., 2007

4.4. Identification of Avian Indicators

4.4.1. Identification of Wetland Bird Species

Several bird species that utilise the Mgeni Estuary and Beachwood Mangrove ecosystems for roosting, feeding and breeding were identified during field visits. This identification process was undertaken by analyzing South African Avian literature such as *Roberts Birds of Southern Africa VII, SAOS Checklist of Southern African Birds* and *The Important Bird Areas of Southern Africa* (Allen, 2008).

4.4.2. Identification of Indicator Species

Reviewing the avian literature proved valuable as it assisted in the establishment of criteria to identify twelve bird species that would be used as 'indicator species' for both estuarine and mangrove habitats. The indicator species were selected based upon their preferred natural habitats within an estuarine or mangrove ecosystem as evidenced by their foraging behaviour, dietary requirements, roosting and reproductive requirements noted after discussions with ornithological experts and the review of available avian literature.

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Table 11: Mgeni Estuary and Beachwood Mangrove Avian Indicator Species

Indicator Bird Species Selected	Habitat Preference
African Darter	Open Water Indicator
White-Breasted Cormorant	Open Water Indicator
Pink Backed Pelican	Open Water Indicator
Goliath Heron	Shallow Water Indicator
Little Egret	Shallow Water Indicator
Pied Kingfisher	Water Zone Indicator
Caspian Tern	Beach and Sand Bank Indicator
Grey Headed Gull	Beach and Sand Bank Indicator
Swift Tern	Beach and Sand Bank Indicator
Water Dikkop	Vegetated Area Indicator
Woolly-Necked Stork	Vegetated Area Indicator
Purple Heron	Vegetated Area Indicator
Sacred Ibis	Mud Flat Indicator
Curlew Sandpiper	Mud Flat Indicator
Little Stint	Mud Flat Indicator
Sanderling	Mud Flat Indicator
Blacksmith Plover	Mud Flat Indicator

4.4.3. Criteria Utilised for Selecting Avian Indicators

The researcher noted that the range of foraging habitats is limited by the morphology of the bird species, as well as the range of prey that the species can locate and eventually consume. The researcher consulted with local ornithologists and reviewed avian literature to develop criteria for the selection of avian indicator species.

For example, Mudflat Zone Indicators (wading wetland avian species) such as the Little Stint, Curlew Sandpiper, Sanderling and Blacksmith Plover prey on a variety of aquatic invertebrates found close to the surface of inter-tribal mudflats (Velásquez and Hockey, 1992). Invertebrates such as snails, worms and crabs are visually identified by the bird as they move across exposed mudflats, and then they are caught, disabled and consumed by pecking or shallow probing with the bird's beak (Allen, 2008). Some wading bird species locate their prey by other clues such as surface casts of poychaetete worms, or the movement of prawns and shrimps as they attempt to irrigate their burrows. These facts indicate that these wetland bird species have the potential to become avian indicator species for monitoring changes in the exposed mudflat land cover class.

A summary of the specific habitats, diets, roosting and breeding requirements of the selected avian indicators was compiled after interviews with local ornithologists and examination of literature sources is provided in the Appendix F and J, found in the Appendix section.

4.4.4. Analyzing the CWAC Bird Census Data

The *Total CWAC Report-Coordinated Waterbird Counts* provided a wealth of historical data relating to the number of wetland birds visiting the Mgeni Estuary and Beachwood Mangrove ecosystems over the last two decades. The researcher captured and analysed only wetland bird census data relevant to the selected avian indicator species. This census data was transferred into Microsoft Office Excel 2007 for easy storage and processing. A series of trend graphs were generated illustrating the fluctuations in populations of avian indicator species within the study area over the chosen period of study. Table 13 is an example of the *Total CWAC Report-Coordinated Waterbird Counts.*

Table 12: Example of CWAC Avian Census Data

Avian Indicator Species	Jan-93	Jul-93	Jan-94	Jul-94	Jan-95	Jul-95	Jan-96	Jul-96
PB Pelican	0	0	2	17	3	20	0	2
WB Cormorant	6	44	0	0	10	3	11	54
African Darter	0	4	0	0	4	4	1	37
GH Gull	963	2	548	31	30	54	282	6
Caspian	1	4	1	2	1	5	2	1
Swift Tern	77	16	52	111	46	107	110	68

Sacred Ibis	8	72	8	26	19	192	20	71
Woolly-Necked Stork	0	3	0	0	0	0	2	1
Curlew S/piper	224	0	545	0	437	0	631	0
L Stint	138	0	288	0	59	0	10	0
BS Plover	15	49	31	57	0	52	30	54
Water Dikkop	2	0	0	0	0	14	4	1
P Heron	1	2	0	0	2	0	2	0
Go Heron	2	2	0	0	2	2	1	2
L Egret	4	0	1	1	5	5	0	12
P K/fisher	2	0	0	4	0	8	1	10

By examining the trend graphs generated via the Excel software, it would be possible to develop a realistic picture of the wetland bird numbers within the study area, and to assess whether these bird populations were increasing or decreasing within the study period.

4.4.5. Interviews with Local Ornithologists

In preparation for the study, a number of noted local ornithological experts were consulted to help determine the relevance and appropriateness of the topic selection, to help define the scope and the geographical boundaries of the intended study area, and to obtain information in the form of research papers, documents and reports which could assist in the progression of this study.

This was done by conducting unstructured interviews. These interviews helped establish a working relationship with these ornithologists and helped identify appropriate indicator bird species to be used for this study. The local ornithologist consulted include Mr David Allen (*Curator of Birds at the Durban Natural History Museum*), Mr Roy Cowgill and Mr Simon Davis of *Birdlife South Africa,* and finally Mr Shaun Wilkinson, Manager of the *Mgeni River Bird Park.*

A series of guiding questions about wetland bird species in general was developed and more specific questions related to each indicator specie's foraging behaviour, dietary requirements, roosting and reproductive requirements were formulated. Leading questions were avoided during the interviews. The respondents were allowed to answer the questions in their own terms, voicing their own views and experiences. Probing questions were asked to try and go beyond the expected answers given by the respondents to obtain a better understanding of their assumptions.

These interviews helped the researcher to establish an in-depth insight and understanding of wetland bird species and their behaviour patterns, changes in land use/ cover within the study area, and other essential information that went beyond the mere "answers". This is an ideal means of exploring and investigating a topic very broadly. These questions were specific to the particular ornithologist being interviewed, and the interviews had no formal structure or protocol. All responses were recorded by writing them down and/or by means of a Dictaphone, to ensure that data crucial to the study was not lost. The recorded responses were analysed and collated after the completion of interviews.

4.4.6. Field Survey of current status of Mgeni Estuary and Beachwood Mangrove Swamps

A series of field surveys were conducted within the Mgeni Estuary and Beachwood Mangrove Swamp ecosystems to determine precisely where each habitat was located within the ecosystems, and to generate adequate additional data to test the quality and accuracy of the aerial image classification process undertaken at desktop level. The field surveys were carefully planned to give due consideration to the objectives of the study, and the nature of habitats being surveyed. Most importantly, the field surveys had to coincide with both high and low tide regimes of the Mgeni Estuary.

Before undertaking a field survey, a basic understanding of the concept of remote sensing is essential. Remote sensing is a mapping approach that does not require field surveys, and is often referred to as a 'desk top study'. The aerial imagery obtained from the *Map Centre CC* eThekwini Municipality and the library aerial photograph archives from the *Environmental Science Department's Westville Campus*, provided the opportunity to distinguish between different features and habitats within the Mgeni Estuary and Beachwood Mangrove Swamps according to colour, contrast, pattern, texture and context. The examination of the aerial imagery was made easier by the high quality of the images. This allowed the boundaries of the different habitats to be readily indentified and defined. This assisted the series of field surveys by identifying key features that required physical verification and examination on the ground.

4.5. Assessing the Relationship between Counts of Wetland Bird Indicators and Changes in Land Cover

The overall aim of the study was to determine whether wetland bird species could act as effective environmental indicators of undesirable change in land use and cover within and surrounding estuaries and mangrove swamps ecosystems in Southern Africa. In order to assess the relationship between wetland bird populations and land cover change, a systematic process was adopted.

A systematic process of identifying and proving a link between the fluctuations in the populations of indicator bird species, and related changes in land cover, would involve analyzing and identifying a common trend between the data processed when reviewing the *CWAC Report*, and the decline or increase in the total area of each land cover class. In order to establish the existence of relationships between different variables a process of statistical analysis was implemented.

4.5.1. Statistical Analysis and the Correlation Coefficient

The researcher undertook a statistical analysis to determine if there was a relationship between the values provided by the CWAC Wetland Avian Census data for the avian indicator species and the number of hectares covered by particular land cover classes identified within the study area that these species rely upon for foraging, roosting and reproduction within the Mgeni Estuary and Beachwood Mangrove Swamp study area. The most appropriate means of establishing if there was indeed a relationship between two variables of interest and how closely the two variables change in relationship to each other, is the application of a correlation coefficient and linear regression (Hogg and Craig, 1975).

In simple regression the coefficient of determination, R^2 is the square of the correlation coefficient, and $0 \leq R^2 \leq 1$. An R^2 value close to 1 indicates a strong linear relationship (Hogg and Craig, 1975). Consider the variables (x,y) with data points (x1, y1),...m (xn,yn) . The sample correlation coefficient is defined as:

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}}.$$

The correlation coefficient is a statistical measure which determines the strength of the linear relationship. The two variables that are compared against each other are known as the independent and dependent variables (Hogg and Craig, 1975). The independent variable is the variable that changes which is beyond human control. In the case of this study, time is the independent variable because it goes on whether the researcher would like it or not. Basically, in a very simple sense, time always increases and will never decrease (Hogg and Craig, 1975).

The dependent variable changes as a result of the changes taking place in the independent variable (Hogg and Craig, 1975). For example, the dependent variables in this study are the number of avian indicators recorded and the areas covered by the land cover classes and subclasses within the study area. Therefore, the number of birds recorded and the area covered by a specific land cover class or sub-class within the study area depends on the amount of time that passes.

For the purposes of this study it was essential to find a mathematical device to determine the amount by which these variables correlated with each other. A correlation coefficient can take on values between -1 and 1. A correlation coefficient of 0 means that changes in the independent and dependent variable appear to be random and completely unrelated to each other (Hogg and Craig, 1975). In other words there is no relationship between the variables and thus there is no linear correlation. A correlation coefficient of +1 basically indicates that the two variables are perfectly correlated with each other and as the independent variable increases or decreases it will be accompanied by the exact increases or decreases in the dependent variable. A correlation coefficient of +0.75 indicates that a change in the independent variable should result in a comparable increase in the dependent variable (Hogg and Craig, 1975).

If there is a negative correlation coefficient like -0.6508 this means that the two variables will respond in opposite directions. While the one increases, the other variable will decrease. It is important to note that any correlation coefficients between .00 and .30 should be considered weak, while those between .30 and.70 are taken as been moderate and any coefficients between .70 and 1.00 are to be considered high (Hogg and Craig, 1975).

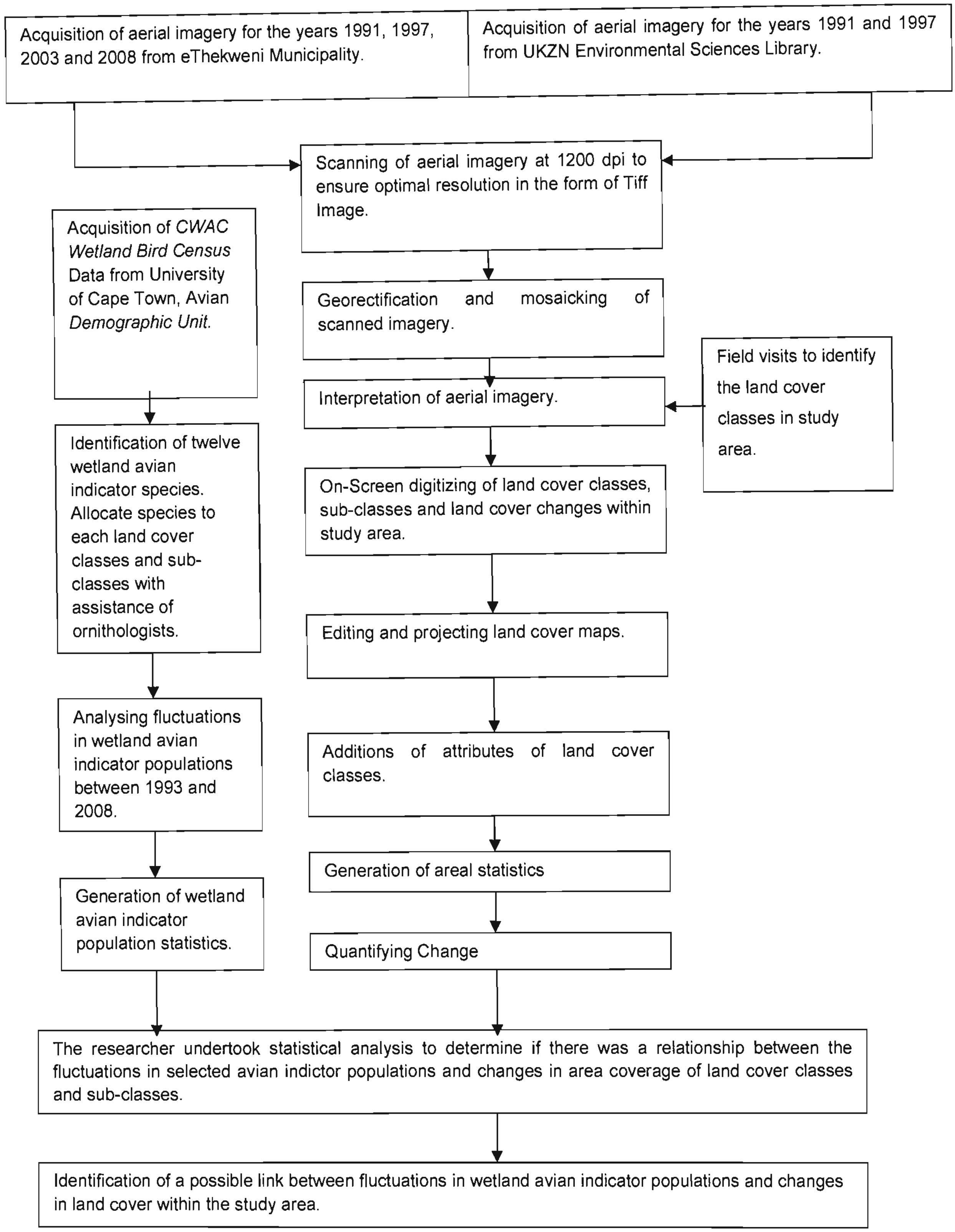

Figure 1: Summary of the Steps Followed to Develop the Historical Avian Indicator Changes, Land Cover Change Database and Maps

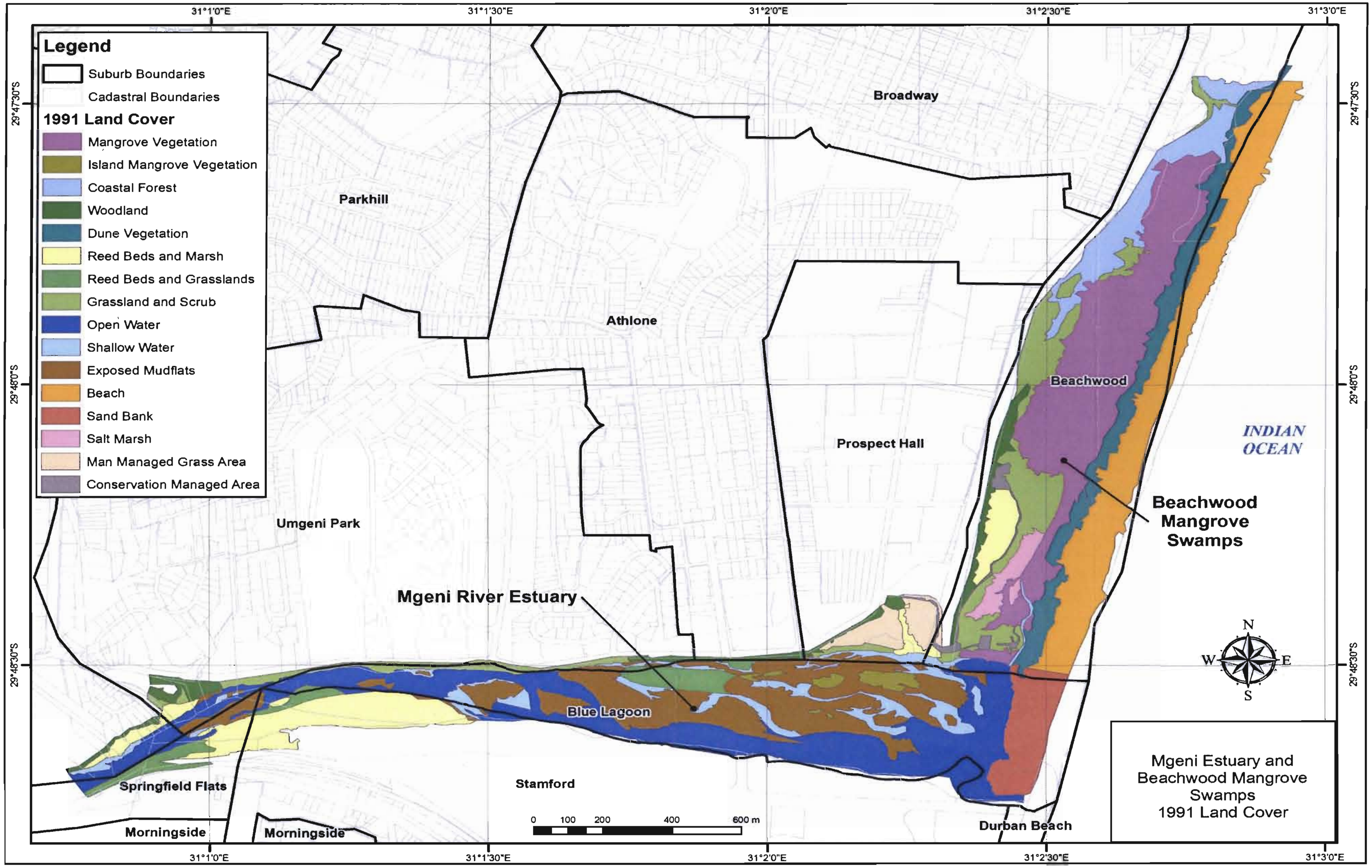

Plate 7: Mgeni Estuary and Beachwood Mangrove Swamps 1991 Land Cover

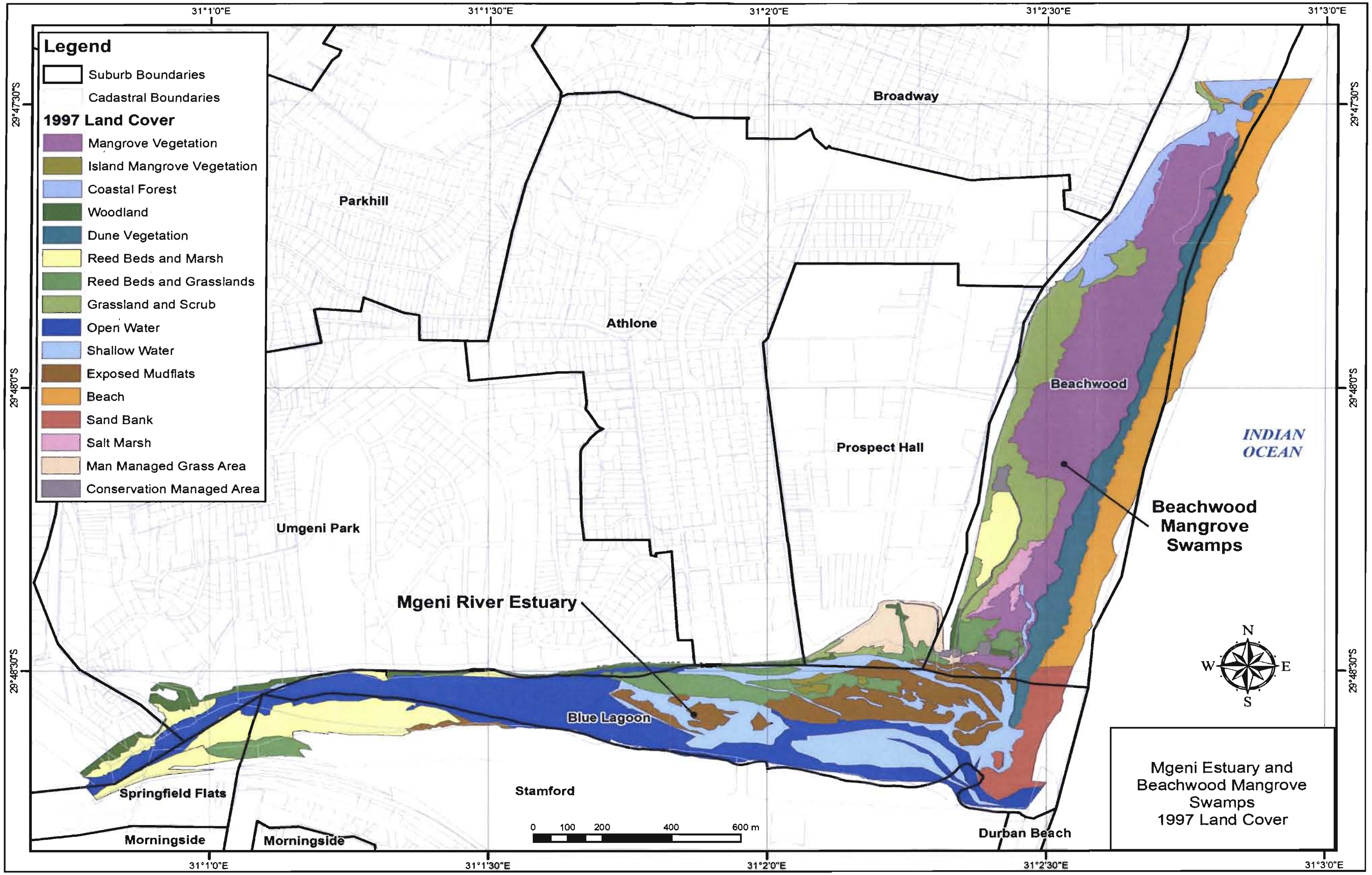

Plate 8: Mgeni Estuary and Beachwood Mangrove Swamps 1997 Land Cover

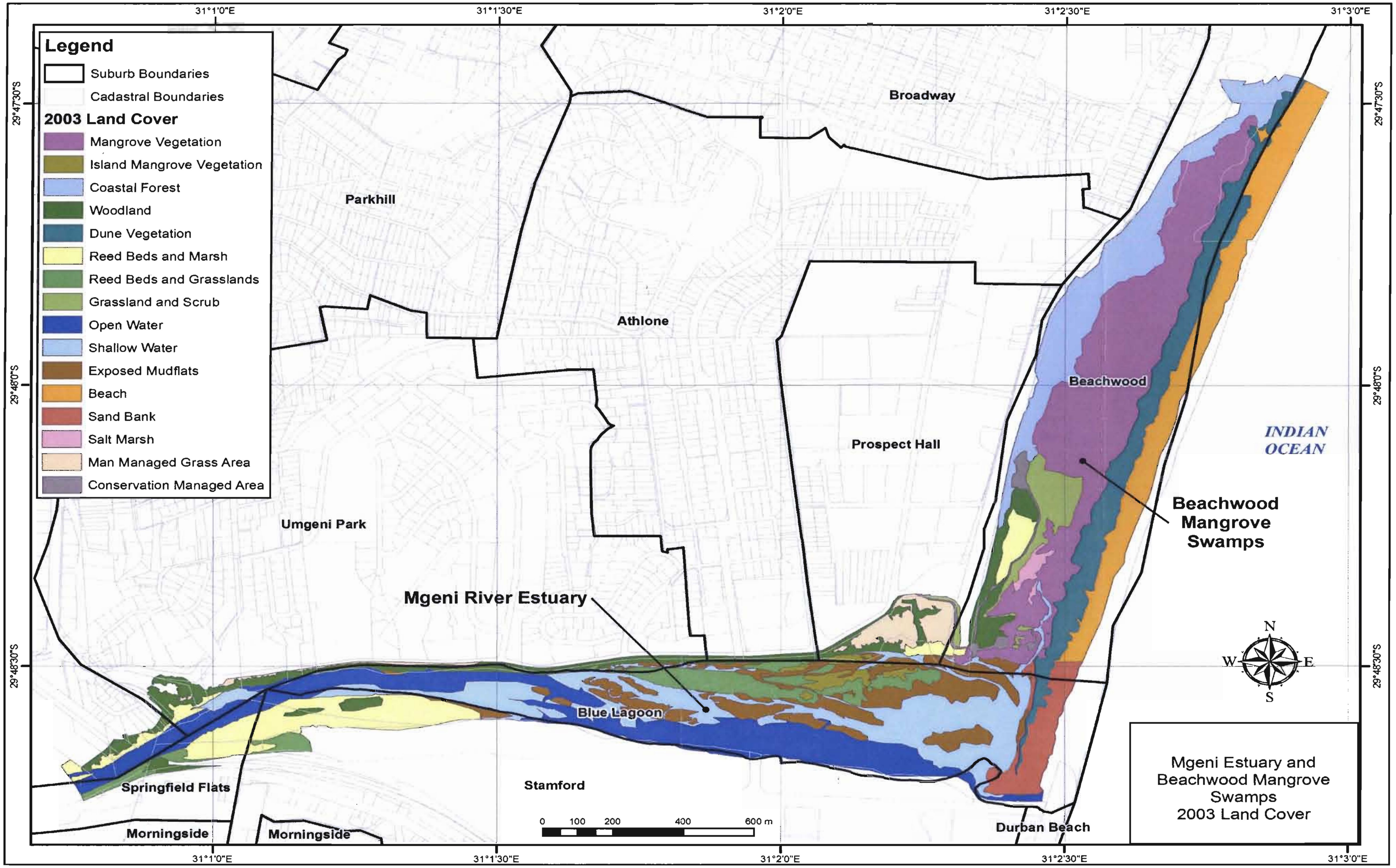

Plate 9: Mgeni Estuary and Beachwood Mangrove Swamps 2003 Land Cover

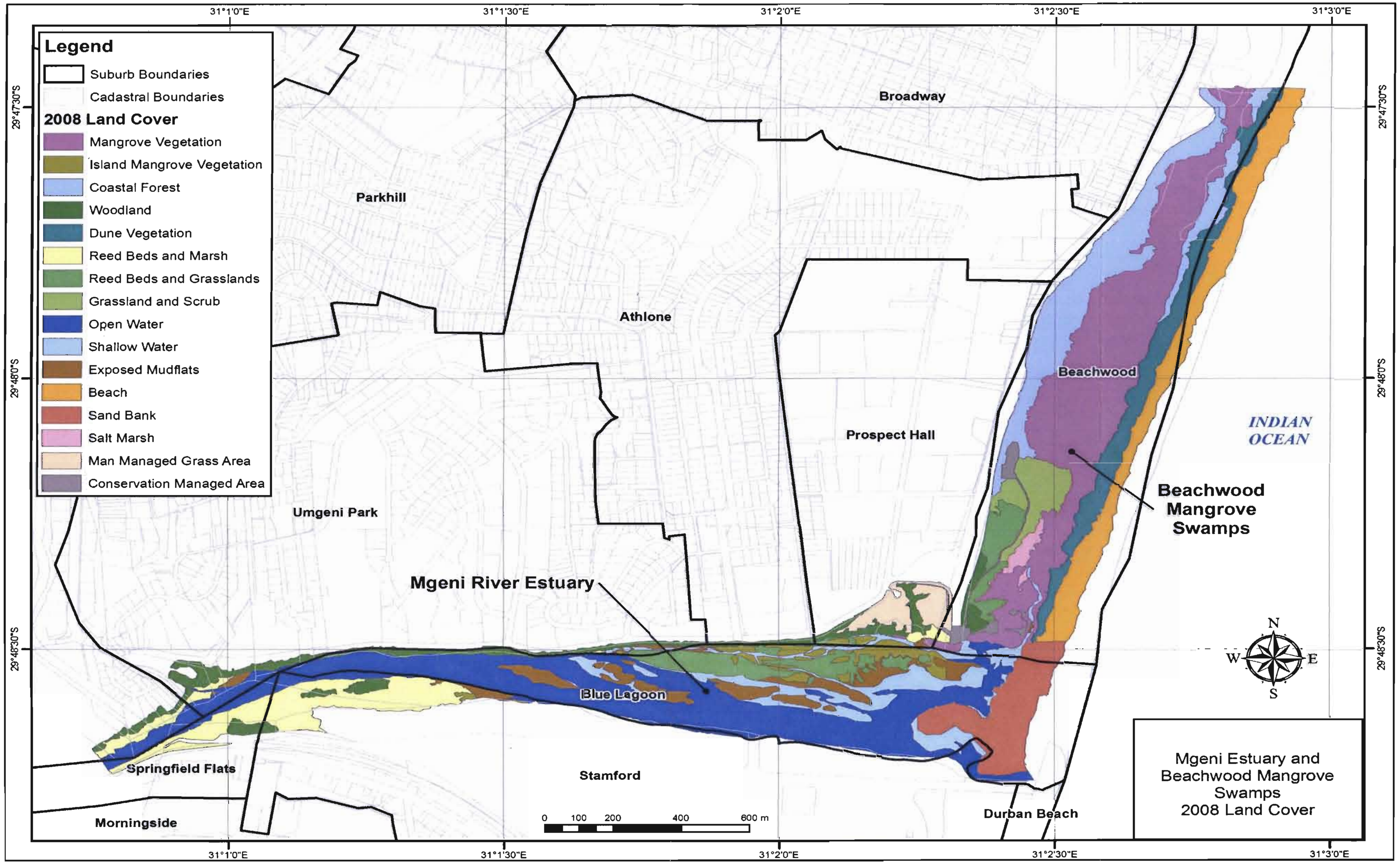

Plate 10: Mgeni Estuary and Beachwood Mangrove Swamps 2008 Land Cover

Results and Discussion

5.1. Categorization and Mapping of Changes in Land Cover within the Study Area

Categorizing and mapping different land cover types within the Mgeni Estuary and Beachwood Mangrove Swamps is an essential component of this study. This process would provide an opportunity to assess whether land cover and related habitats have changed over time, and consequently whether such changes have impacted on wetland bird populations. Land cover change detected within an estuary or mangrove swamp should be cause for concern because of the ecological sensitivity of such ecosystems. Such change could be the result of for example, fuel wood collection, and water pollution or over utilization of these ecosystems for recreational purposes. Table 14 illustrates the current land cover types found within the study area.

5.2. Land Cover Change within the Study Area

Using aerial survey imagery, it was possible to document and map the different land cover types within the study area. Below the Inanda Dam, the Mgeni River has been extensively modified, with riparian vegetation and the direction of flow having been drastically altered opposite the Springfield Industrial Park to accommodate industrial and commercial activities, and extensive human settlement along the river course, and in the immediate vicinity of the study area. As a consequence of upstream alterations and modifications to the Mgeni River course, land cover within the study area has steadily changed in terms of land cover area (%) as represented in Table 14 below.

This study had to consider the impact of natural tidal movements within the Mgeni Estuary and Beachwood Mangrove ecosystems. Although limited somewhat by the condition of the sandbar at the estuary mouth, the study area is influenced by the tidal fluctuation. The rise and fall of the tides lead to the submersion and eventual exposure of mudflats, sand banks by fluctuations in water levels.

Table 13: Land Cover Changes (1991-2008)

Land Cover	Year							
	1991		1997		2003		2008	
	Total Area (ha)	% of Study Area	Total Area (ha)	% of Study Area	Total Area (ha)	% of Study Area	Total Area (ha)	% of Study Area
Beach	18.67	11.6	16.38	10.2	13.04	8.1	11.23	6.9
Coastal Forest	7.12	4.5	5.69	3.5	14.07	8.8	18.06	11.2
Conservation Managed Area	1.13	0.7	0.92	0.6	1.36	0.8	1.39	0.9
Dune Vegetation	9.43	6.0	10.46	6.5	12.60	7.9	7.78	4.8
Exposed Mudflats	16.51	12.8	14.00	6.6	11.54	7.2	4.25	3.8
Man-Managed Grass Area	3.07	2.0	3.65	2.3	3.30	2.1	2.95	1.8
Grassland and Scrub	13.21	8.2	11.51	7.1	3.47	2.2	3.52	2.2
Island Mangrove Vegetation	1.38	2.0	0.52	0.3	1.53	1.0	3.17	1.9
Mangrove Vegetation	24.85	15.4	28.05	17.4	27.82	17.4	29.81	18.4
Open Water	26.00	16.2	25.69	16.0	19.75	12.3	25.99	16.1
Reed Beds and Grasslands	4.51	2.8	8.38	5.2	6.79	4.2	9.7	6.0
Reed Beds and Marsh	11.64	7.2	12.38	7.7	10.43	6.5	9.6	5.9
Salt Marsh	1.85	1.1	1.27	0.7	0.68	0.4	0.95	0.5
Sand Bank	5.46	3.4	4.42	2.7	4.29	2.7	8.75	5.4
Shallow Water	7.28	4.5	16.81	10.4	18.49	11.6	8.03	5.4
Woodland	4.69	2.9	4.19	2.6	10.91	6.8	8.87	5.5
Total	**160.96**	**100**	**161.11**	**100**	**160.07**	**100**	**154.05**	**100**

5.3. Tidal Fluctuations and the Impact on Water Bodies, Sand Banks and Exposed Mudflats

Closer examination of the aerial survey imagery has revealed the gradual decline of exposed mudflats, deep and medium depth water bodies and the increase in shallow water bodies within the estuarine and mangrove ecosystems. However, these initial assumptions based on observations, digitization and the calculation of the area covered by exposed mudflats from a series of aerial images could be misleading. Aerial images are simply a 'snap shot' in time. They cannot be considered a true reflection of the actual land cover classes occurring within dynamic ecosystems such as an estuaries or mangrove swamps subjected to tidal fluctuations.

Coastal areas experience two daily high (and two low) tides, and the Mgeni Estuary and Beachwood Mangrove Swamp are therefore affected by such tidal fluctuations. The rise and fall of the tides leads to dramatic changes in specific land cover within the study area within a matter of hours, and sometimes minutes. The submerging and exposure of mudflats and fluctuating water levels make it difficult to establish the true extent of the total area coverage of various land cover classes.

However, examination of historical tidal archives provided online by Mobile Geographic's LLT for the eThekwini area, provided a substantial amount of data about low and high tide events. In order to establish whether an aerial image was captured during a high or low tide event, the researcher examined the aerial images and contacted the eThekwini Municipality for the missing times and dates of aerial images to establish the exact time and date of each image capture.

After comparing the data provided by the tidal archives, and the dates and times of the flights over the study area, it was discovered that all aerial imagery utilised during the cause of this study was captured during a transition from low tide to high tide. Therefore, this provided the researcher with some degree of confidence to continue the land cover change assessment for water bodies and exposed mudflats.

5.4. Open and Shallow Water Bodies Land Cover Sub-Classes

The Mgeni Estuary and Beachwood Mangrove Swamps cover an area of 161 ha. Water bodies (open and shallow water bodies) are some of the dominant land cover types within these ecosystems. The water bodies land cover class are broken into two sub-classes. The first is Open Water and the other Shallow Water. Figure A1 in the Appendix A displays the fluctuations in the area covered by Shallow and Open water bodies since 1991.

Table 14: A Summary Table of Area Coverage of Water Land Cover in Mgeni Estuary and Beachwood Mangrove Swamp Study Area

Land Cover Type	Aerial Image 1991		Aerial Image 1997		Aerial Image 2003		Aerial Image 2008	
	Hectares	% of Study Area	Hectares	% of Study Area	Hectares	% of Study Area	Hectares	% of Study Area
Open Water	26.00	16.1	25.69	15.9	19.75	12.3	25.99	16.1
Shallow Water	7.28	4.5	16.81	10.4	18.49	11.5	8.63	5.4

Open water zones occupied 26.00 ha (16.1%) of the Mgeni Estuary and Beachwood Mangrove Study Area in 1991 (Table 14). The open water zone areas decreased gradually to 25.69 ha (15.9%) cover by 1997. In 2003, deep and medium deep water zones covered approximately 19.75 ha (12.3%) of the study area. Currently, this land cover type covers 25.99 ha (16.1%) of the study area. These areas, previously designated as open water zones, have steadily reverted to significantly shallower zones as evident from aerial imagery.

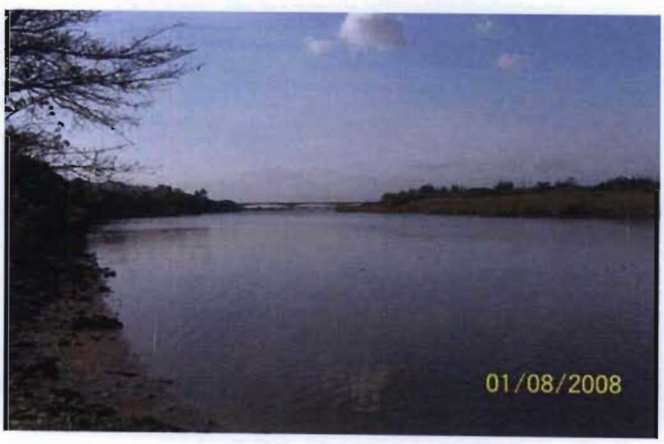

Plate 11: Open Water

The decline in the percentage area covered by the open water land cover class has contributed to an increase in the percentage area covered by shallow water zones. In 1991, shallow water covered an area of 7.28 ha (4.5%) of the study area, this gradually increased to 16.81 ha (10.4%) by 1997.

Plate 12: Open Water 2

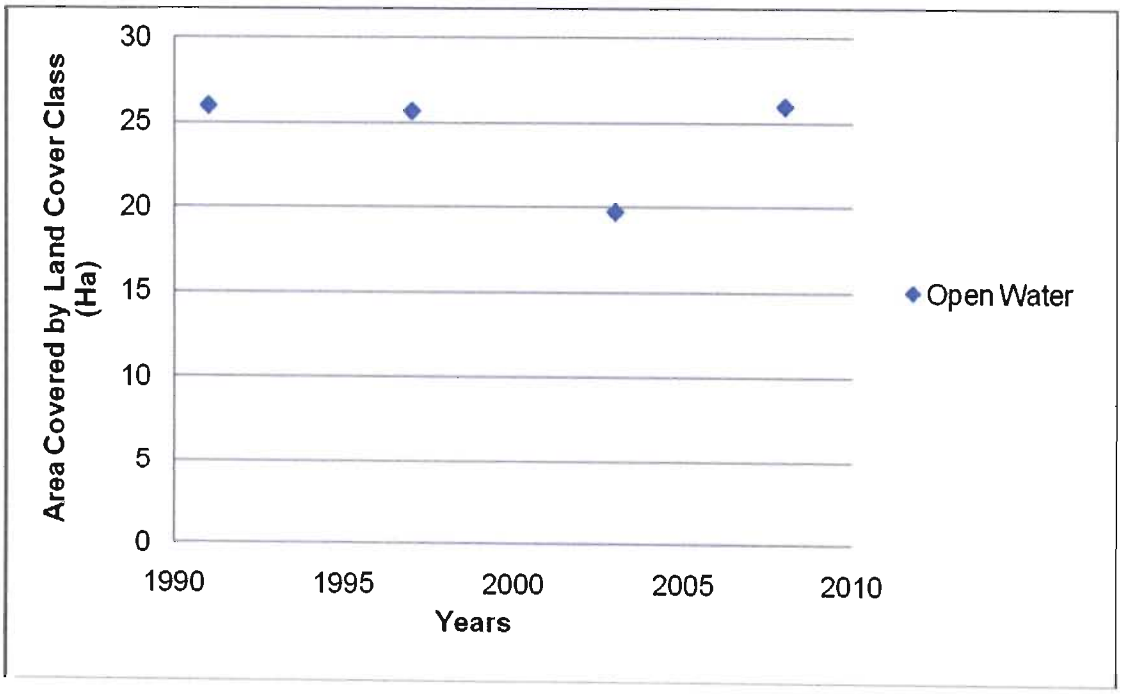

Figure 2: Open Water Land Cover Sub-Class

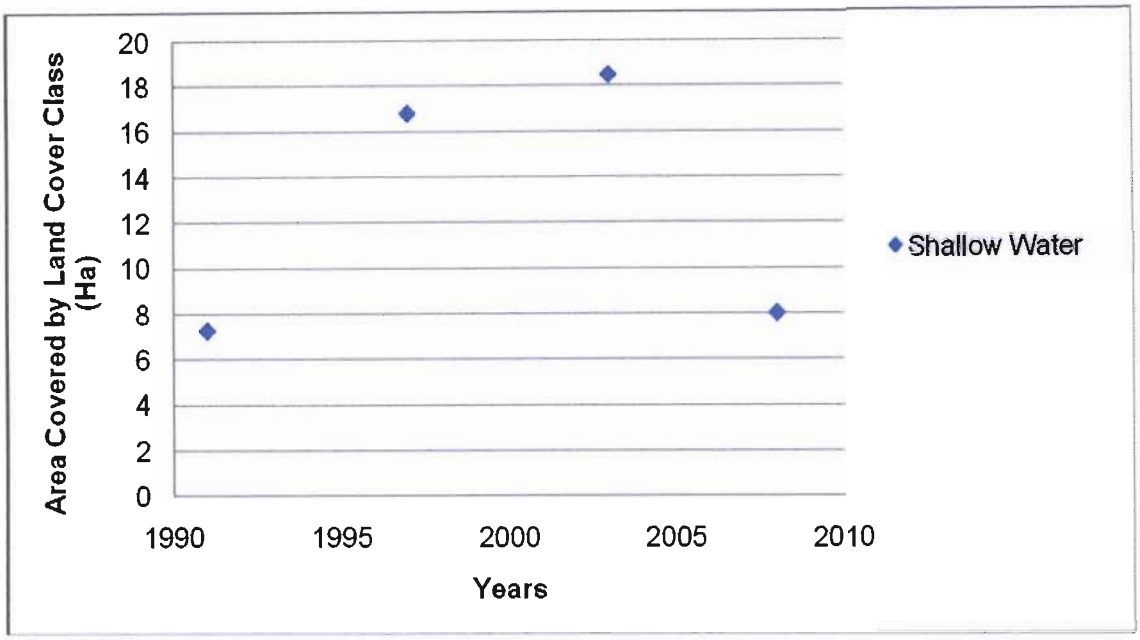

Figure 3: Shallow Water Land Cover Sub-Class

If the correlation coefficient is 0, this means that the changes in the independent and dependent variable are random and unrelated to one another. In other words no relationship or bond exists between the variables and thus there is no linear correlation. Figures 2 and 3 both have a correlation coefficient of 0. Therefore, it can be assumed that there is no relationship between the changes in the areas covered by the two water bodies and the time index.

Currently, shallow water covers 8.63 ha (5.4%) of the Mgeni Estuary and Beachwood Mangrove Swamp study area. This decline in open water zones is linked to the absence of regular flushing as a result of significant flooding of the river system and estuary between 1993 and 2008 (Gillard, 2008) . This has been attributed to a controlled release of water by the water authorities subsequent to the completion of Inanda Dam in 1989 (Garland and Moleko, 2000).

Plate 13: Shallow Water Zone

5.5. Corrected Exposed Mudflat Land Cover Class

In 1991, exposed mudflats covered 16.51 ha (10.3%) of the study area .This declined to just 14.00 ha (8.7%) by 1997. The 1997 aerial image was taken during an aerial survey that coincided with low tide. Figure A2 in the Appendix A provides an illustration of changes in this particular land cover class over the last two decades.

Table 15: A Summary Table of Area Coverage of Exposed Mudflat Land Cover in Mgeni Estuary and Beachwood Mangrove Swamp Study Area

Land Cover Type	Aerial Image 1991		Aerial Image 1997		Aerial Image 2003		Aerial Image 2008	
	Hectares	% of Study Area	Hectares	% of Study Area	Hectares	% of Study Area	Hectares	% of Study Area
Exposed Mudflats	16.51	10.3	14.00	8.7	11.54	7.2	4.25	2.8

There was an increase in the area covered by exposed mudflats to 11.54 ha (7.2%) of the area in 2003. By 2008, these mudflat areas represented only 4.25 ha (2.8%) of the total study area. This decline could be the result of a combination of factors. Firstly, the colonisation and growth of reed, sedge, grass and mangrove vegetation cover on the now established estuarine islands, combined with the gradual expansion of the mangrove swamps into the estuary has decreased the area of exposed mudflats that are visible. In addition, tidal fluctuations do have a significant impact on the rise and fall of water levels within the study area and this could have had an impact on the exposure of mudflats during the collection of images during the aerial survey process.

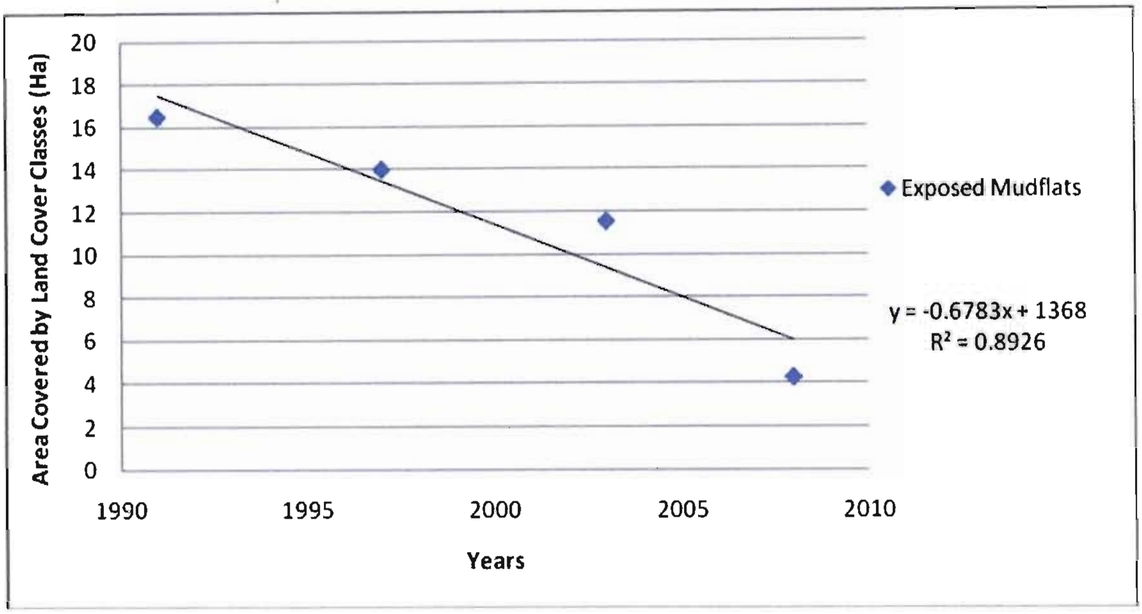

Figure 4: Decline in the Area Coverage of Exposed Mudflats Land Cover Class

Figure 4 represents the corrected mudflat area values due to tidal variances. It is evident in the above figure that the area coverage of exposed mudlfats have declined progressively since 1993. Figure 4 graphically represents a strong negative linear trend with a regession equation of $\hat{y}= - 0.6783x+1368$ with $R^2 = 0.8926$. This indicates a steady decline of exposed mudflat habitats within the study area between 1991 and 2008.

5.6. Wooded Land Cover Classes

There are several other land cover types that can be identified via aerial imagery and field surveys. The estuary and mangrove swamps have large areas of densely wooded habitats consisting of a mixture of indigenous and invasive trees, bushes, vines and shrubs. The study identified four woody land cover types which were designated as coastal forest, woodland, mangrove vegetation and island mangrove vegetation.

Table 16: A Summary Table of Area Coverage of Wooded Land Cover in Mgeni Estuary and Beachwood Mangrove Swamp Study Area

Land Cover Type	Aerial Image 1991		Aerial Image 1997		Aerial Image 2003		Aerial Image 2008	
	Hectares	% of Study Area	Hectares	% of Study Area	Hectares	% of Study Area	Hectares	% of Study Area
Mangrove	24.85	15.4	28.05	17.4	27.82	17.3	29.81	18.4
Island Mangrove	1.38	0.8	0.52	0.3	1.53	0.9	3.17	2.0
Coastal Forest	7.12	4.4	5.69	5.3	14.07	8.7	18.06	11.7
Woodland	4.69	2.9	4.19	2.6	10.91	6.8	8.87	5.5

The researcher has defined coastal forest, for the purpose of this study, as areas with a tree canopy cover of between 60-100% that consists of indigenous or invasive woody vegetation (preferably trees). In 1991 this coastal forest covered a 7.12ha (4.4%) of the study area. By 1997 coastal forest had consolidated and expanded its hold, covering an estimated 5.69 ha (5.3%) of the area as seen in Figure A3 in the Appendix A.

Examination of the 2003 aerial imagery during the course of this study has revealed that the coastal forest has continued to expand and consolidate its cover within the Beachwood Mangrove Nature Reserve by encroaching and colonizing areas previously designated as grassland, scrubland and dune vegetation. It covered approximately 14.07 ha (8.7%) of the study area in 2003, and without the interference of human harvesting of trees and regular fires, it currently forms 18.06 ha (11.7%) of the study area.

Figure 5 below represents the area covered by the coastal forest land cover class plotted against the time index. The figure shows a strong positive linear trend with a regression equation of $\hat{y} = 0.5144x - 1018.5$ and $R^2 = 0.722$. This indicates that coastal forest habitats are consolidating and gradually expanding throughout the study area.

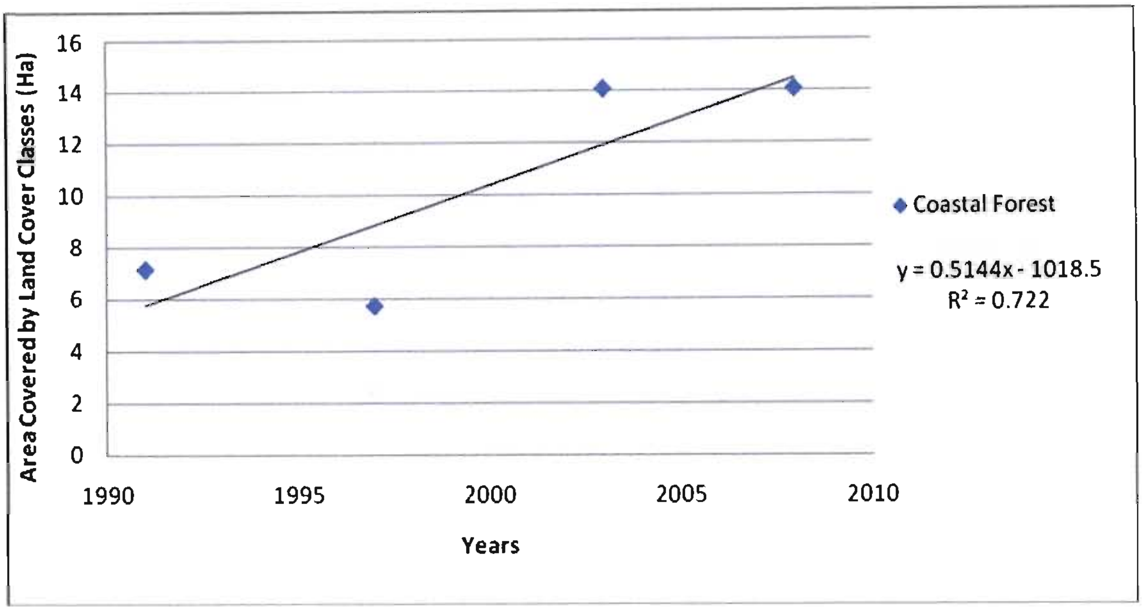

Figure 5: Increase in Area Coverage of Coastal Forest Land Cover Class

Woodland occupied 4.69 ha (2.9%) of the Mgeni Estuary and Beachwood Mangrove Swamp area in 1991 (Table 16). Examination of the imagery indicates a gradual expansion of woodland into areas once occupied by grassland, scrubland and areas designated as grass areas. By 1997 woodlands covered an area of 4.19 ha (2.6%), and by 2003, this had increased to 10.91 ha (6.8%) of the area. By 2008 woodland covered an estimated 8.87 ha (5.5%) of the study area. This exponential growth of coastal forest, mangrove vegetation and woodland is linked to the absence of subsistence or commercial harvesting of trees within the Beachwood Mangrove Nature Reserve; and careful management of fires by the local authority due to the close proximity of residential areas.

Plate 14: Woodland, Grassland and Scrub Land Cover Classes

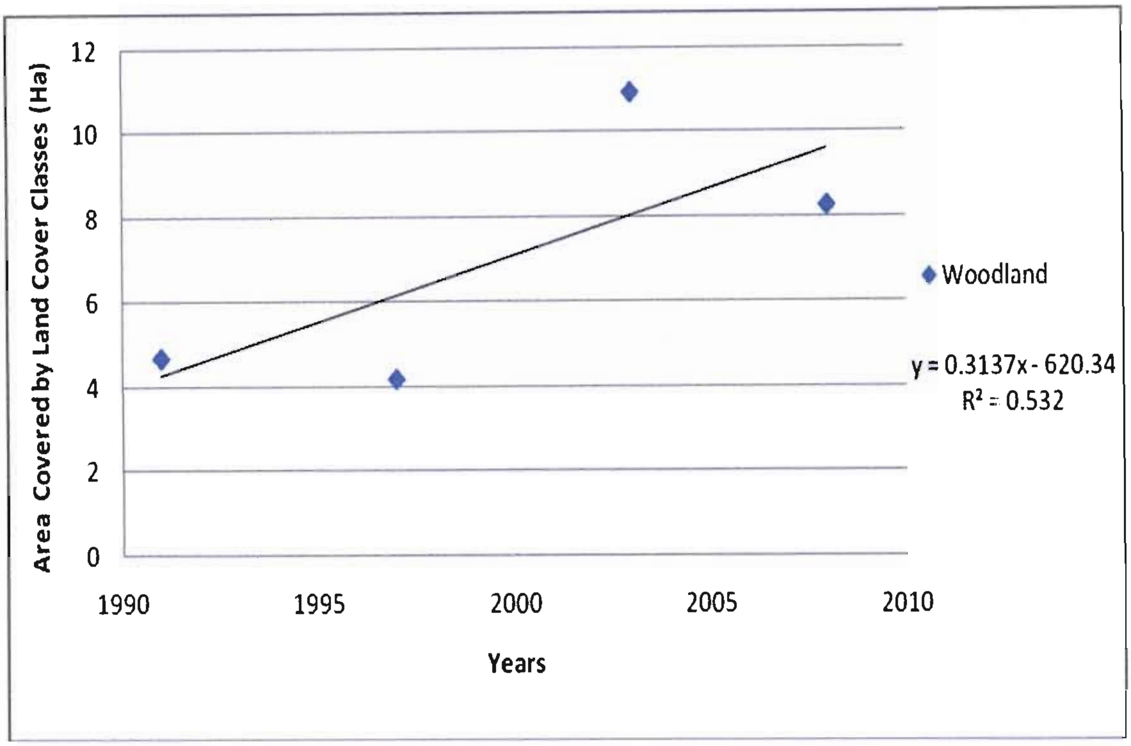

Figure 6: Increase in Area Coverage of Woodland Land Cover Class

Figure 6 above graphically illustrates the increase in the area that is covered by woodland land cover class within the study area, plotted against the time period. The figure demonstrates a moderately positive linear trend with the equation $\hat{y}= 0.3137x - 620.34$ and $R^2= 0.532$.

The second most dominant land cover type within the study area is mangrove forest. This land cover is dominated by mangrove trees such as *Bruguiera gymnorrhiza,* and *Avicennia marina*. Mangrove vegetation covered an estimated 24.85 ha (15.4%) of the study area in 1991 (Table 16). This woody land cover continued to expand its domination of the estuarine ecosystem and covered 28.05 ha (17.4%) of the study area by 1997. This expansion has continued with mangrove vegetation making gradual inroads into areas previously occupied by coastal forest, grassland, scrubland, salt marshes and dune vegetation. In 2008 mangrove vegetation covered 29.81 ha (18.4%) of the study area as noted in Figure A4 situated in the Appendix.

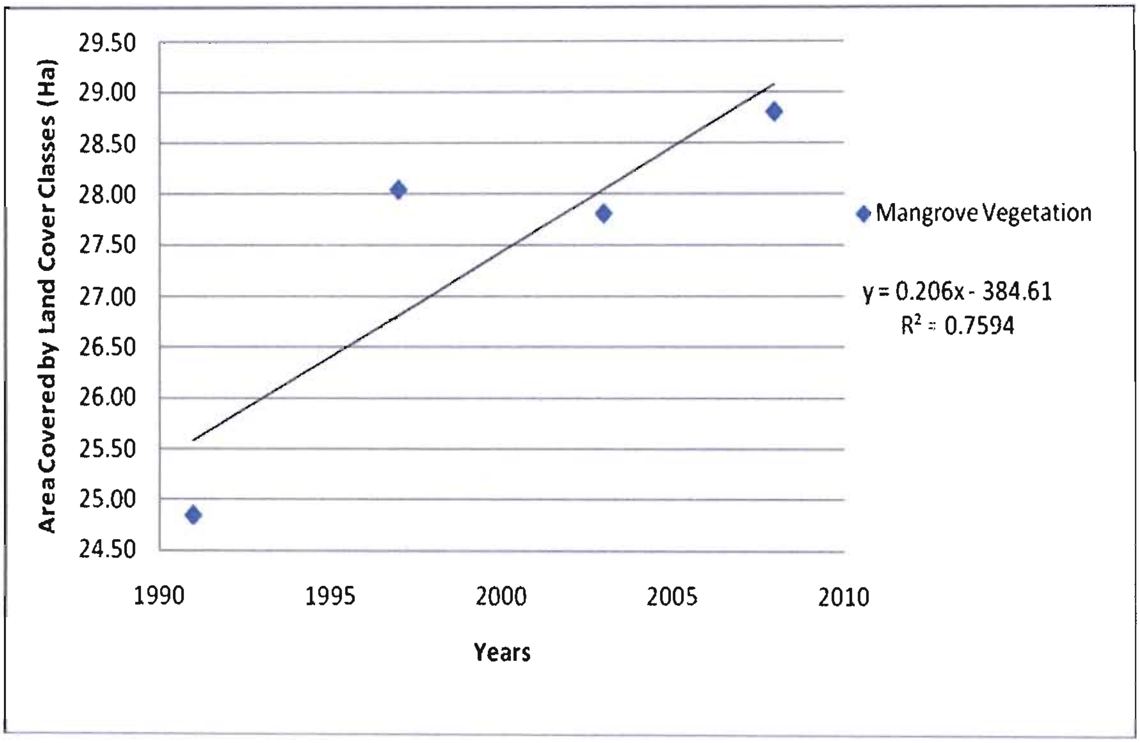

Figure 7: Increase in Area Coverage of Mangrove Forest Land Cover Class

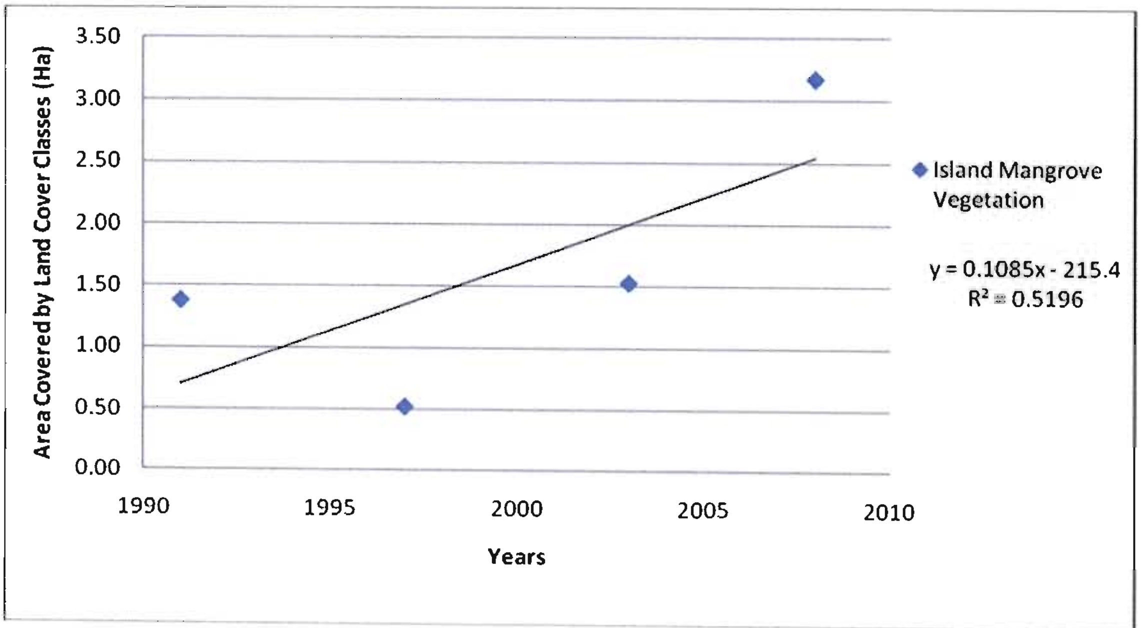

Figure 8: Increase in Area Coverage of Island Mangroves Land Cover Class

Figures 7 & 8 both indicate a significant increase in the area coverage of Mangrove Forest and Island Mangroves Vegetation between 1991 and 2008. This is reflecting in both figures showing positive linear trends. Figure 7 has a regression equation of $\hat{y} = 0.206x - 384.61$

and R^2 = 0.7594. Meanwhile, Figure 8has an equation of $\hat{y}$= 0.1085x - 215.4 and R^2= 0.5196. Figures 7 & 8 both indicates that the area covered by the mangrove community is increasing.

Plate 15: Mangrove Vegetation

The Mgeni Estuary is well known for its vegetated islands covered in mangrove tree thickets, reed beds and grassland habitats. The aerial images show a pattern of colonization, consolidation and expansion of mangrove vegetation on the islands and mudflats of the estuary within the study period. The currents and tidal changes within the estuary carry mangrove seeds pods and deposit them on mud and sediment area on the islands and surrounding mudflats (Plate 15). Gradually these seeds germinate and the seedlings consolidate their position on the islands and form mangrove thickets scattered all over the islands that consist of a mixture of mature mangrove trees and seedlings. In 1991 mangrove vegetation had begun to colonize and establish its hold on the eastern islands of the Mgeni Estuary. Island mangrove vegetation covered about 1.38 ha (0.8%) of the study area at this stage. Further information is provided in Figure A4 Appendix A.

Plate 16: Woodland and Mudflat Land Cover

By 1997 clusters of mangrove trees and seedlings had consolidated their position on the islands, and soon began to expand throughout the estuary covering 0.52 ha (0.3%) area. In 2003 this land cover dominated 1.53 ha (0.9%) of the study area. In 2008, island mangrove vegetation covered approximately 3.17 ha (2.0%) of the study area in the absence of human disturbances, fires, erosion and the flushing of the estuary and river by flooding (Table 16). This reflects an increase of 1.2 % between 1991 and 2008.

Plate 17: Island Mangrove Vegetation

5.7. Grassland, Scrubland and Reed Bed

Reed beds, marshes and mixed grassland land cover types are found throughout the estuary and inland from the mangrove community of the Beachwood Mangrove Swamp Reserve (Plate 15). Further details on this land cover class are found in Appendix A.

Table 17 : Summary Table of Area Coverage of Reed Beds, Marshes and Mixed Grassland Land Cover in Mgeni Estuary and Beachwood Mangrove Swamp Study Area

Land Cover Type	Aerial Image 1991		Aerial Image 1997		Aerial Image 2003		Aerial Image 2008	
	Hectares	% of Study Area	Hectares	% of Study Area	Hectares	% of Study Area	Hectares	% of Study Area
Reed Beds and Marsh	10.64	6.7	12.38	7.6	10.43	6.5	9.6	6.0
Reed Beds and Grasslands	4.51	2.8	8.38	5.2	9.79	6.1	9.7	7.1
Grassland and Scrub	11.21	7.0	11.51	7.1	5.47	3.4	3.52	2.2

Reed beds and marshes in the Mgeni Estuary and Beachwood Mangrove Swamps once covered 10. 64 ha which is (6.7%) of the area in 1991. This proportion increased to 12.38 ha in 1997, which was estimated to be (7.6%) of the total area. Reed beds and marshes have continued to expand within the study area as indicated in Table 17 above. In 2003, reed beds and marshes made up 10.43 ha which is approximately (6.5%) of the area. By 2008, reed beds and marshes covered 9.60 ha (6.4%). This is decrease of 0.1% over twenty years as shown in Figure A5 in the Appendix A.

Plate 18: Reed Beds and Marsh

Meanwhile, reed beds and grassland covered 4.51 ha in 1991. This is around (2.8%) of the study area (Plate 18). This increased to 8.38 ha (5.2%) of the study area by 1997. In 2008, reed beds and grassland covered 9.6 ha (6.0%) of the study area. These land covers are vulnerable to flooding and fires. However, these threats are rare occurrences within the study area allowing vegetation to expand without hindrance.

Another land cover type which has seen a gradual decline is grassland and scrub. Grassland and scrub covered 13.21 ha (7.0%) of the study area in 1991, it declined steadily to cover an area of 11.51 ha (7.1%) by 1997 and by 2003, covered only 5.47 ha (3.4%) of the Mgeni Estuary and Beachwood Mangrove Swamps. In 2008, this land cover type covered 3.52 ha (2.2%) of the study area (Table 17). The decline in this land cover type is connected to the expansion of woody vegetation into areas of the study area that was once covered in grassland and scrub vegetation. Grassland ecosystems require regular burning to prevent bush encroachment. However, local authorities control all fires within the study area, and local conservation officials do not practise a policy of controlled burning of grasslands within the Beachwood Nature Reserve which would help keep these ecosystems clear of invasive woody vegetation.

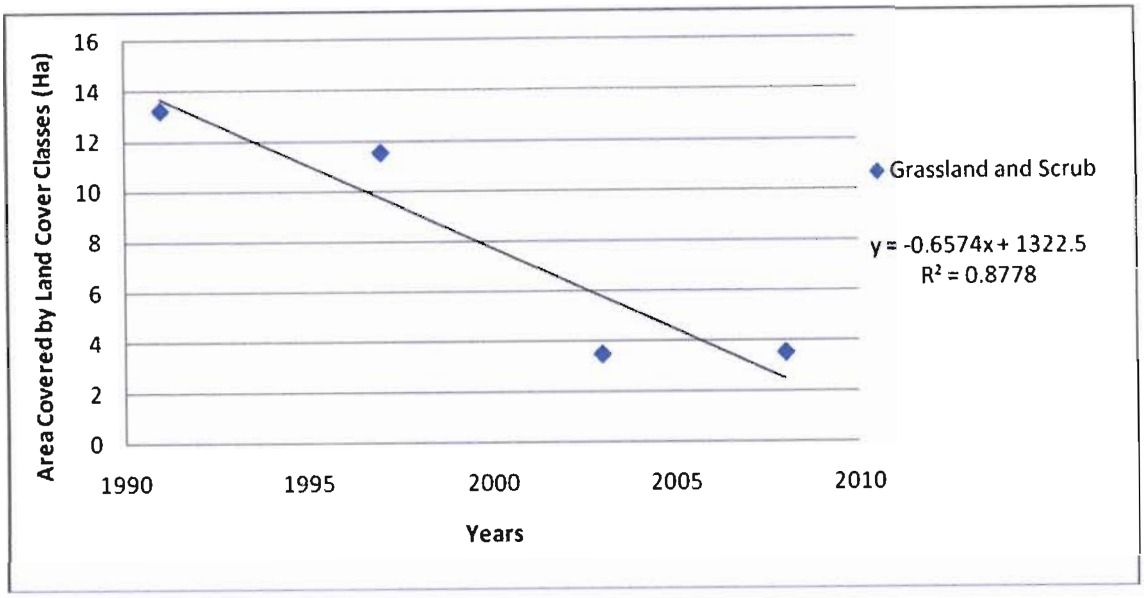

Figure 9: Decline in Area Coverage of Grassland and Scrub Land Cover Class

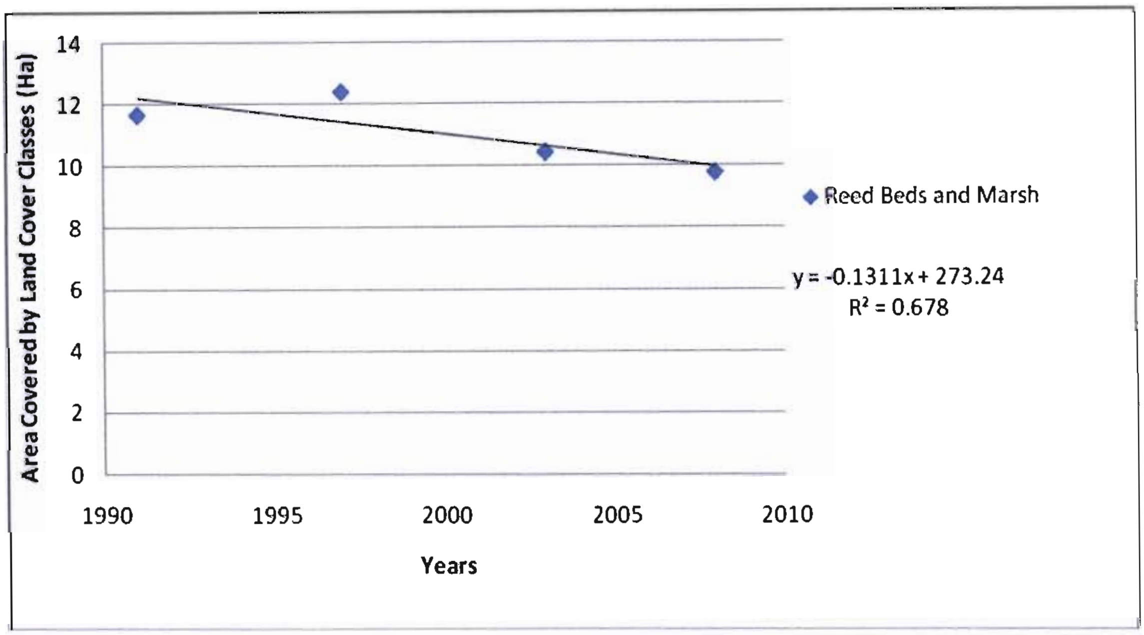

Figure 10: Decline in Area Coverage of Reed Beds and Marsh Land Cover Class

Figures 9 & 10 both represent the area covered by land cover class plotted again the time period. Both illustrate have a strong negative linear trends. Figure 9 has a regression equation of $\hat{y}$=0.6574x+1322.5 with R^2= 0.8778. This shows that this reed bed and marsh land cover class is declining within the study area. Figure 10 has a regresssion equation of $\hat{y}$= 0.1311x + 273.24 and R^2= 0.678. This reveals a decline in the area covered by the reed bed and marsh land cover class within the study area.

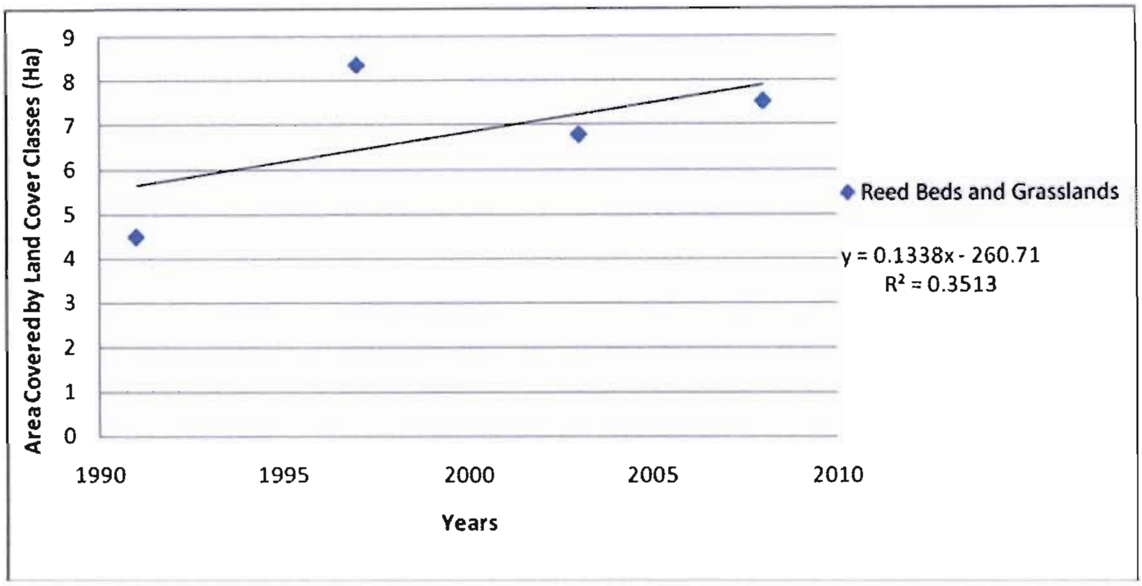

Figure 11: Increase in Area Coverage of Reed Beds and Grassland Land Cover Class

Figure 11 shows the area covered by the reed beds and grassland land cover class plotted against the time index. The figure displays a weak positive linear trend with a regression equation of $\hat{y} = 0.13338x + 260.71$ and $R^2 = 0.3513$. This shows that the area covered by this particular land cover type has gradually increased over time and continues to expand its influence within the study area.

Plate 19: Reed Beds and Grassland

5.8. Other Vegetation Land Cover

Several other vegetation land cover classes exist within the study area. The existence of these vegetation classes was clarified through field surveys. Salt Marshes and the dense dune vegetation adjacent the mangrove swamps are such vegetation classes. Salt Marshes are only found within the Beachwood Mangrove Swamp Reserve and are restricted to a relatively small location in the centre of the reserve. This habitat has shown signs of decline over the last couple of decades as other vegetation types such as mangrove vegetation, grassland and scrubland have expanded and taken over areas previously designated as salt marsh habitat.

Table 18: A Summary Table of Area Coverage of Other Vegetation Land Cover in Mgeni Estuary and Beachwood Mangrove Swamp Study Area

Land Cover Type	Aerial Image 1991		Aerial Image 1997		Aerial Image 2003		Aerial Image 2008	
	Hectares	% of Study Area	Hectares	% of Study Area	Hectares	% of Study Area	Hectares	% of Study Area
Man-Managed Grass Area	3.07	1.9	3.65	2.2	3.29	2	2.95	1.9
Dune Vegetation	9.43	5.8	10.46	6.4	12.60	7.8	7.78	5.7
Salt Marsh	1.85	1.1	1.27	0.7	0.68	0.4	0.95	0.6

In 1991 salt marshes covered 1.85 ha (1.1%) of the study area (Table 18), declining gradually with the expansion of the grassland, scrubland and mangrove vegetation to a coverage of 1.27 ha (0.7%) in 1997. Salt marshes covered an area of 0.68 ha (0.4%) in 2003, by 2008 this natural habitat further declined to only cover 0.95 ha (0.6%) of the total area. See Table 18.These changes are graphically represented in Figure A6 in the Appendix A.

Dune vegetation is found along the coastline to the east of the mangrove swamps; once covered approximately 9.43 ha (5.8%) in the early 1990s. This vegetation type currently covers 8.78 ha (5.4%) of the study area due to the destructive nature of recent high tides, wind erosion and human activity that has removed and steady thinned out the dune vegetation.

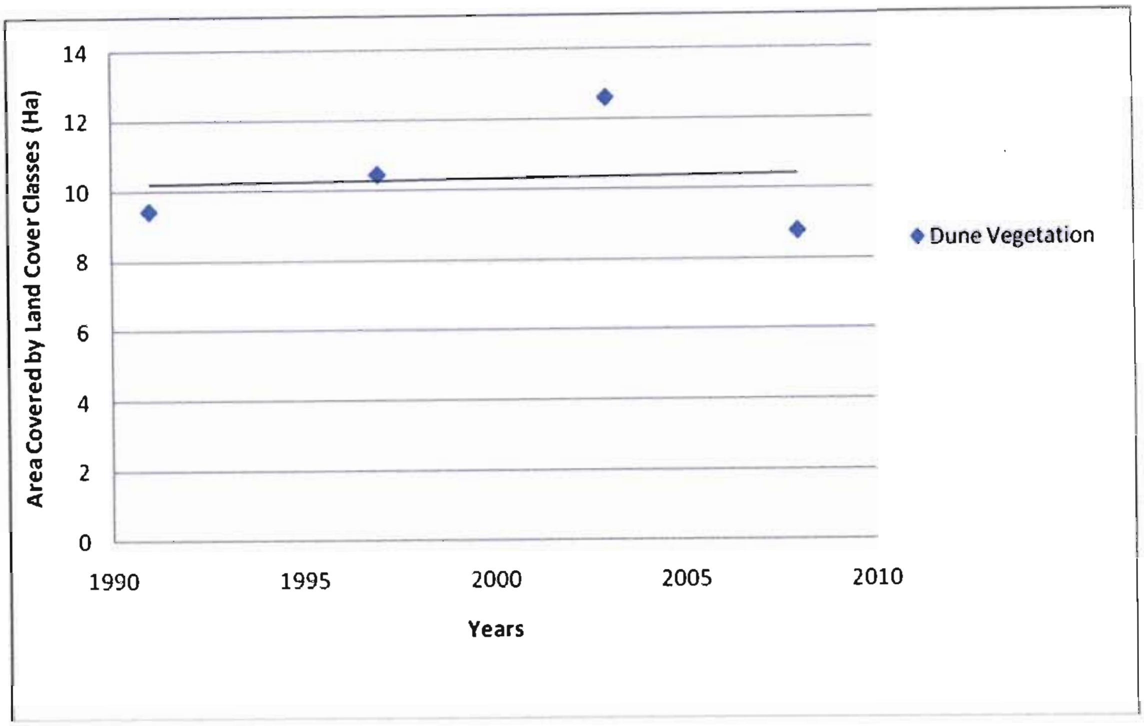

Figure 12: Area Coverage of Dune Vegetation Land Cover Class

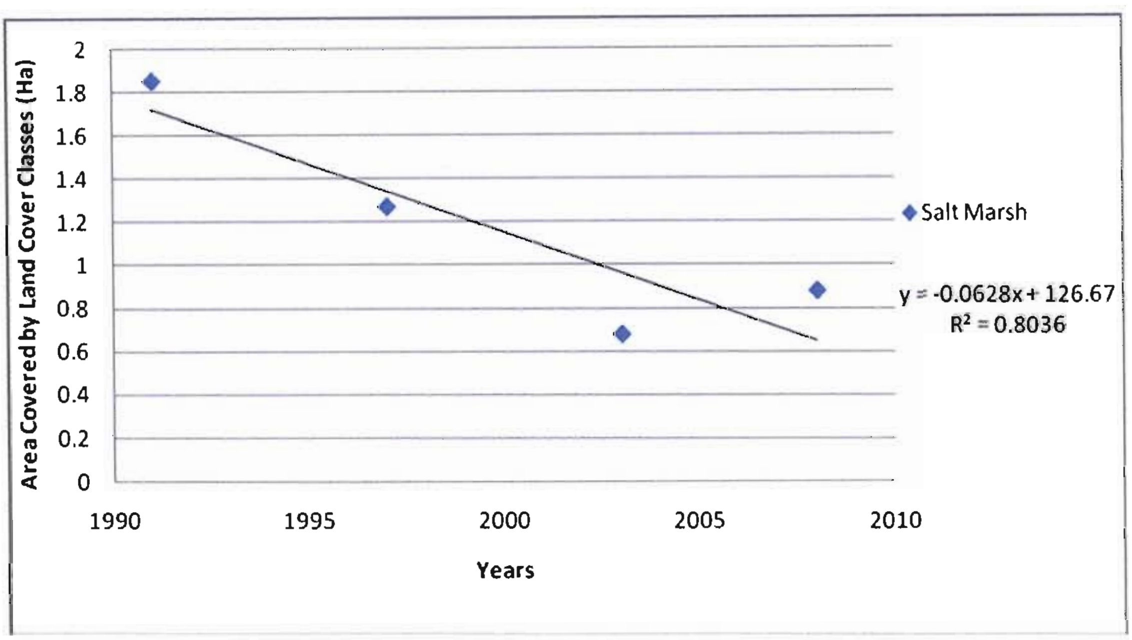

Figure 13 : Decline in the Area Coverage of Salt Marsh Land Cover Class

Figures 12 represents the area covered by the dune vegatation land cover class poltted againts the time period of the study. The figure indicates that this land cover class has only changed slightly but otherwise has remained relativelly constant over the established time period. Figure 13 illustrates area covered by the Salt Marsh land cover class against the time index. The figure displays a strong negative linear trend ,and the regression equation for this figure is $\hat{y} = -0.0628x + 126.67$ and $R^2 = 0.8036$. This indicates a steady decline in the area coverage of Salt Marsh habiats within the study area.

Plate 20: Salt Marsh

Man-Managed Grass Areas within the study area covered 3.07 ha (1.9%) of the study area in 1991. This gradually increased to 3.65 ha (2.2%) by 1997. However, this land cover declined gradually and only covered 2.95 ha (1.8%) of the area by 2008. This decline is largely due to the increase in areas of development within the study area and the expansion of woodland into areas previously designated as grass areas. The changes in the area covered by this land cover class can be seen in Figure A7 in the Appendix.

Plate 21: Transission from Salt Marsh to Mangrove Vegetation

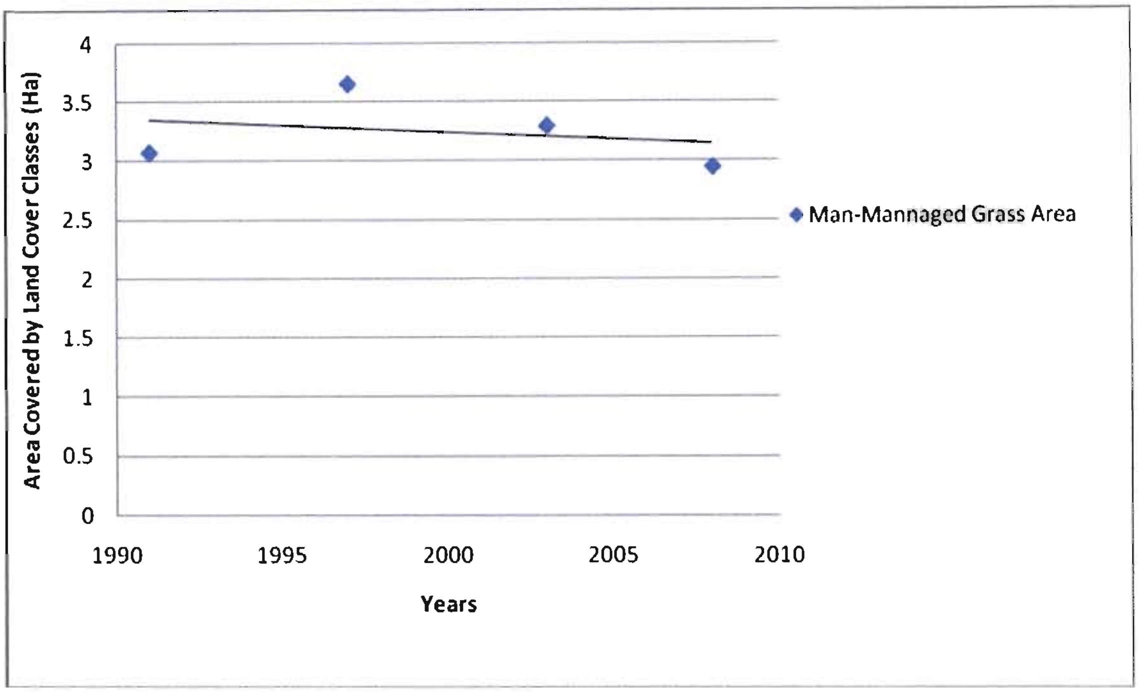

Figure 14: Decline in the Area Coverage of Man-Managed Grass Area Land Cover Class

Figure 14 graphically illustrates the area covered by Man-Managed Grass Areas against the time index. The area covered by this land cover type has only undergone minor changes but otherwise has remained relativelly constant over the established time period.

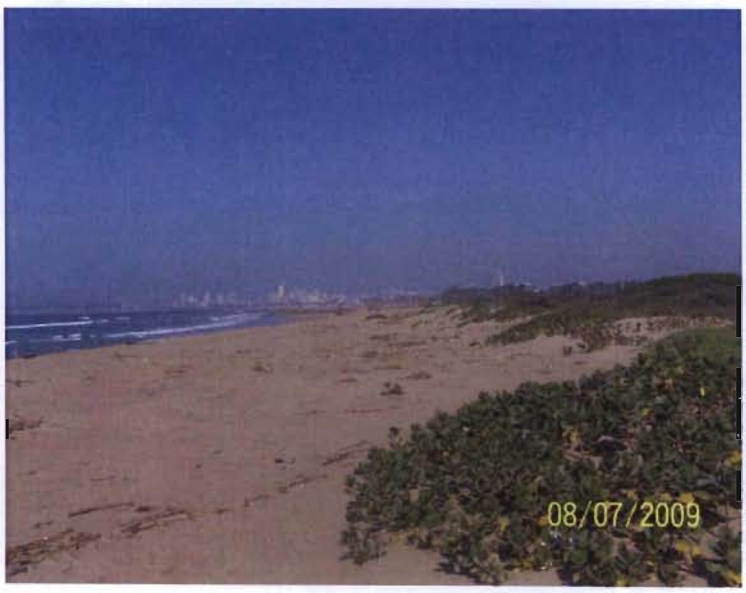

Plate 22: Dune Vegetation and Beach

5.9. Other Land Cover Classes

There are several other land cover types that exist within the Mgeni Estuary and Beachwood Mangrove Swamp study area that require examination.

Table 19: A Summary Table of Area Coverage of Other Land Cover Classes in Mgeni Estuary and Beachwood Mangrove Swamp Study Area

Land Cover Type	Aerial Image 1991		Aerial Image 1997		Aerial Image 2003		Aerial Image 2008	
	Hectares	% of Study Area	Hectares	% of Study Area	Hectares	% of Study Area	Hectares	% of Study Area
Sand Bank	5.46	3.3	4.42	2.7	4.29	2.6	8.75	5.4
Beach	18.67	11.5	16.38	10.1	13.04	8.1	11.23	7.0
Conservation Managed Area	1.13	0.7	0.92	0.5	1.36	0.8	1.39	0.8

The sandbanks found in the vicinity of the Mgeni estuary mouth covered 5.46 ha (3.3%) of the study area in 1991, but declined steadily to cover an area of approximately 4.4211 ha (2.7%) of the total area by 1997. By 2003 sandbanks only covered 4.29 ha (2.6%). By 2008 sandbanks covered 8.75 ha (5.4%).This represents an increase of 2.1 % over the last couple of decades. These changes can be observed in Figure A8 in Appendix A.

Plate 23: Sand Banks at Estuary Mouth

The beach in the vicinity of the mangrove swamps has undergone significant changes over the last couple of decades. In 1991, the beach covered an estimated 18.67 ha (11.5%) of the study area, declining to 13.04 ha (8.1%) in 1997. By 2008, the beach only covered 11.23 ha (7.0%) of the Mgeni Estuary and Beachwood Mangrove Swamp study area. The gradual disappearance of the beach and the sand banks is directly linked to the completion of the Inanda Dam and the subsequent reduction in sediment flow into the lower reaches of the river system (Garland and Moleko, 2000).

Plate 24: Beach

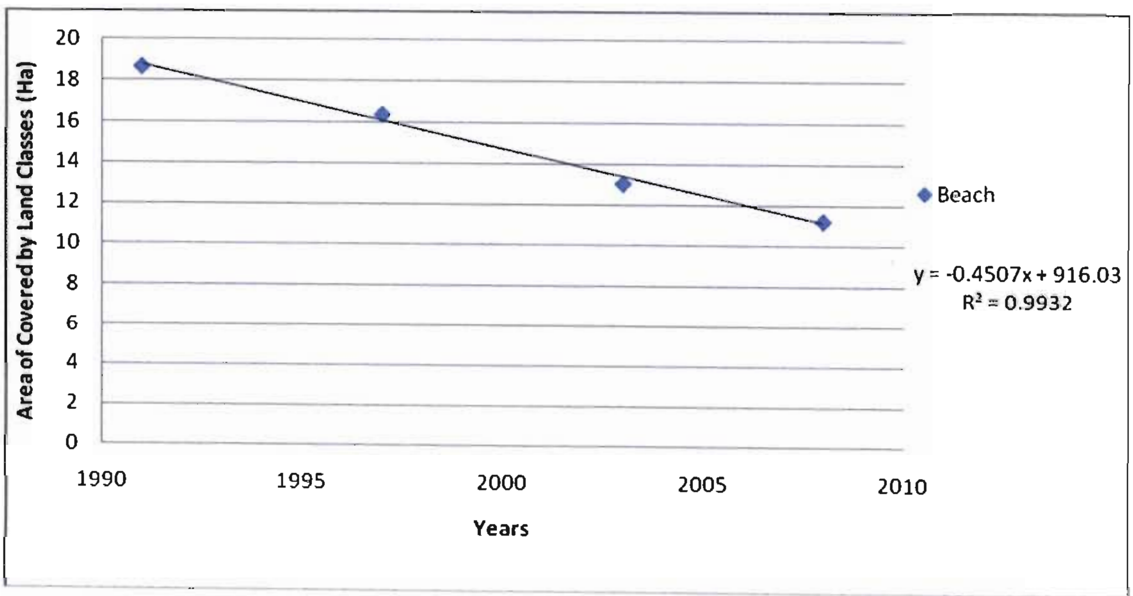

Figure 15: Decline in Area Coverage of Beach Land Cover Class

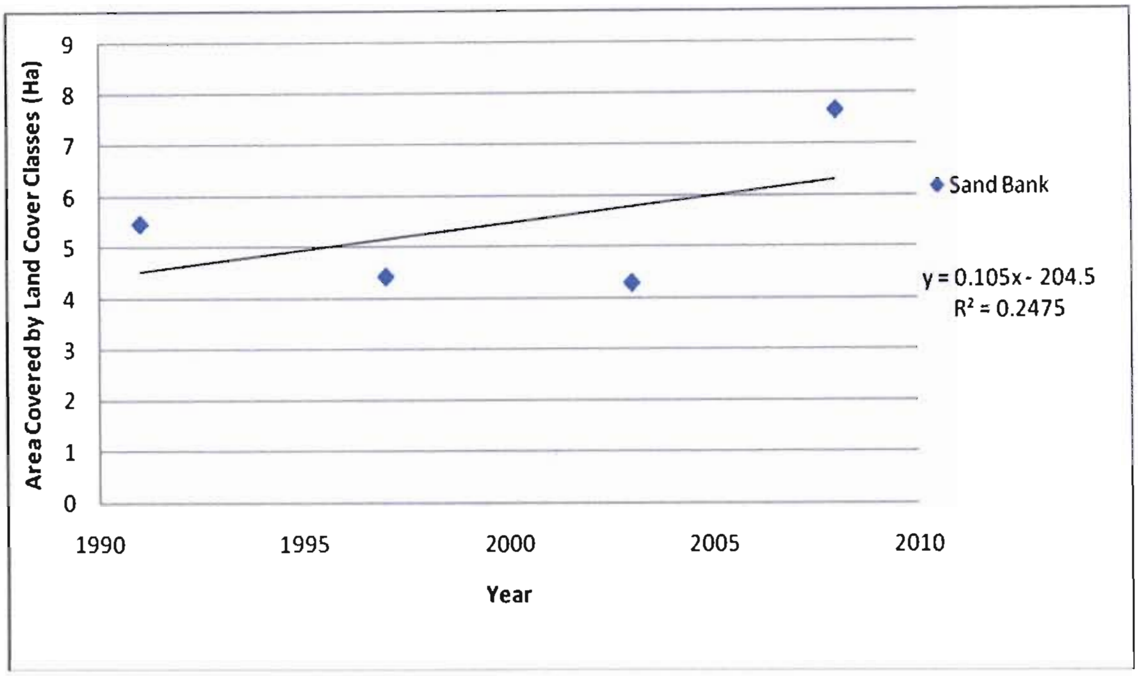

Figure 16: Increase in Area Coverage of Sand Bank Land Cover Class

Figure 15 illustrates the area covered by the beach land cover class within the study area against the established time period of the study. Examination of the figure reveals the existence of a strong negative linear trend with a regression equation of $\hat{y}$= - 0.4507x + 916.03 and R^2 = 0.9932. This indicates that the land cover class is showing signs of decline. Meanwhile, Figure 16 shows the area covered by the sand banks land cover class plotted against the time period. There is a moderately positive linear trend that has a regression equation of $\hat{y}$= 0.105x + 204.5 and R^2 = 0.2475. This reveals that the area covered by this land cover class is increasing steadily within the study area.

Plate 25: Sand Banks

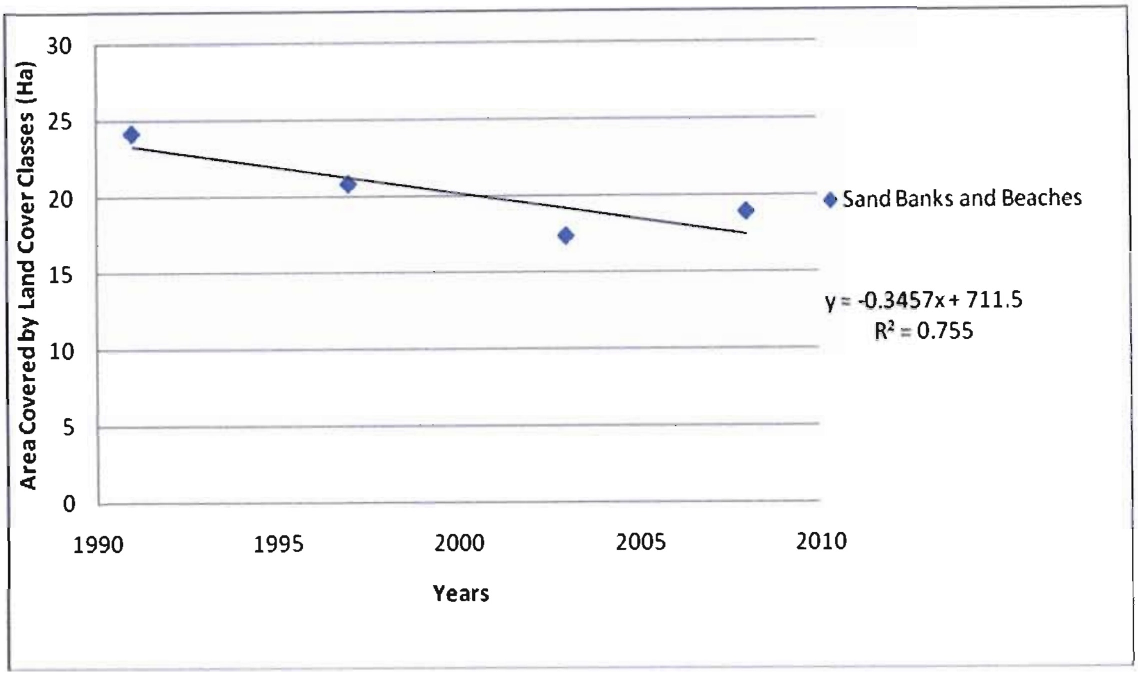

Figure 17: Decline in the Area Coverage of Sand Banks and Beach Land Cover Class

There is a strong negative linear trend with a regression equation of $\hat{y} = -0.3457x + 711.5$ and $R^2 = 0.755$ when these land cover classes are combined for the purposes of this study (Figure 17). This indicates that there is a strong relationship between the change in the area covered by the combined land cover classes of Beaches and Sand Banks within the estuarine and mangrove swamp study area and the time period. The justification for combining sand banks and beaches is based on examinations of estuarine literature, and the advice of local conservation officials who indicate that the sand banks at the mouth of the Mgeni Estuary can be considered an extension of the beach land cover class (Gillard, 2008).

The Conservation Managed Area is defined as any buildings, roads, picnic sites, parking lots and paths within a designated conservation area managed by a conservation authority like Ezembelo Wildlife. Development within the study area has been minimal. This is due to the fact the area has been designated as a conservation area and no unauthorized developments can take place. In 1991, the area designated as a conservation managed area, controlled by Ezembelo Wildlife, covered approximately 1.13 ha (0.7%) of the study area. By 2008, the conservation managed area was responsible for covering 1.39 ha (0.9%) of the study area due to the expansion and improvement of the road network and tourist sites in the Beachwood Mangrove Swamp Nature Reserve. Please see Figure A9 in the Appendix A for more information on changes in this land cover type.

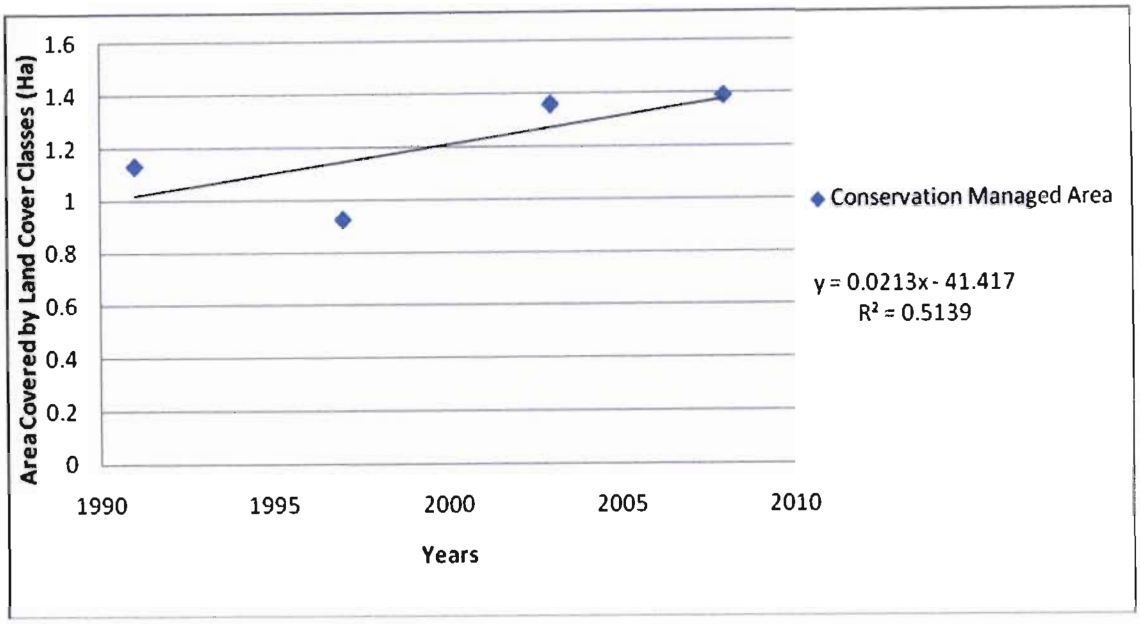

Figure 18: Increase of Area Coverage of Conservation Managed Area Land Cover Class

Figure 18 displays the area covered by the conservation managed area land cover class against the time period of the study. There is a moderately positive linear trend with a regression equation of $\hat{y} = 0.0213x - 41.417$ and $R^2 = 0.5139$. This indicates that over the established time period, the area covered by Conservation Managed Areas has increased as new paths, roads and picnic sites have been installed as seen in the aerial imagery.

5.10. Land Cover Change within the Study Area

The study documented extensive land cover change within the study area between 1991 and 2008. These changes could be the result of human interaction or natural progressive change within the estuarine and mangrove ecosystem. Measuring the change is essential in order to analyze and interpret the results appropriately. The changes in land cover occurring within the study area, and the subsequent effect these changes are having on wetland bird populations, all are directly linked to the alteration of the river flow (Botes, 2009). The flow has been affected by the establishment of several dams within the catchment system that has transformed the previously flood dependent and permanently open Mgeni Estuary into a temporary open/closed system (Garland and Moleko, 2000). In the absence of regular flooding, sediment accumulates steadily within the estuary and the mangrove zones with the result that other vegetation communities are allowed to establish and consolidate their presence, which impacts upon the entire ecology of the estuarine and mangrove ecosystem (Botes, 2009).

5.11. Changes in Avian Indicator Populations within the Mgeni Estuary and Beachwood Mangrove Swamp Ecosystem

The abundance of all wetland indicator bird species combined together within their categories, and all individual bird species were investigated during the course of this study. The abundance of birds varied significantly through time within the Mgeni Estuary and Beachwood Mangrove Swamp study area (Allen, 2008). Analysis of the *CWAC Wetland Bird Census Data* as tabulated in the series of figures below covering the period 1993 to 2008 have revealed a steady decline in the populations of certain wetland bird species that utilise the Mgeni Estuary and Beachwood Mangrove Swamp ecosystem for foraging, roosting and reproductive purposes. The following factors all play a role in the decline of birdlife within the study area:

- A decrease in the quality and quantity of feeding habitats.
- A decline in food supply has a negative impact on bird populations.
- Decrease in the quality or quantity of nesting habitats within the ecosystem.
- The existence of pollutants which are concentrated in the water of the estuary, sediments, or the prey species consumed by the wetland bird species (Slack, 1992).

However, certain wetland bird species have shown a steady increase in their populations whilst other wetland bird populations are experiencing a population decline over the same period. It is speculated that this could be due to an increase in the quality and quantity of feeding habitats within the study area or an increase in food variety and supply. Ornithologists also suggest that an increase in the quality and quantity of nesting sites within the study area could be playing a role in the increase in certain bird populations (Allen, 2008).

5.12. Open Water Avian Indicator Species

Populations of wetland bird species that are designated as water habitat bird indicators by the researcher, for example the Pink-Backed Pelican, White-Breasted Cormorant and African Darter, have progressively declined over the last two decades as evident in Figure B1 in the Appendix B. Further information regarding foraging, roosting and breeding behaviour of these species is found in Appendix E and F.

The number of birds recorded is dependent not only on the conditions within the ecosystem, but also the time of year. The seasonality of certain bird species was taken into account, and fluctuations in bird numbers could also be associated with the time of year, either summer or winter.

Table 20: A Summary Table of Declining Water Habitat Avian Indicator Populations Recorded between 1993-2008

Avian Indicator Species	Jan-93	Jul-93	Jan-97	Jul-97	Jan-03	Jul-03	Jan-08	Jul-08
Pink Backed Pelican	0	0	1	3	0	0	1	0
White-Breasted Cormorant	6	44	9	16	11	24	12	11
African Darter	0	4	1	4	1	0	0	2

Research indicates that conditions within the estuarine and mangrove ecosystem are playing a significant role in the decline in water habitat indicator populations. This population decline can be linked to the decrease in the quality and quantity of feeding habitats, and possibly a related decline in food supply within the study area. Another theory proposed by ornithologists is an increase in predators within the ecosystem (Gillard, 2008).

People bring their pet dogs to the estuary for recreational purposes and populations of feral cats within the study area have also increased significantly (Allen, 2008). These predators are a threat to certain bird species, effectively denying them roosting and nesting sites. In January 1995, 20 Pink-Backed Pelicans, 3 White-Breasted Cormorants and 4 African Darters were counted by ornithologists. In July 1998, 20 Pink-Backed Pelicans, 20 White-Breasted Cormorants and 4 African Darters were recorded. Ornithologists recorded 18 White-Breasted Cormorants and only 2 African Darters in July 2008.

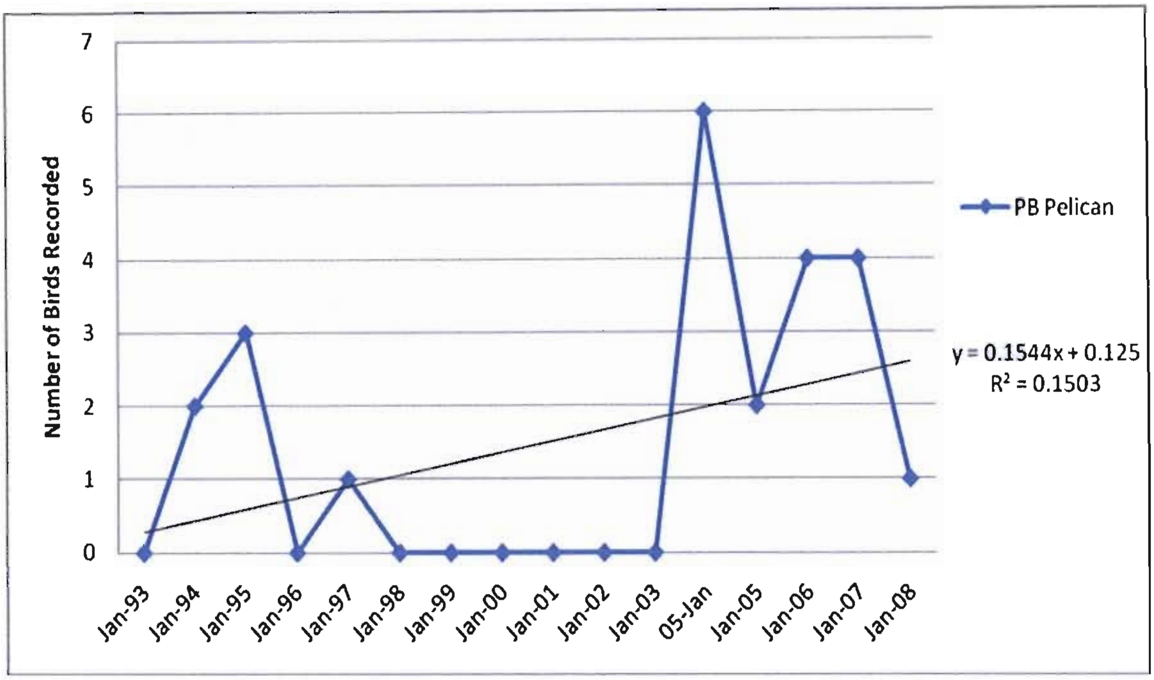

Figure 19: Summer Surveys- Increase in Pink-Backed Peclican Population

Figure 19 shows the number of Pink-Backed Pelicans recorded plotted against the time index. The weak positive linear trend displayed on this figure has a regression equation of $\hat{y}= 0.1544x+0.125$ with a $R^2= 0.1503$. This figure indicates that numbers of Pelicans recorded within the study area during summer months are increasing. This is despite their absence from the study area between January 1998 and 2003.

Plate 26: Pink Pelican (*Pelecanus rufescens*)

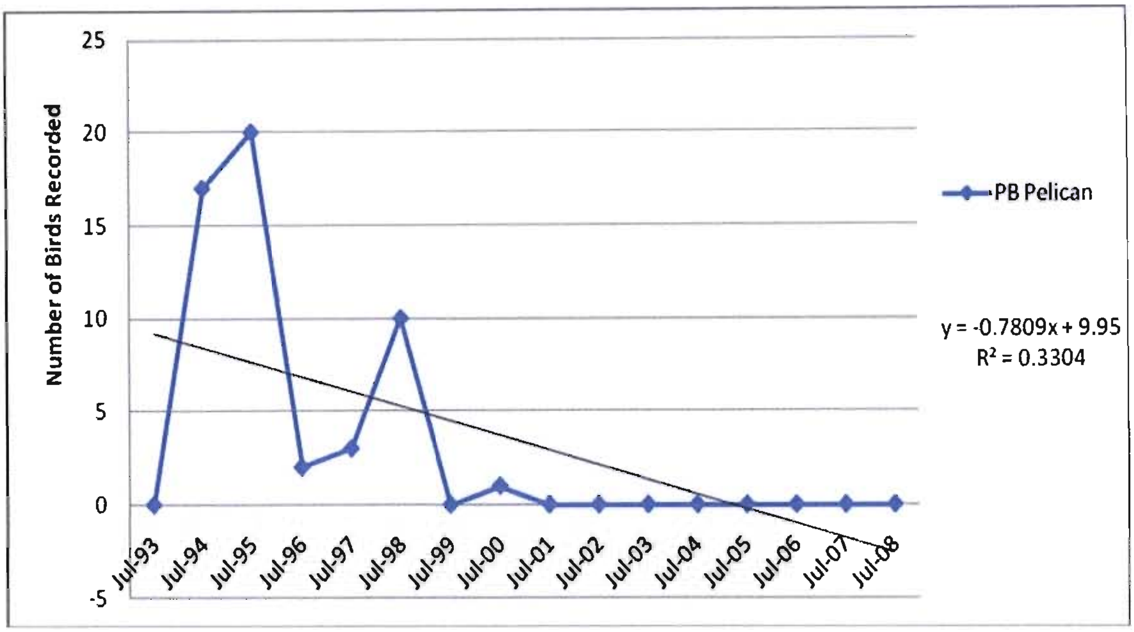

Figure 20: Winter Surveys- Increase in Pink-Backed Peclican Population

Figure 20 meanwhile, illustrates a decline in Pelican numbers during the winter months. The figure graphically illustrates a weak linear trend with a regression equation of $\hat{y} = -0.7809x + 9.95$ and $R^2 = 0.3304$. This reveals that the numbers of Pelicans present within the estuarine and mangrove study area are declining. In fact, it can be assumed that Pink-Backed Pelicans are no longer utilising the study area during the winter period for roosting and foraging because no birds have been recorded since July 2001. The last recorded sighting was of an individual bird in July 2000.

Plate 27: White Breasted Cormorant (*Phalacrocorax carbo*)

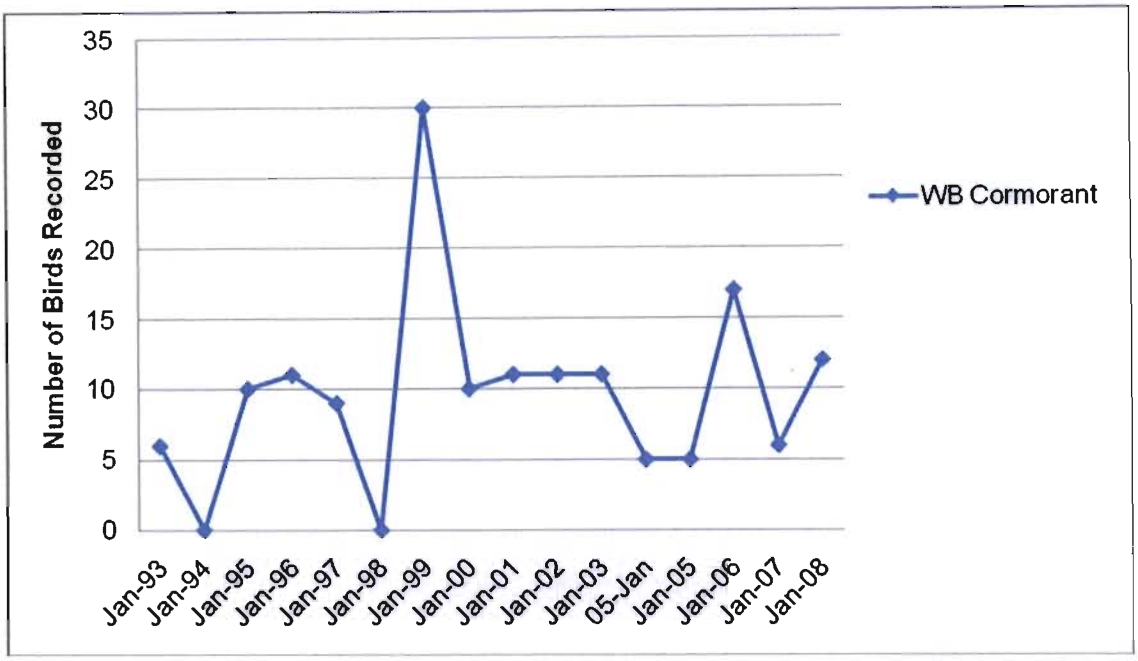

Figure 21: Summer Surveys- Decline in White-Breasted Cormorant Population

Figure 21 is a graphical representation of the numbers of White-Breasted Cormorants recorded during the summer period. The figure shows an increase in the numbers of Cormorants recorded within the study area over time. However, it is evident that there is no linear correlation between recorded bird numbers and the established time period of the study. This means that the population increase evident in the figure cannot be conclusively confirmed.

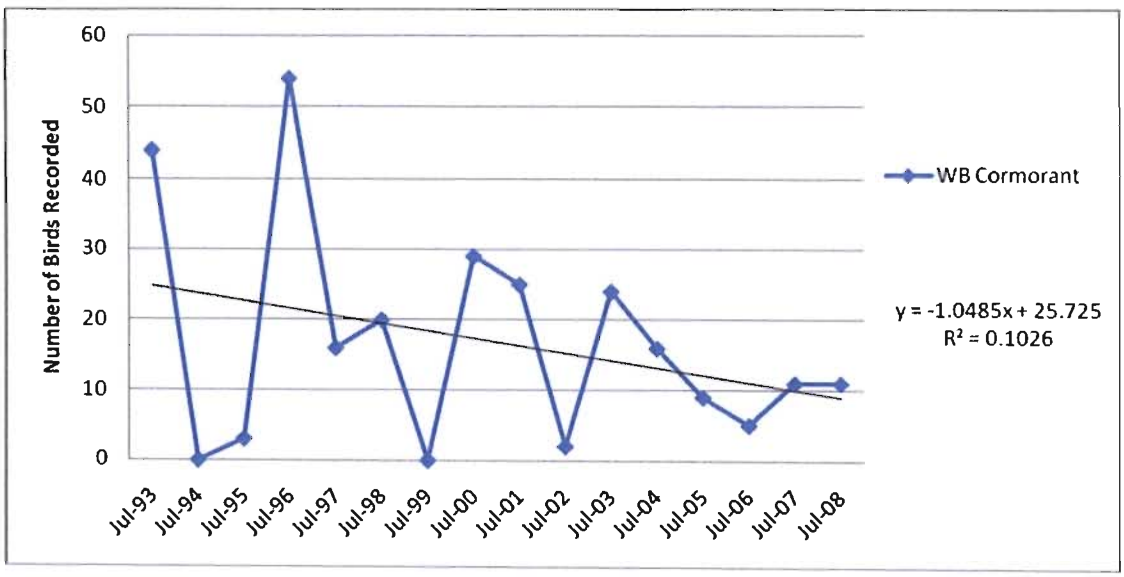

Figure 22: Winter Surveys - Decline in White-Breasted Cormorant Population

The Figure 22 displays the number of birds recorded within the study area plotted against the time period. The figure shows a weak negative linear trend and a regression equation of $\hat{y}= -1.0485x + 25.725$ of $R^2 = 0.1026$. If there is a negative correlation coefficient like -0.1026 this means that the two variables will respond in opposite directions. While the one increases, the other variable will decrease. Therefore, as time increases the population of Cormorants is declining. Careful analysis of the entire time period indicates an overall population decline as displayed in Figure C1 found in the Appendix C.

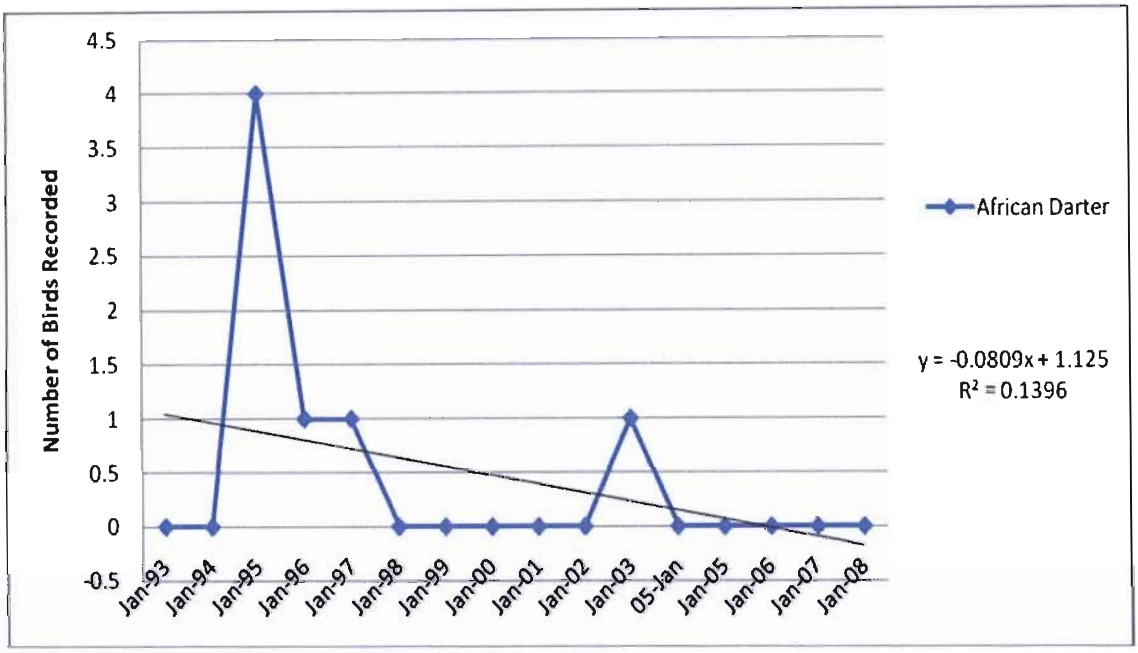

Figure 23: Summer Surveys- Decline in African Darter Population

Figures 23 shows a weak negative linear trend with an equation of $\hat{y}= -0.0809x+1.125$ with a $R^2= 0.1396$. This indicates a weak relationship between the number of birds recorded and the time period. No birds were recorded during surveys between January 1999 and January 2002. In later years the species seems to have disappeared from the study area during the summer months.

Figure 24 illustrates the number of African Darter recorded during the winter months of the year. This figure indicates that the number of birds recorded during the winter months is declining. However, there is no linear correlation between the variables. This makes it difficult to confirm there is a relationship between the variables, the number of birds recorded and the time period.

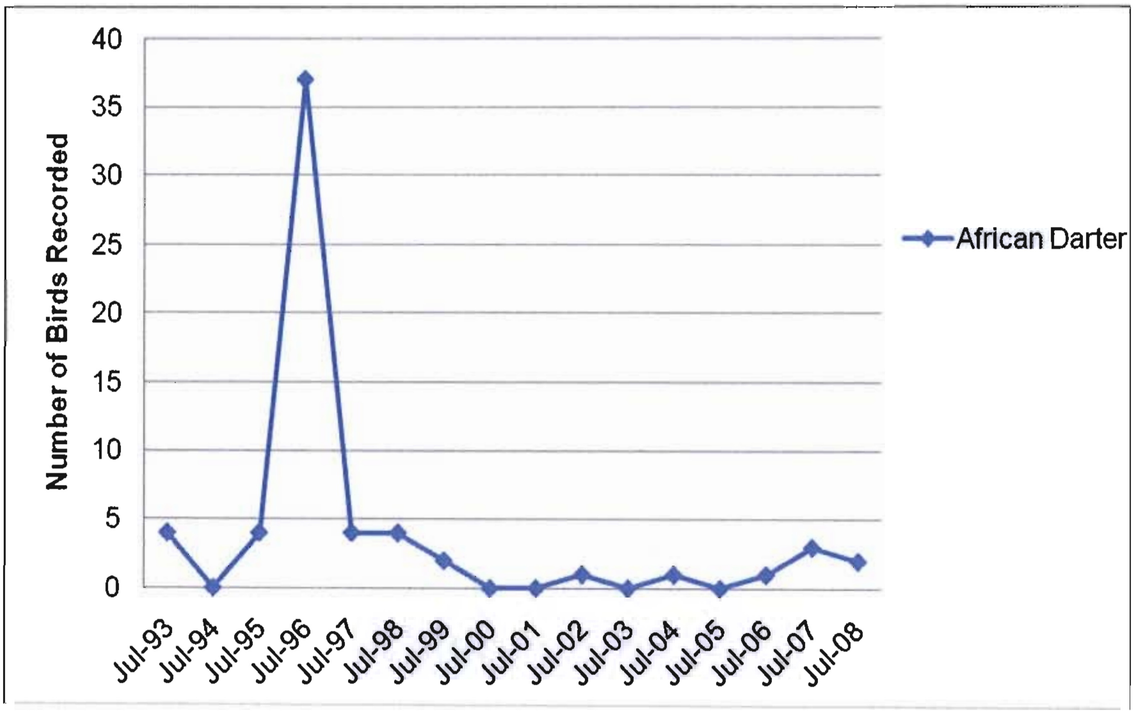

Figure 24: Winter Surveys - Decline in African Darter Population

Plate 28: African Darter (*Anhinga melanogaster*)

5.13. Shallow Water Avian Indicator Species

Populations of Goliath Heron and Little Egrets have steady increased due to either an improvement in the quality and quantity of their feeding habitats, or an increase in food variety and supply within the study area. This steady increase in population is represented in Table 21 below. Population fluctuations are graphically illustrated in Figure B2 in the Appendix B. Further information on these species is found in Appendix E and F.

Table 61: A Summary Table of the Increase of Water Habitat Avian Indicator Populations Recorded between 1993-2008

Avian Indicator Species	Jan-93	Jul-93	Jan-97	Jul-97	Jan-03	Jul-03	Jan-08	Jul-08
Goliath Heron	2	2	1	0	1	5	2	1
Little Egret	4	0	0	11	1	2	8	8

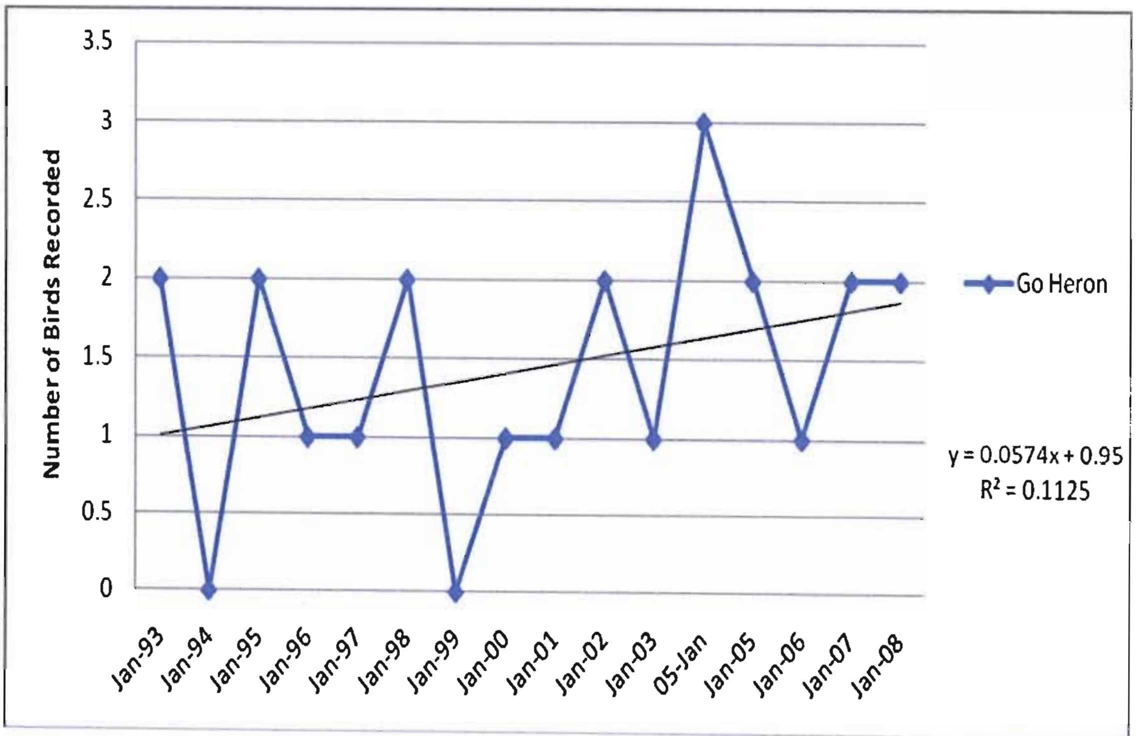

Figure 25: Summer Surveys - Increase in Goliath Heron Population

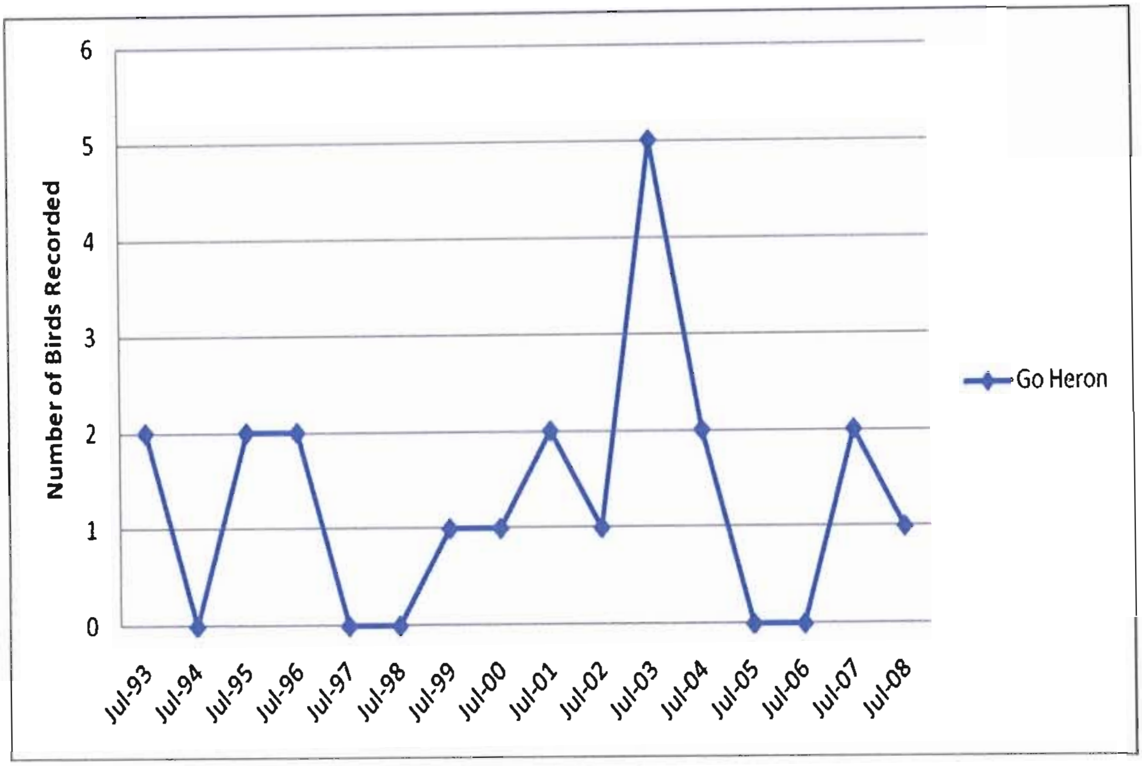

Figure 26: Winter Surveys- Goliath Heron Population

Plate 29: Goliath Heron (*Ardea goliath*)

Figures 25 and C3 in Appendix C graphiclaly display the numbers of Goaith Heron within the study area. Figure 25 demostrates the number of birds recored against time with a weak positive linear trend with a regression equation of $\hat{y} = 0.0574x + 0 .95$ and a $R^2 = 0.1125$.

This indicates that Goliath Heron numbers have steadily increased over the time period of the study.

Meanwhile, Figure 26 reflects the number of Goliath Herons recorded plotted against the time period. This figure indicates that there is no connection between the variables. The fluctuations in bird numbers were too inconsistent to determine if they were statistically relevant.

Apparent human error during the CWAC Wetland Bird Census could be responsible for inconsistencies in certain avian data sets. Below, Figure 27 displays a positive linear trend in favour of a general Little Egret population increase over the summer periods since the induction of the CWAC Wetland Avian Census.

Figure 27 below indicates a weak positive linear trend with a regression equation of $\hat{y}= 0.2515x + 1.8$ and $R^2= 0.1353$. Therefore, a change in the independent variable should result in a comparable increase or decrease in the dependent variable. Therefore, as time increases there is a comparable increase in the population of Little Egrets in the study area.

Figure 28 just reflects the number of Little Egrets recorded during the winter time period. However, no linear correlation was established. See Figure C4 in Appendix C for more details.

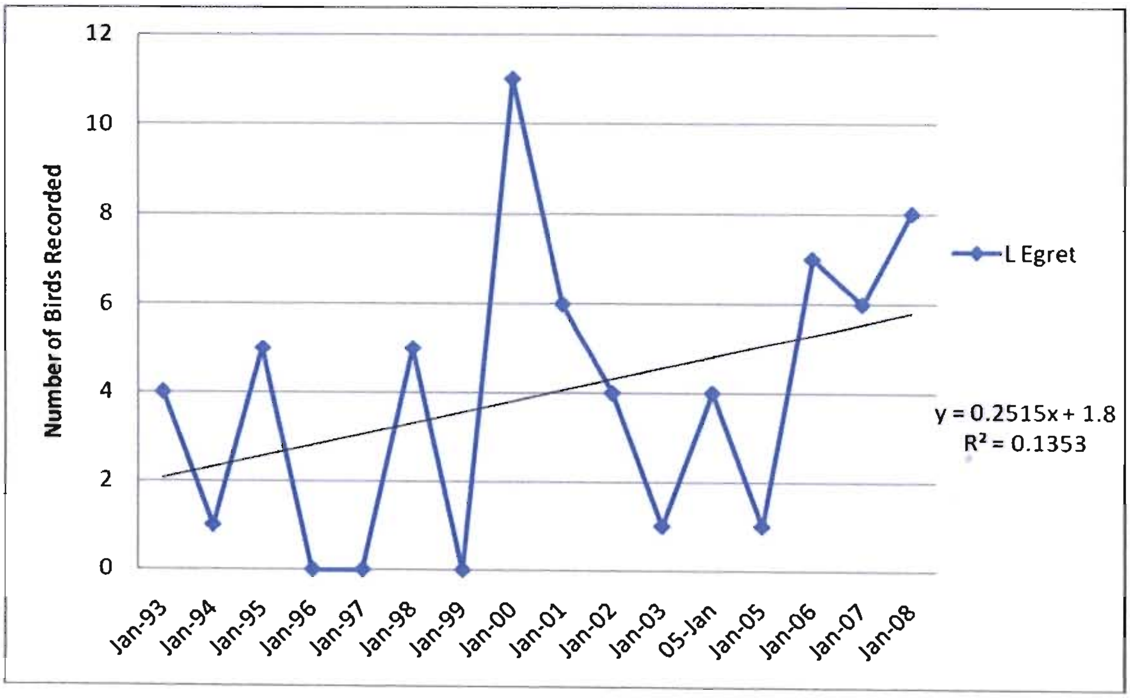

Figure 27:Summer Surveys - Increase in Little Egret Population

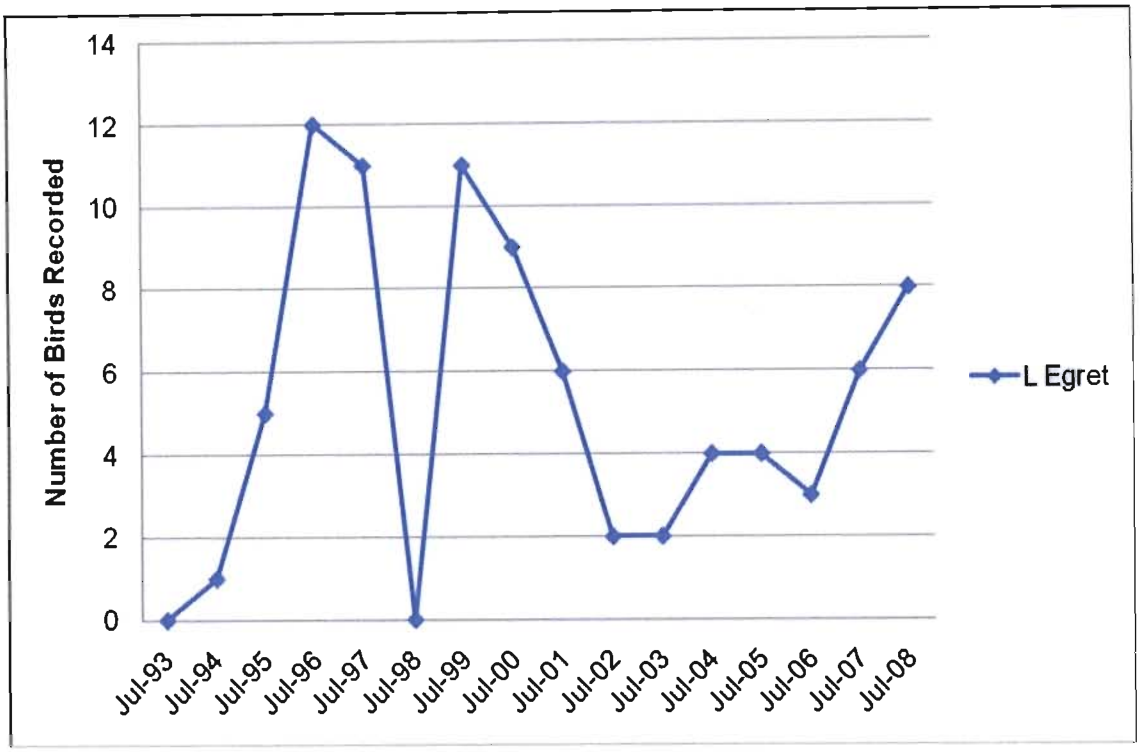

Figure 28: Winter Surveys - Little Egret Population

Plate 30: Little Egret (*Egretta garzetta*)

Another species which has adapted to foraging in water habitats is the Pied Kingfisher. The researcher selected the Pied Kingfisher as a generalist indicator species for water bodies within the study area. This Kingfisher species was selected for this role largely due to the species's adaptability and versitlity in terms of its foraging behaviour and technqiues. It has the ability to forage in a wide variety of water habitats ranging from shallow creeks and inlets of the mangroves, to deep open water channels of the estaury. Pied Kingsfisher numbers flucuate throught the year as evident in the figures below.

However, birds tend to congregate around water bodies during the summer breeding season which accounts for the higher number of birds recorded during the summer period. Birds tend to move away from the more permanent water bodies such as the creeks, streams and greater water body of the esturine and mangrove ecosystems to inland lakes, dams and streams during the winter months. See Appendix E and F for more details.

Plate 31: Pied Kingfisher (*Ceryle rudis*)

Table 22: A Summary Table of the Increase in Pied Kingfisher Populations between 1993-2008

Avian Indicator Species	Jan-93	Jul-93	Jan-97	Jul-97	Jan-03	Jul-03	Jan-08	Jul-08
P K/fisher	2	0	1	11	0	12	3	4

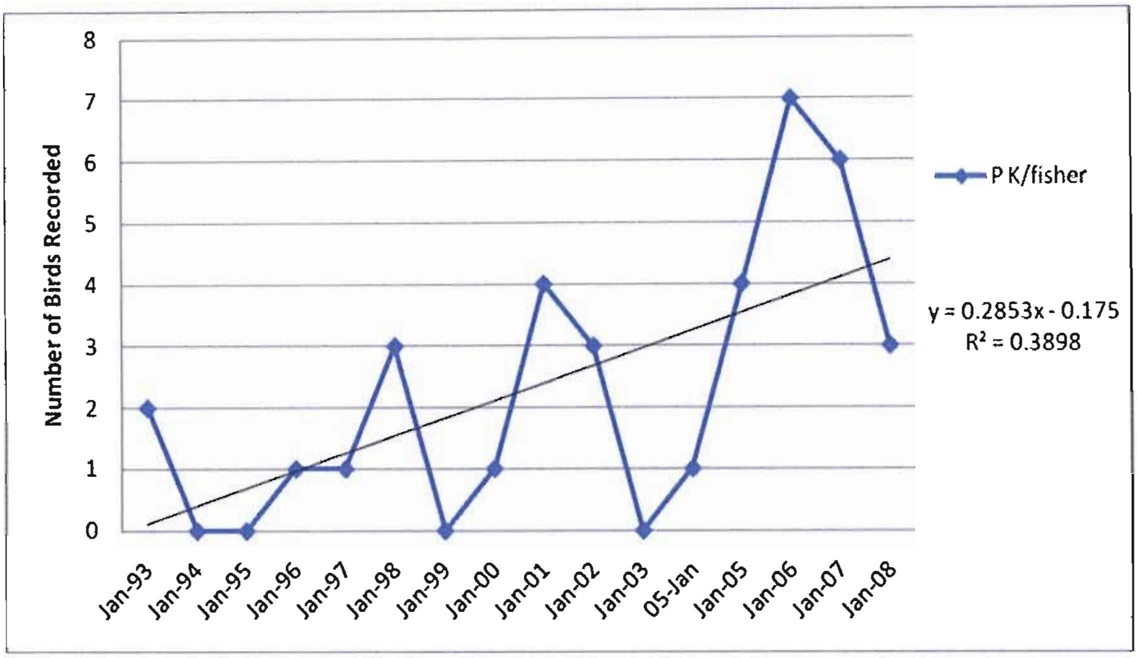

Figure 29: Summer Surveys - Increase in Pied Kingfisher Population

Examination of the figures indicates a significant increase in Pied Kingfisher numbers within the summer periods, and a slight decline in bird numbers over the winter period. The reasons for such population flucuations have been discussed above. Figure 29 shows a modertly positive linear trend with a regression equation of $\hat{y}= 0.2853x + 0.175$ and a $R^2= 0.3898$. It is clearly evident that Kingfisher numbers are increasing during the summer period.

Figure 30 displays the number of Pied Kingfishers recorded plotted against time. However, there is no linear correlation between the values. Further information regarding the increase in the numbers of kingfishers recorded within the study area can be found in Figure B3 and C6 in the Appendix B and C.

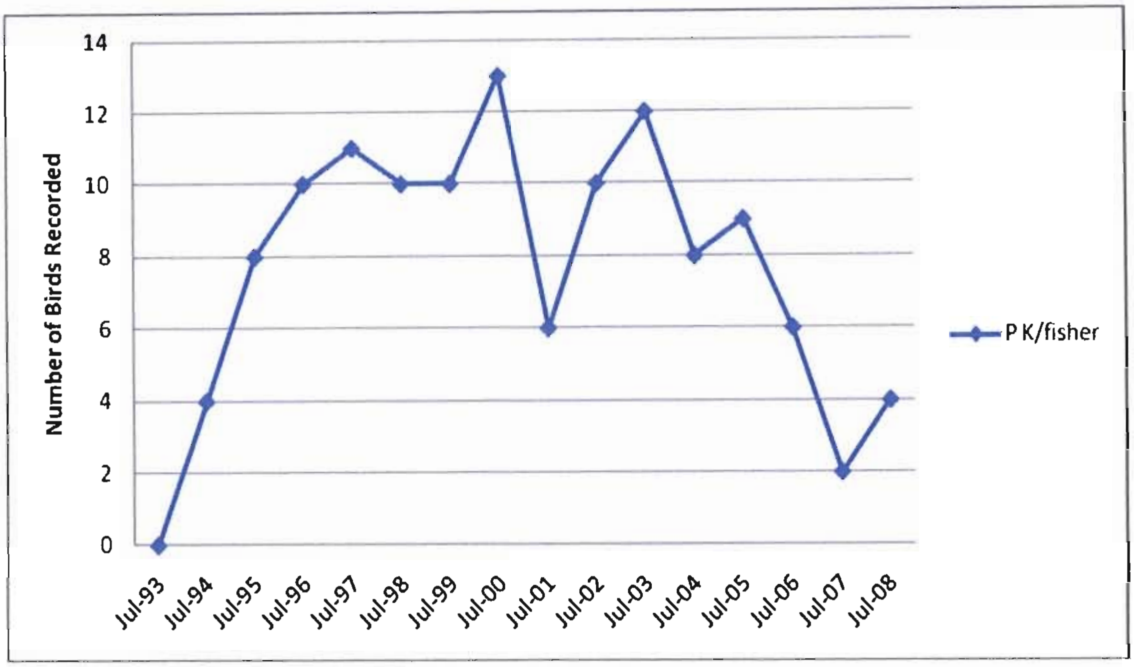

Figure 30: Winter Surveys - Pied Kingfisher Population

The Pied Kingfisher population has increased significantly over the last two decades. population growth is largely due to an increase in food supply, and possibly an improvement in terms of quality and quantity of foraging and nesting habitats within the study area.

5.14. Mudflat Avian Indicator Species

Ornithologists have recorded a gradual decline in wading bird species within the study area during the past couple of decades. The researcher decided to designate these bird species as mudflat indicators because of their reliance on mudflats for foraging and roosting.

Table 23: A Summary Table of the Number of Mudflat Avian Indicators Recorded between 1993-2008

Avian Indicator Species	Jan-93	Jul-93	Jan-97	Jul-97	Jan-03	Jul-03	Jan-08	Jul-08
Sacred Ibis	8	72	119	110	107	10	9	4
Sanderling	0	0	0	0	60	0	97	0
Curlew S/piper	224	0	170	0	0	0	162	0
L Stint	138	0	38	0	61	0	3	0
BS Plover	15	49	54	45	98	60	91	82

The study revealed a decline in the number of Little Stints, Curlew Sandpipers and Sacred Ibis recorded within the Mgeni Estuary and Beachwood Mangrove Swamp Study Area. The decline in Sacred Ibis populations is illustrated in Figure B4 in Appendix B. The decrease in wading bird populations could be due to predation, disease or the reduction in the quality and quantity of feeding and roosting habitats within the study area (Slack, 1992). However, this is just pure speculation until further research can be conducted.

Despite the decline in certain indicator populations, Sanderling numbers have increased from no recorded sightings within the study area during the early 1990s, to 97 birds in January 2008 as evident in the Table 23 above. Figure 32 below has a weak positive linear trend with a regression equation $\hat{y}= 3.1985x + 3.875$ and a $R^2 = 0.257$. This indicates that the number of Sanderlings visiting the Mgeni Estuary and Beachwood Mangrove Swamps is increasing.

This increase in numbers of Sanderlings visiting the Mgeni Estuary and Beachwood Mangrove Swamps could be due to the following:

- A decline in the populations of competing species of wading birds such as Little Stints and Curlew Sandpipers. Less competition in terms of foraging and roosting locations and abundance in prey species contributes to an increase in Sanderling numbers (Gillard, 2008).

- An increase in the abundance of preferred prey species within the Mgeni Estuary and Beachwood Mangrove Swamp Study area. In addition, an increase in the abundance of preferred roosting and suitable foraging habitats could be another influencing factor (Allen, 2008).

- A decline in predator species within the study area.

- A decline in the quality and quantity of other previously suitable roosting and foraging habitats in vicinity of other water bodies encouraging birds to use study area.

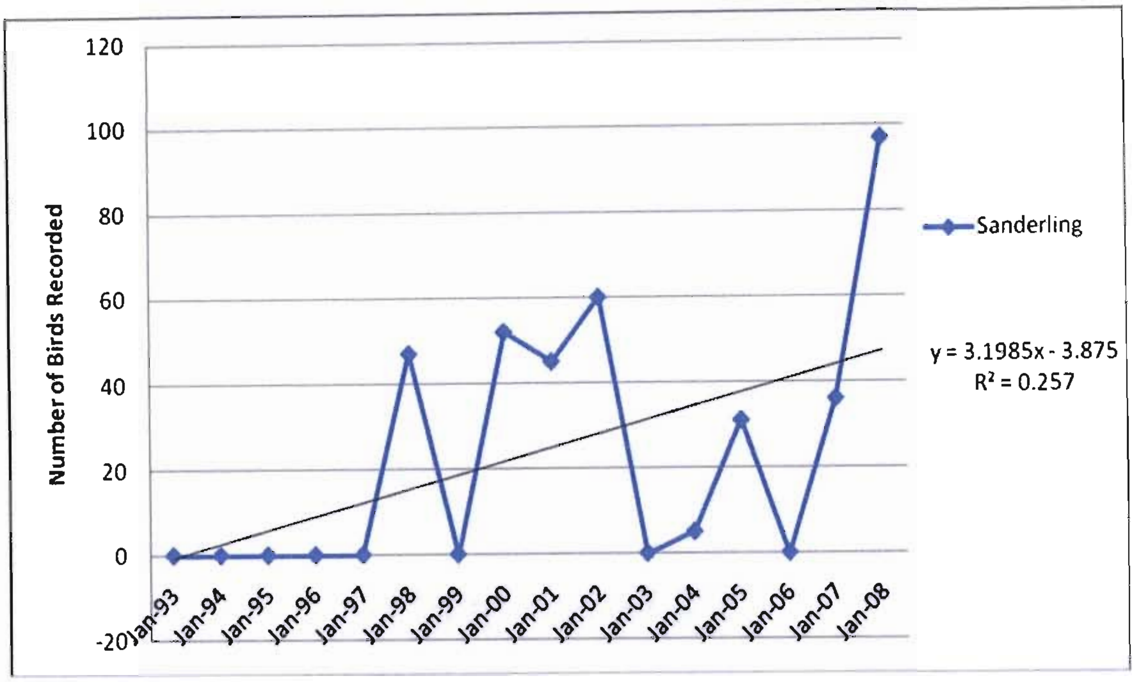

Figure 31: Summer Surveys - Increase in Sanderling Population

Plate 32: Little Stint (*Calidris minuta*)

Meanwhile, Little Stint and Curlew Sandpiper populations show signs of decline within the study area as illustrated in Figures 32 & 33 below. Figure 32 below shows a moderately negative linear trend and the equation is $\hat{y}$= -8.9618x + 123.93 and R^2 = 0.334, whilst Figure 33 also has a moderately negative linear trend with the regression equation of $\hat{y}$= 22.526x + 399.48 and R^2 = 0.3187.

This decline could be the result of the following:

- High mortality rate outside of study area i.e. high death rate due to predation or disease in other breeding grounds.
- Loss of suitable foraging and roosting habitat within study area.
- Reduction in the abundance of suitable prey species.
- High death rate due to disease and predation within study area. However, evidence to suggest such conditions does not exist.

Plate 33: Curlew Sandpiper (*Calidris ferruginea*)

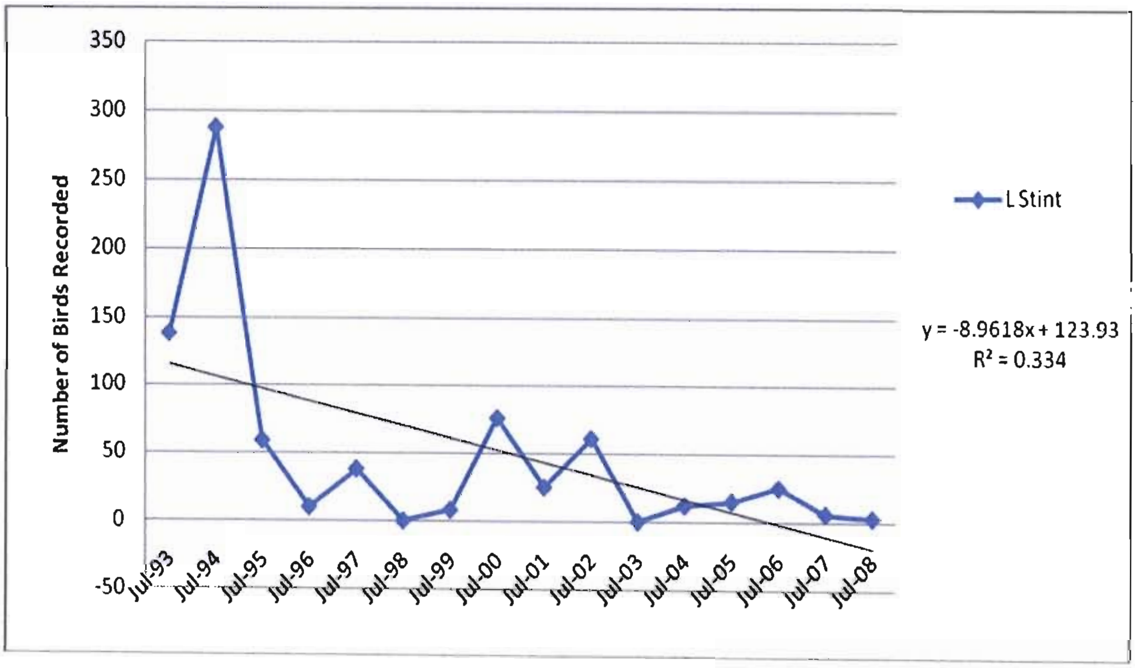

Figure 32: Summer Surveys - Decline in Little Stint Population

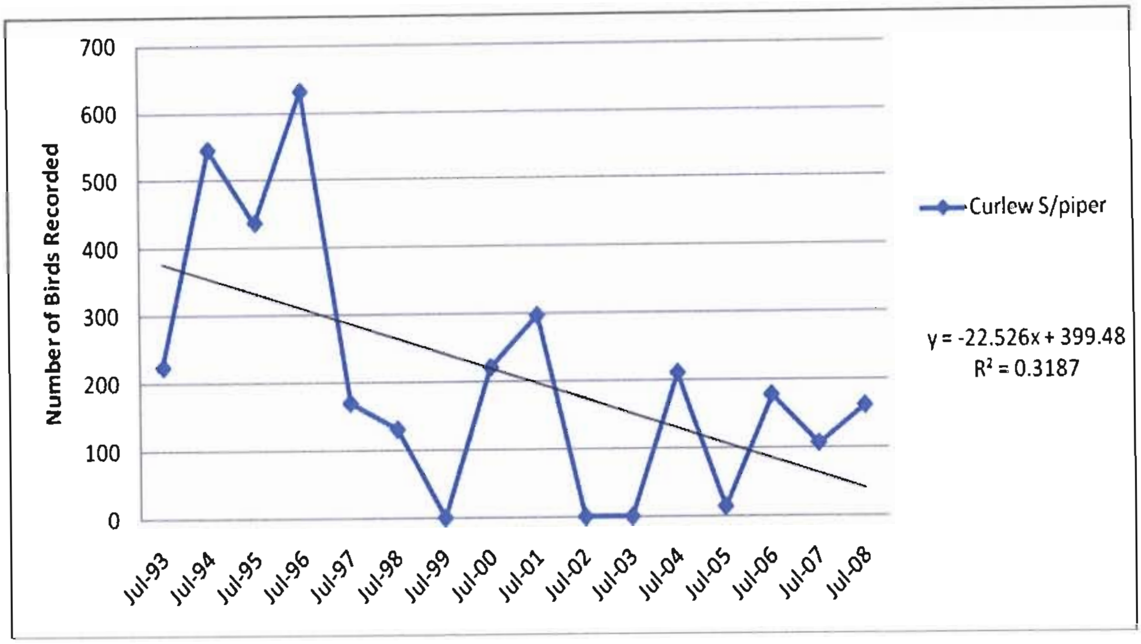

Figure 33: Summer Surveys - Decline in Curlew Sandpiper Population

Sacred Ibis populations have also shown signs of population fluctuations over the last couple of decades. In 1993 ornithologists recorded the presence of +/- 100 Ibises within the study area during five separate surveys.

Plate 34: Sacred Ibis (*Threskiornis aethiopicus*)

Numbers grew substantially within the study area following the establishment of a breeding and roosting colony on the grounds of the Umgeni River Bird Park during 1996/97 (Gillard,2008). However, the Ibises were responsible for the spreading of a highly contagious and lethal bactericidal infection through the park's captive water bird population through their faeces. Park management implemented a programme to remove the Ibis colony and prevent birds from settling on the grounds in large numbers in mid-2003 (Allen, 2008). The decline in the population of Sacred Ibises over the last two decades can be seen in Figure C2 of Appendix C.

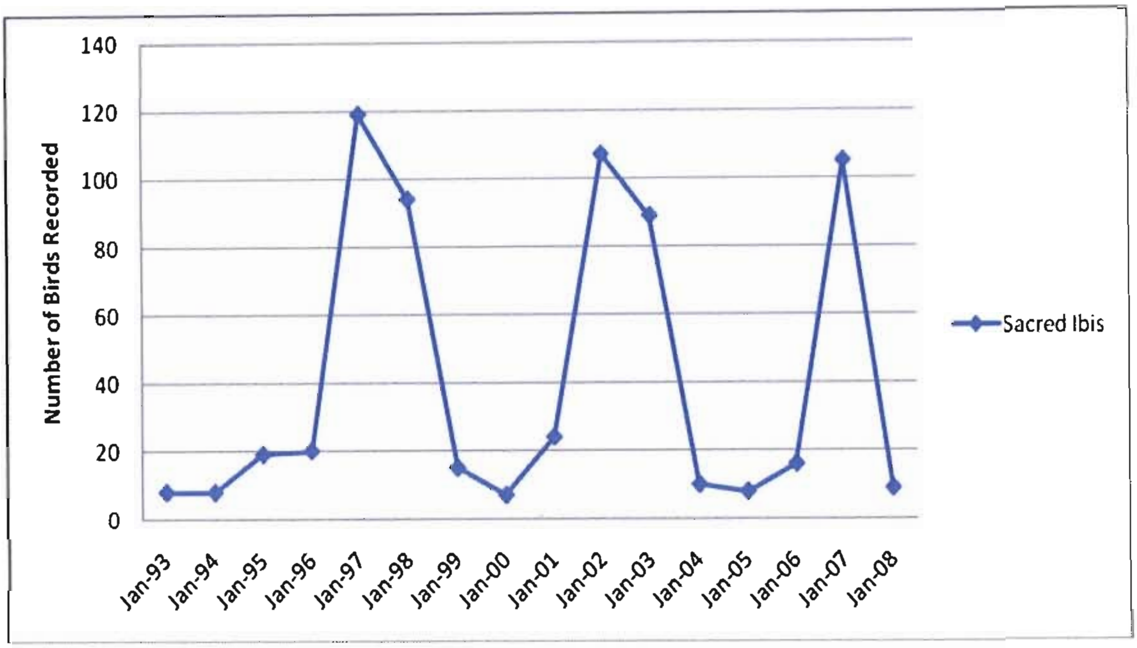

Figure 34: Summer Surveys - Increase in Sacred Ibis Population

Figure 34 illustrates that there is no relationship between the dependent and independent variables and thus there is no linear correlation. However, the peaks in the Ibis population displayed in 1997/98, 2002/03 and 2007/08 could be due to the abundance of prey species and an increase in suitable foraging locations within the study area during the summer months. In addition, ornithologists indicate that Sacred Ibises will congregate in large numbers near water bodies surrounded by tall trees and other vegetation as such areas are ideal for the establishment of breeding colonies. Prior to the removal of the Ibis breeding colony from the Umgeni River Bird Park property in 2003, most of the Ibises recorded during CWAC Wetland Avian Censuses within the Mgeni Estuary and Beachwood Mangrove Swamp study area, were adult birds from the breeding colony situated in the bird park grounds that were vigorously foraging to ensure a constant supply of sustenance to raise their chicks. It was assumed that the establishment of a new breeding colony on the adjacent golf course on the south bank of the estuary during 2006/2007 period would eventually lead to a gradual recovery of the Sacred Ibis population in the area.

Figure 35 below, representing the numbers of Ibises recorded within the study area during the winter months, indicates a weak negative linear trend with an equation of $\hat{y}$= -4.838x +

114.05 with the R^2 = 0.2302. This figure displays a population decline during the winter period.

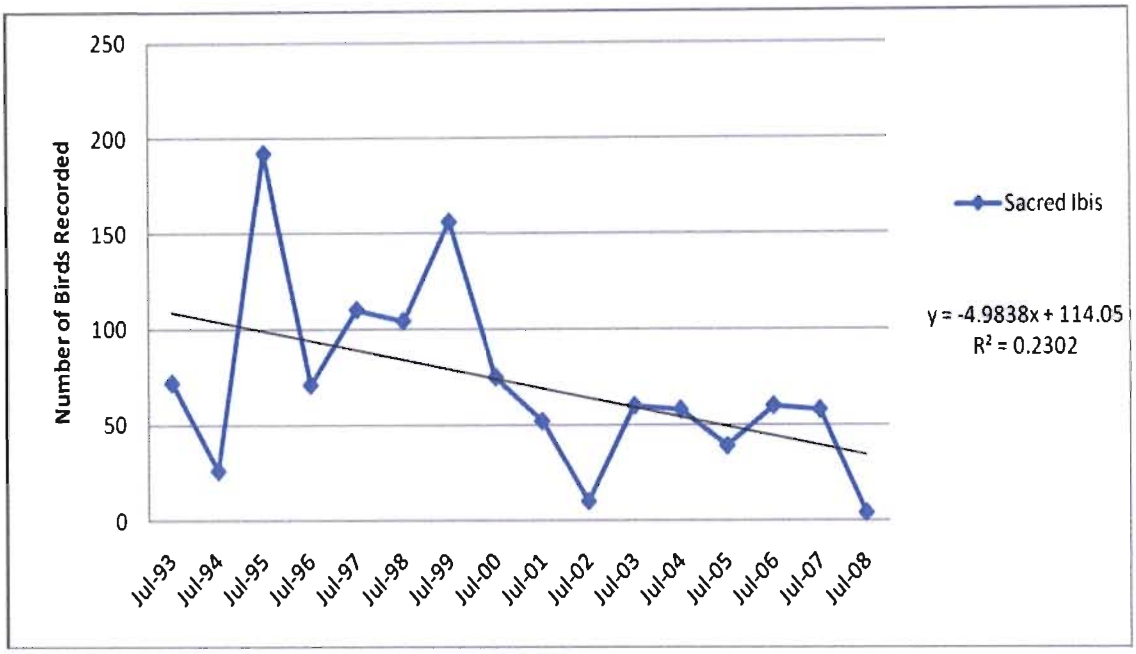

Figure 35: Winter Surveys - Decline in Sacred Ibis Populations

However, the gradual decline in Ibis populations during the winter period shown in Figure 35 is representative of a general Sacred Ibis population decline within the Mgeni Estuary and adjacent Beachwood Mangrove Swamps over the last two decades. Ibis numbers within the study area show signs of a steady decline after the implementation of this Umgeni River Bird Parks removal programme, as birds moved to other more suitable breeding, roosting and feeding areas around the Durban area and have not return. For example, Ibises have recently established a breeding colony in Durban Botanical Gardens. This population decline is illustrated in the Figure C2 which can be found in the Appendix C.

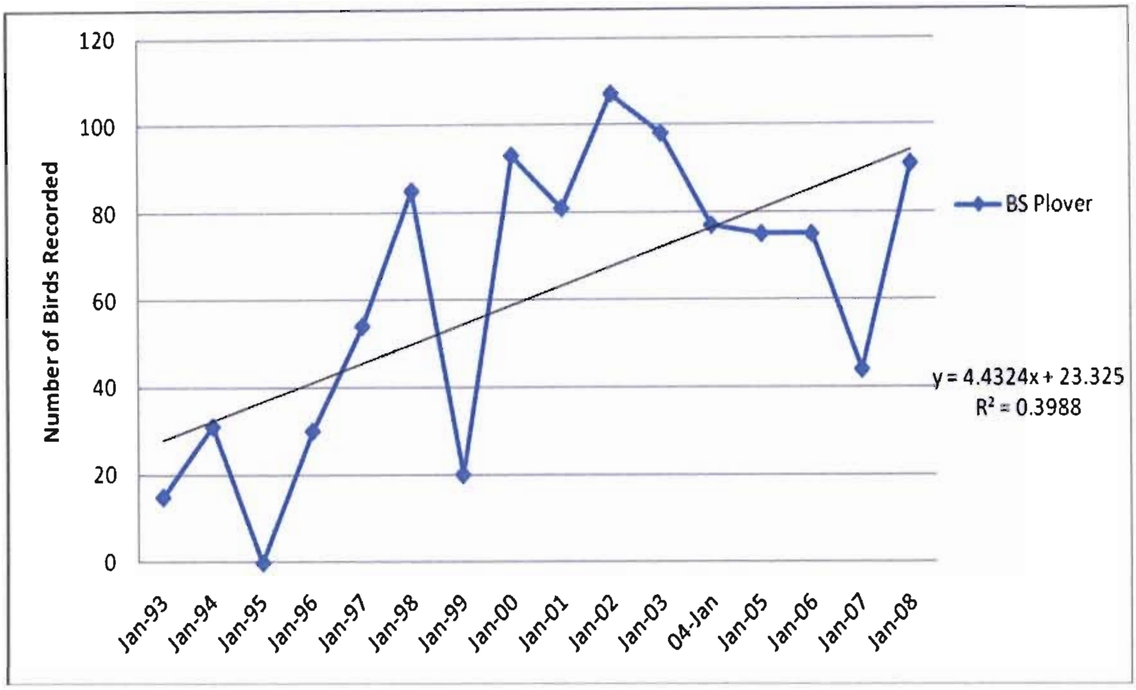

Figure 36: Summer Surveys - Increase in Black-Smith Plover Population

The Blacksmith Plover population increased steadily between 1993 and 2008. Figure 36 illustrates the number of birds recorded plotted against the time index and shows a moderately positive linear trend with a regression equation of $\hat{y}= 4.4324x + 23.325$ and $R^2= 0.3988$.

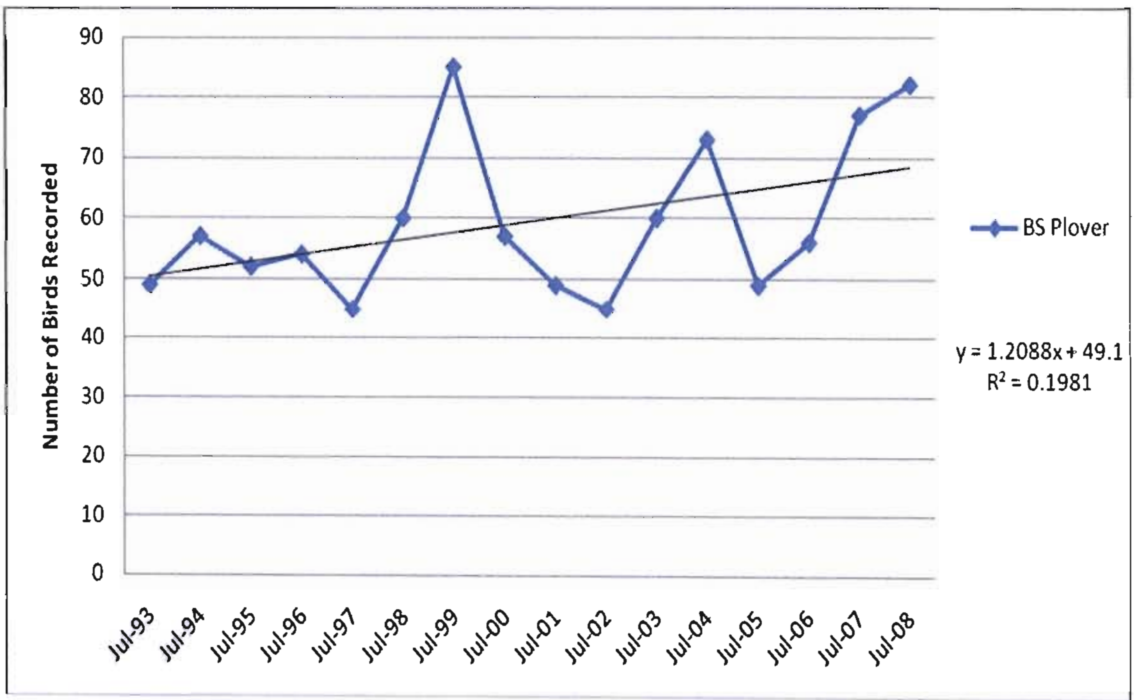

Figure 37: Winter Surveys - Increase in Black-Smith Plover Population

The second figure, Figure 37, presents a weak positive linear trend with an equation of $\hat{y}= 1.2088x+49.1$ and a $R^2 = 0.1981$. Both figures indicate the population of Black-Smith Plovers are increasing within the study area. Ornithologists indicate that this is due to an increase in the quality and quantity of foraging, roosting and nesting habitats within the study area. Blacksmith Plovers breed in the rough grass areas on the Windsor Golf course along the south bank of the Mgeni Estuary (Allen, 2008). The surveys indicated that 54 plovers were recorded within the study area during 1993. The population steadily grew and censuses conducted in 2003 indicate that the estuary and mangrove swamps were a refuge for 158 plovers. By 2008 the resident population of plovers had grown to 173 birds. See Appendix A.

Plate 35: Black-Smith Plover (*Vanellus armatus*)

5.15. Vegetated Area Avain Indicator Species

The researcher noticed a gradual increase in the populations of skulking/vegetated area indcator bird species that rely on heavily vegetated habitats for foraging, roosting and breeding. These areas include reedbeds, marshes, riverine bush, grassland and sedge ecosystems. This population increase is largely due to the increased quality and quantity of feeding, roosting and breeding habitats within the Mgeni Estuary and Beachwood Mangrove Swamp ecosystem (Slack, 1992). This population increase is reflected in Figure 52 below.

Table 24: A Summary Table of the Number of Vegetated Areas Indicators Recorded between 1993-2008

Avian Indicator Species	Jan-93	Jul-93	Jan-97	Jul-97	Jan-03	Jul-03	Jan-08	Jul-08
Water Dikkop	2	0	2	14	3	0	17	0
P Heron	1	2	3	0	2	3	0	3
Woolly-Necked Stork	0	3	1	0	10	12	2	1

Purple Heron and Water Dikkop were classified vegetated area indicator species due to their reliance on reedbeds, marshes, grassland and dense vegetation along water courses for foraging, roosting and reproduction. This increase in population of birds dependent upon vegetated areas is evident in the table above.

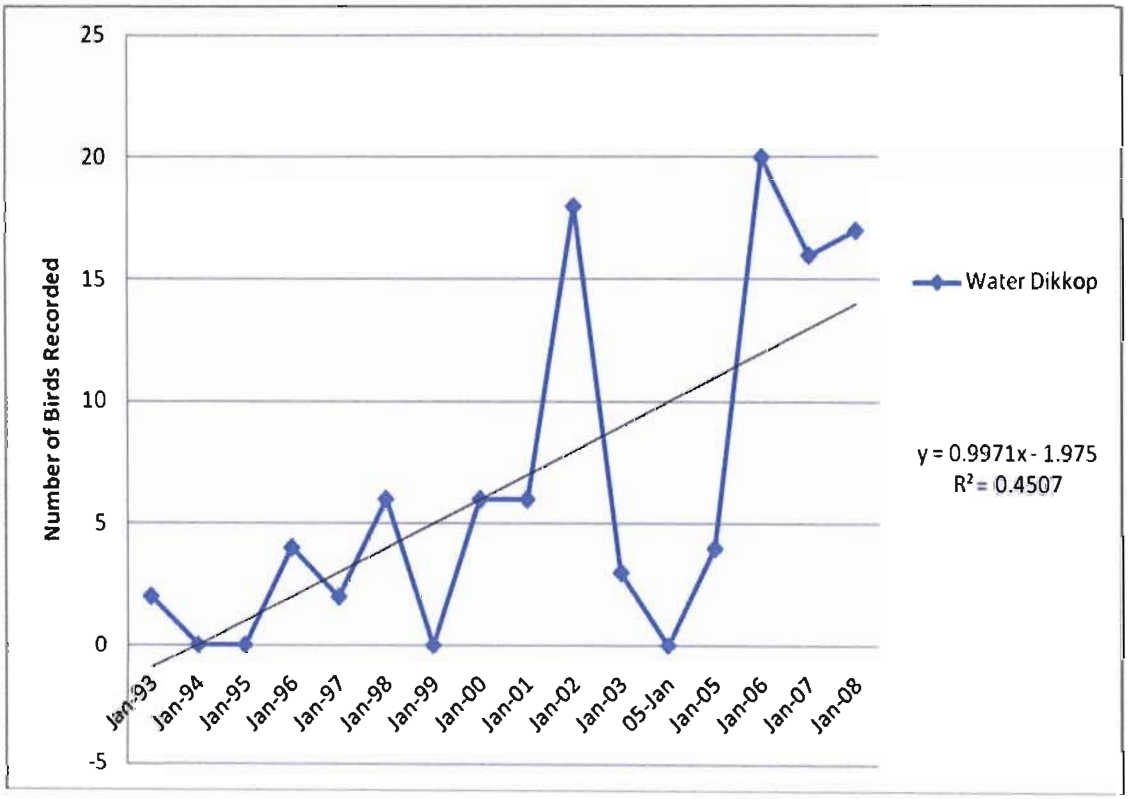

Figure 38 :Summer Surveys - Increase in Water Dikkop Population

Plate 36: Purple Heron *(Ardea purpurea)*

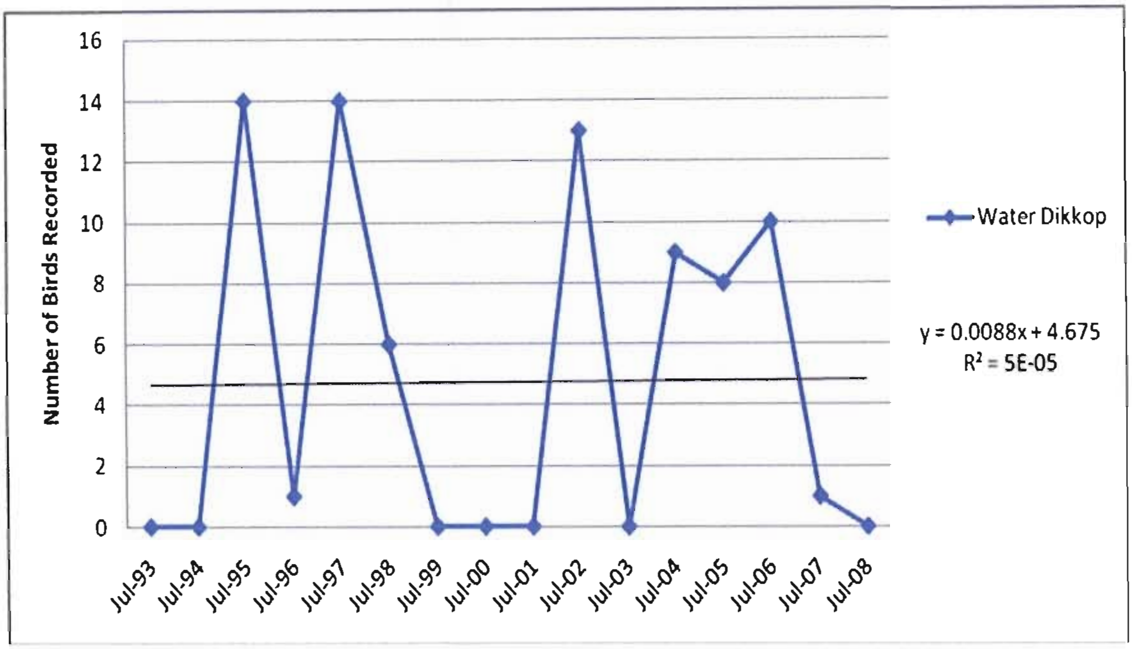

Figure 39: Winter Surveys - Consistant Water Dikkop Population

In 1993, 1 Purple Heron and 2 Water Dikkops were observed by ornithologists. In July 2008, Ornitholgist recored 17 Water Dikkop and 3 Purple Herons. These recordings indicate a gradual increase in the number of sightings of particular species pointing to population increase within the study area. This general population increase is displayed in a series of figures displayed in the Appendix C.

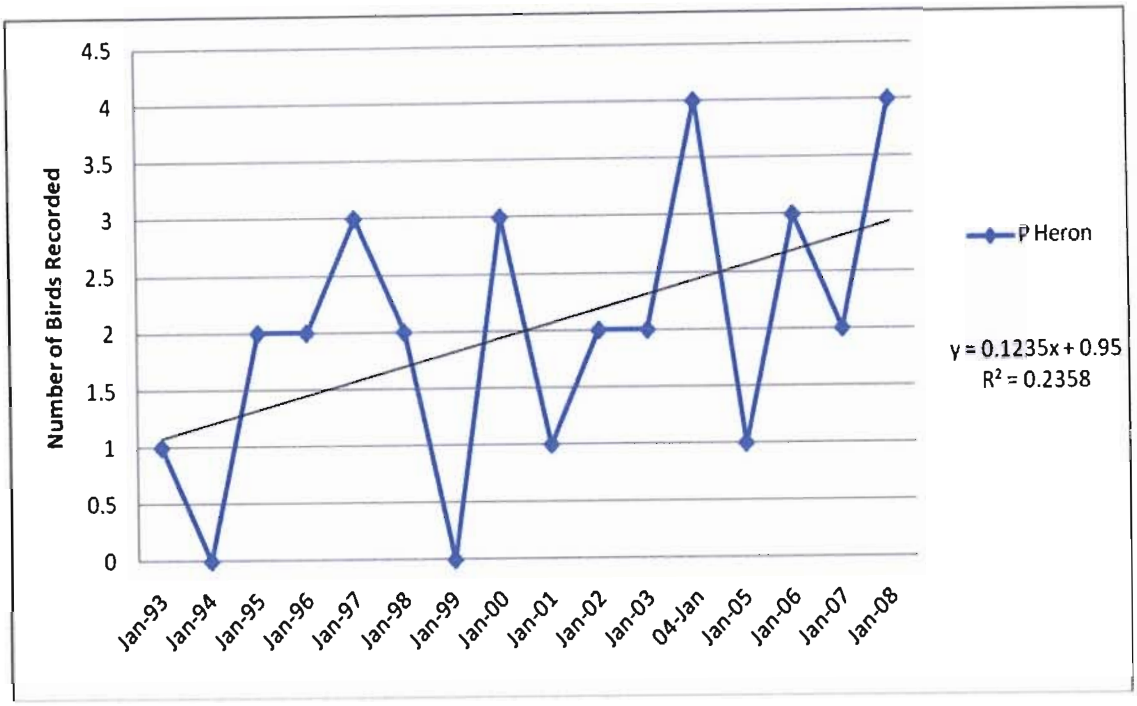

Figure 40: Summer Surveys - Increase in Purple Heron Population

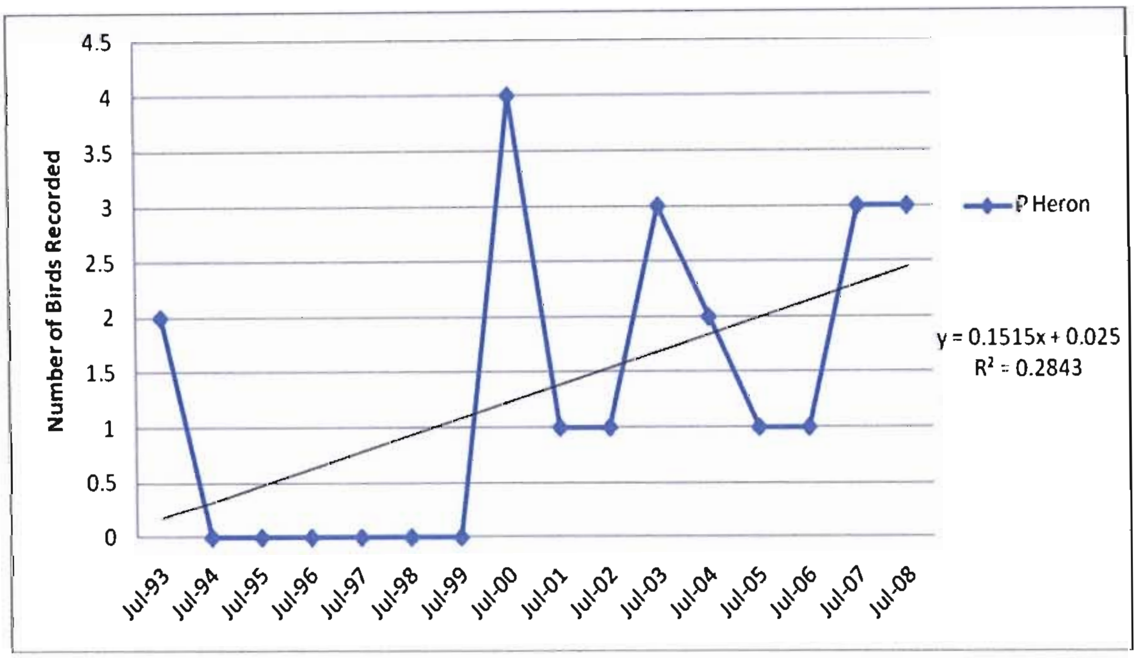

Figure 41: Winter Surveys - Increase in Purple Heron Population

The figures above illustare a gradual increase in the Water Dikkop and Purple Heron populations, whilst the figures below graphically demostrate the increase in Woolly-Necked Stork populations within the study area during the introduction of the CWAC Wetland Avian Census counts.

Plate 37: Water Dikkop (*Burhinus vericulatus*)

Figure 38 graphically represents the increase in the number of Water Dikkop recorded within the study area against the time index. The figure displays a moderatly strong positive linear with a regresssion equation of $\hat{y}$= 0.9971x- 1.975 and a R^2= 0.4507. The number of Water Dikkop recorded during the summer period seems to be increasing over time. The Figure 39, also illustartes the number of birds counted plotted against the time period of the study. The regression equation is $\hat{y}$= -0.0088x+4.675 with a R^2=5E-05. This indicates that the Water Dikkop population has remained constant and not flucutated signficantly over the established time peirod.

Meanwhile, Figure 40 and 41 shows the number of Purple Herons recorded during surveys plotted against the time index . The Figure 40 shows a regresssion equation of $\hat{y}$= 0.1235x + 0.95 and R^2= 0.2338.This figure indicates that the population of Purple Heron is gradually increasing during the summer months. Figure 41 displays a regression equation of $\hat{y}$= 0.1515x + 0.025 and R^2= 0.2843. This indicates that Heron numbers are increasing over the winter period.

Plate 38: Woolly-Necked Stork (*Ciconia episcopus*)

Populations of Woolly-Necked Storks increased during the same period. Figures 42 and 43 represent a gradual increase in the Stork population during both the summer and winter months since the start of wetland avian counts in the early 1990s. This increase is due to an improvement or increase in the quality and quantity of feeding habitats within the study area (Slack, 1992). The highest number of Woolly-Necked Storks counted in the study area was 12 birds in July 2003 (Table 19). According to ornithologists, this species of stork does not breed or roost within the study area. Therefore, they visit the area purely to forage for suitable prey species such as insects, amphibians, reptiles and small mammals.

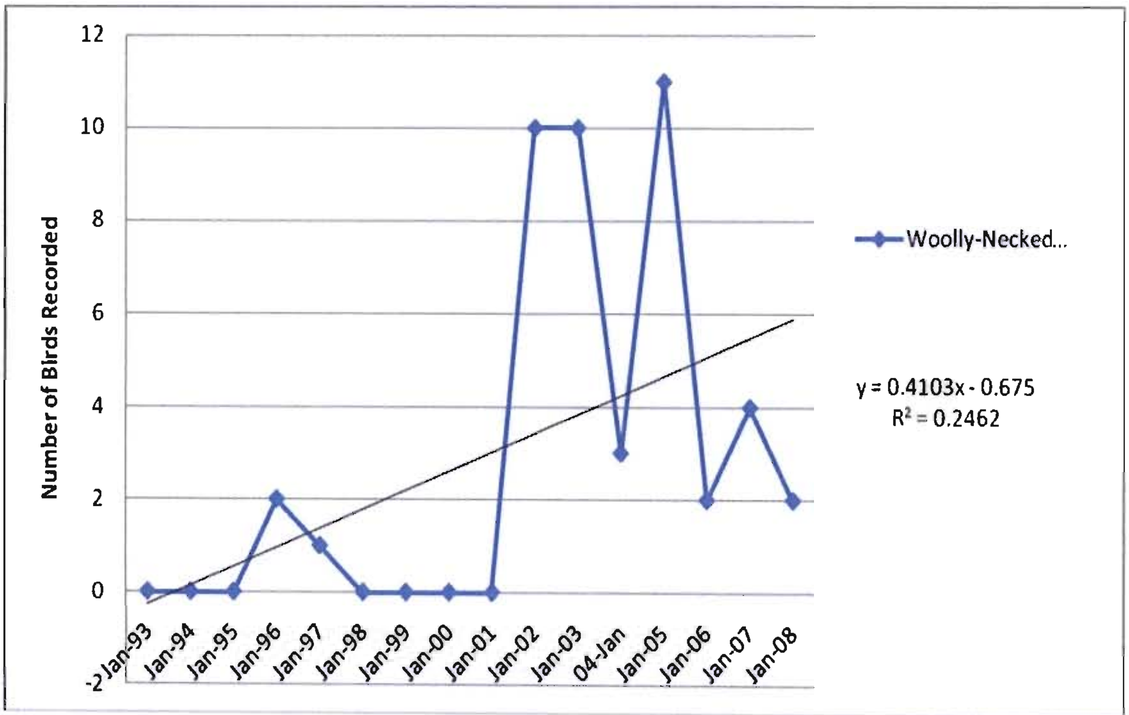

Figure 42:Summer Surveys - Increase in Woolly-Necked Stork Population

Figure 42 indicates that Woolly-Necked Storks are becoming a more regular visitor to the study area during both the summer and winter periods. The reasons for this population growth have already been stated. This figure illustrates the number of birds counted against time and shows a weak positive linear trend with a regression equation of $\hat{y}= 0.4103x - 0.675$ and a $R^2= 0.2462$. Figure 43 is shows a moderatly positive linear trend with a regression equastion of $\hat{y}= 0.2412x + 0.075$ and $R^2 = 0.1238$. This indicates a increase in the number of Storks recorded within the study area over the last +/- 18 years.

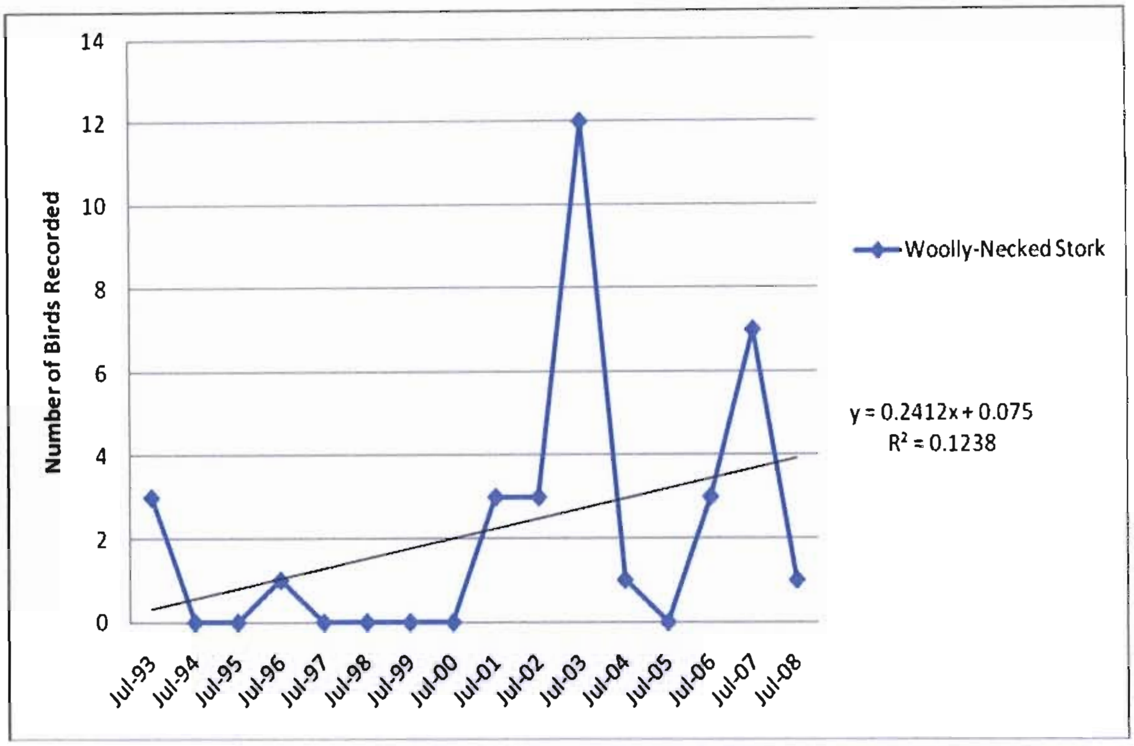

Figure 43: Winter Surveys - Increase in Woolly-Necked Stork Population

5.16. Beach and Sand Bank Avian Indicator Species

Beach and Sand Bank indicator populations indicated signs of decline within the study period as illustrated in Appendix A and C. However, the reliability of the avian census data for these specific wetland bird species is questionable due to regular inconsistencies.

Table 25: A Summary Table of the Number of Dune and Shoreline Avian Indicators Recorded between 1993-2008

Avian Indicator Species	Jan-93	Jul-93	Jan-97	Jul-97	Jan-03	Jul-03	Jan-08	Jul-08
GH Gull	963	2	368	158	412	230	169	75
Caspian	1	4	5	4	2	3	0	2
Swift Tern	77	16	42	91	0	180	58	307

Figure 44 below graphically represents the number of birds recorded during the summer periods against time. This figure indicates that there is no linear correlation between the values. It also reveals the existence of an outlier which calls into question the reliability of the census data for this bird species. In January 1999, a total of ten Caspian Terns were recorded during an avian survey. The researcher had doubts about the reliability of this avian data set, and the avian data obtained for all the bird species selected as Beach and Sand Bank Indicators. However, as the data obtained from the Avian Demographical Unit (UCT) was the only avain census data for the study area over consecutive years, the researcher decided to continue the assessment with these inconsistencies and concerns in mind.

The researcher identified a couple of reasons for the inconsistencies in the avian census data of Swift Terns, Caspian Terns and Grey-Headed Gulls. These include:

- Firstly, confusion during the identification process by the birders leading to the misidentification of a particular bird species. For example, another common large tern species could be misidentified as a Caspian Tern.
- Secondly, the large numbers of birds recorded during surveys over the last two decades calls into question the accuracy of these counts. The establishment of an accurate number of small, active and mobile bird species such as Gulls and Terns within a large study area is challenging. Counts of birds are often conducted over great distances through binoculars and other viewing equipment, and determining the exact number of bird's present is extremely difficult.

Figure 45 represents the number of Caspian Terns recorded plotted against established time period of the study. This figure reflects a weak negative linear trend with the regression equation of $\hat{y}= -0.2059x + 4.125$ with $R^2 = 0.1445$. The decline of Caspian Tern and Grey-Headed Gull populations is due to a decrease in the quality and quantity of roosting habitats (beaches and sand banks. The increase in the numbers of feral cats and dogs within the study area denies these birds access to secure roosting sights. The increase in predation by cats on terns and gulls was confirmed during the conduction of field surveys. The researcher witnessed feral cats catching and consuming gulls and terns on five seperate occassions during the cause of this study. Piles of bones and scattered feathers were also found near the beach and sand banks, abjacent to the Beachwood Mangrove Swamp Nature Reserve. The bones and feathers were confirmed as belonging to gull and tern species by local conservation offical (Gillard, 2008). Orithologists expressed their concern about the influx of feral and domesticed cats into the lower esturine and mangrove ecosystem seeking food in the form of scraps and left over bait from fisherman and food stalls (Allen,2008). This increase in cat numbers within the study area is evidently also threatening wetland bird populations.

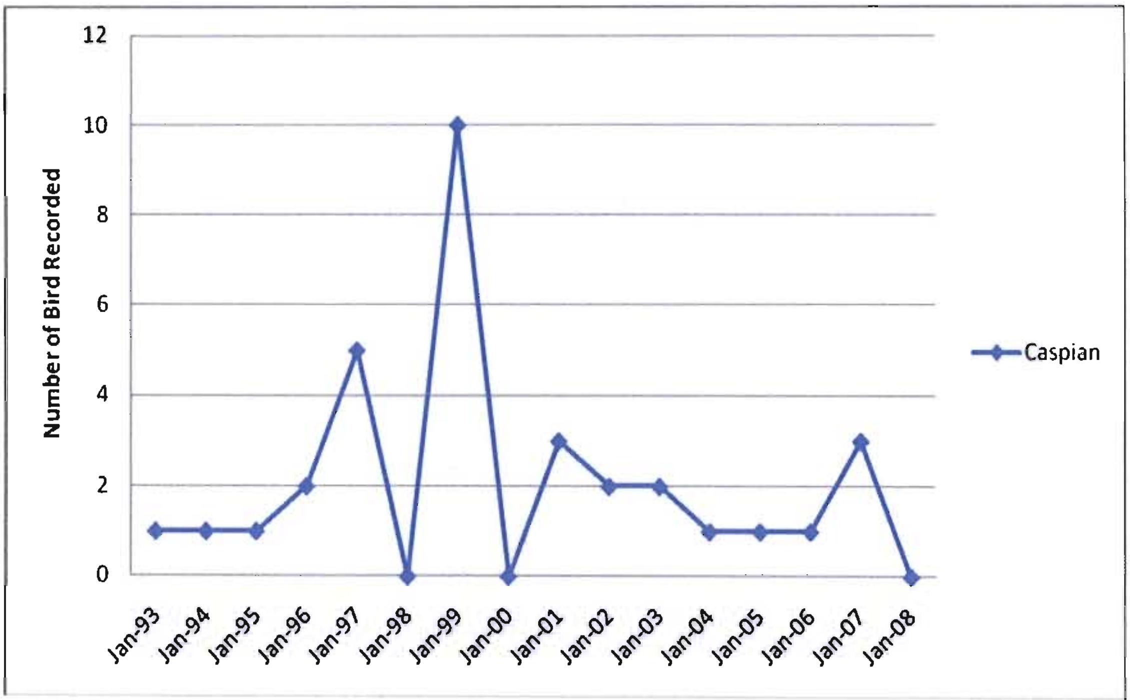

Figure 44: Summer Surveys - Decline in Caspian Tern Population

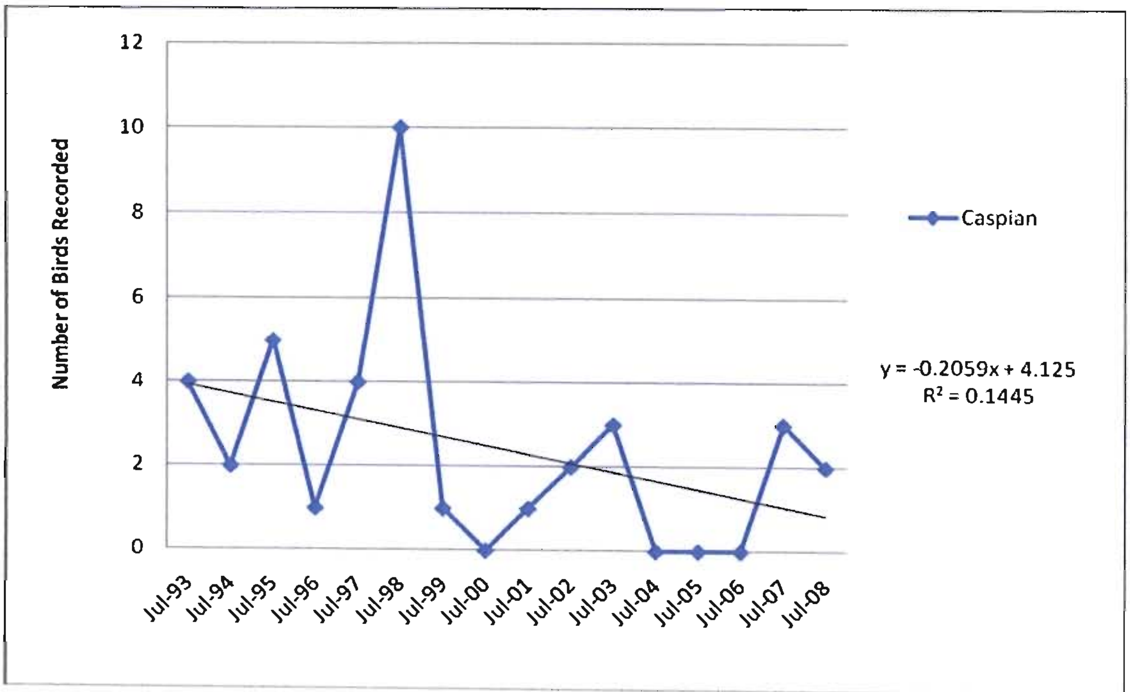

Figure 45: Winter Surveys - Decline in Caspian Tern Population

Regular disturbances by humans travelling through the ecosystem tend to discourage sensitive bird species.

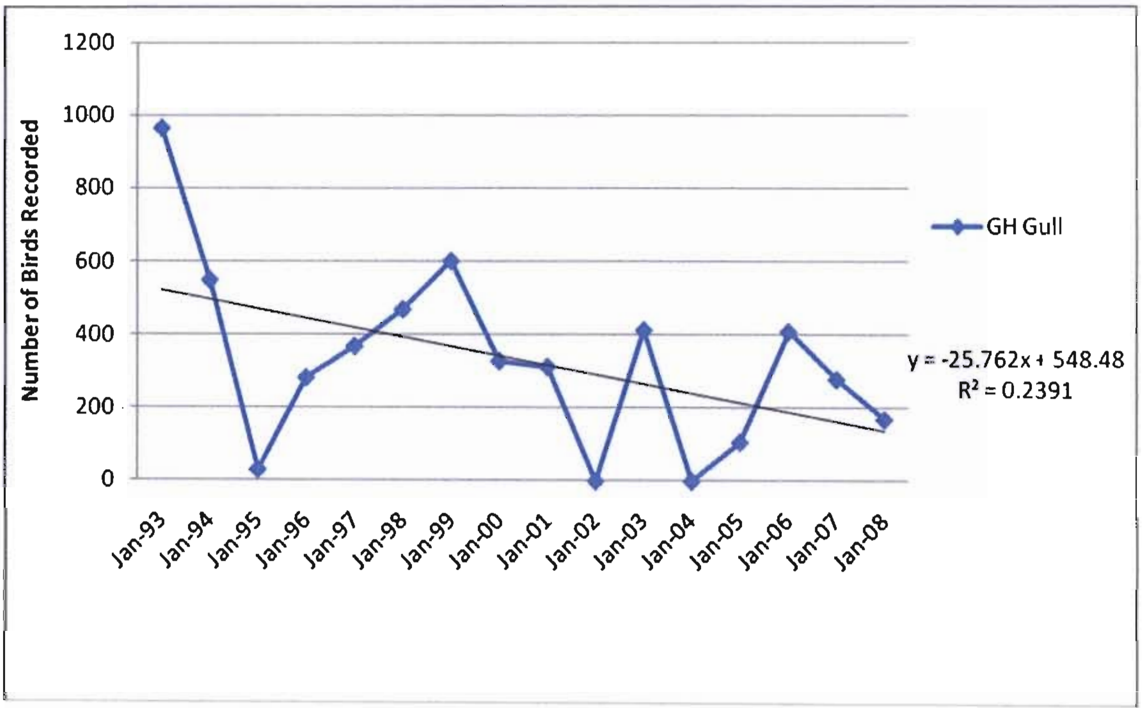

Figure 46: Summer Surveys - Decline in Grey-Headed Gull Population

Plate 39: Caspian Tern (*Hydroprogne caspia*)

The 2003 survey recorded 642 Gulls and 5 Terns within the study area (Table 26). The decline in Grey Headed Gulls and Caspian Tern populations was evident in the 2008 survey which indicated that 244 gulls and 2 terns were seen by ornithologists.

Plate 40: Grey Headed Gull (*Larus cirrocephalus*)

Figure 46 above displays a weak negtaive linear trend with a regression equation of $\hat{y}$ = -25.762x + 548.48 with R^2 = 0.2391. This indicates that the numbers of Gulls are declining during the summer months. Meanwhile, Figure 47 below portrays the number of birds recorded plotted against time period. This figure shows weak positive linear trend with regression equation given by $\hat{y}$= 6.3824x + 11.375 and R^2 = 0.1933. Grey-Headed Gull population showed signs that is has increased during the winter period according to surveys and this is evident in the figure below. Local ornithologists concluded that this increase in population could be due to ideal foraging and roosting conditions within the study area during the winter period. Should conditions within a particular habitat deteriorate or conditions within another habitat in another area become more attractive than others, birds will relocate/migrate to these more favourable habitats in significant numbers to take advantage of such conditions.

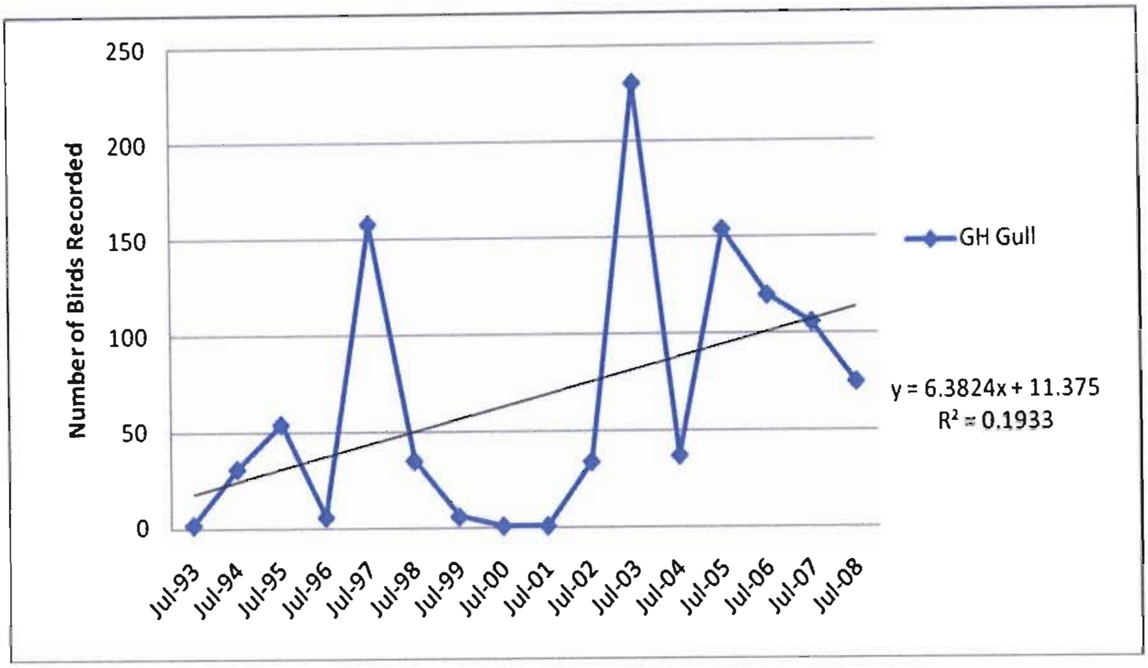

Figure 47: Winter Surveys - Increase in Grey-Headed Gull Population

Plate 41: Swift Tern (*Sterna bengii*)

Examination of Figure C6 of Appendix C will indicate a steady increase in the Swift Tern population within the Mgeni Estuary and Beachwood Mangrove Swamps. This increase in the number of birds observed during the summer period in particular, is directly linked to the increase in food supply, and an increase in the quality and quantity of foraging habiats (Allen,2008).

Figure 48 below displays the number of Swift Terns recorded during the surveys against the established time index. There is no linear correlation between the values in this case.

Inconsistencies in the number of birds recorded during surveys have contributed to this situation and could be the result of human error.

Figure 49 indicates that there is a strong positive linear trend with a regression equation of $\hat{y} = 13.291x + 14.4$ and a $R^2 = 0.6465$. This has established that as one variable changes, the other variable will change in a similar manner which indicates that the population of Swift Terns is progressively increasing over the establish time period. Ornithologists counted 93 terns during 1993, and 133 in 1997. In 2003 the number of birds recorded had grown to 180 individuals. The last count in July 2008 recorded 300 terns within the study area – a dramatic increase.

Ornithologists conclude that increased instances of disturbance caused by humans and their pets visiting or travelling through the estuarine and mangrove ecosystem during the summer holidays scares away waterbirds. Swift Terns are a retiring and shy tern species and generally avoid roosting or foraging in areas frequented by fisherman, canoeist, beach-goers and their dogs (Allen, 2008).

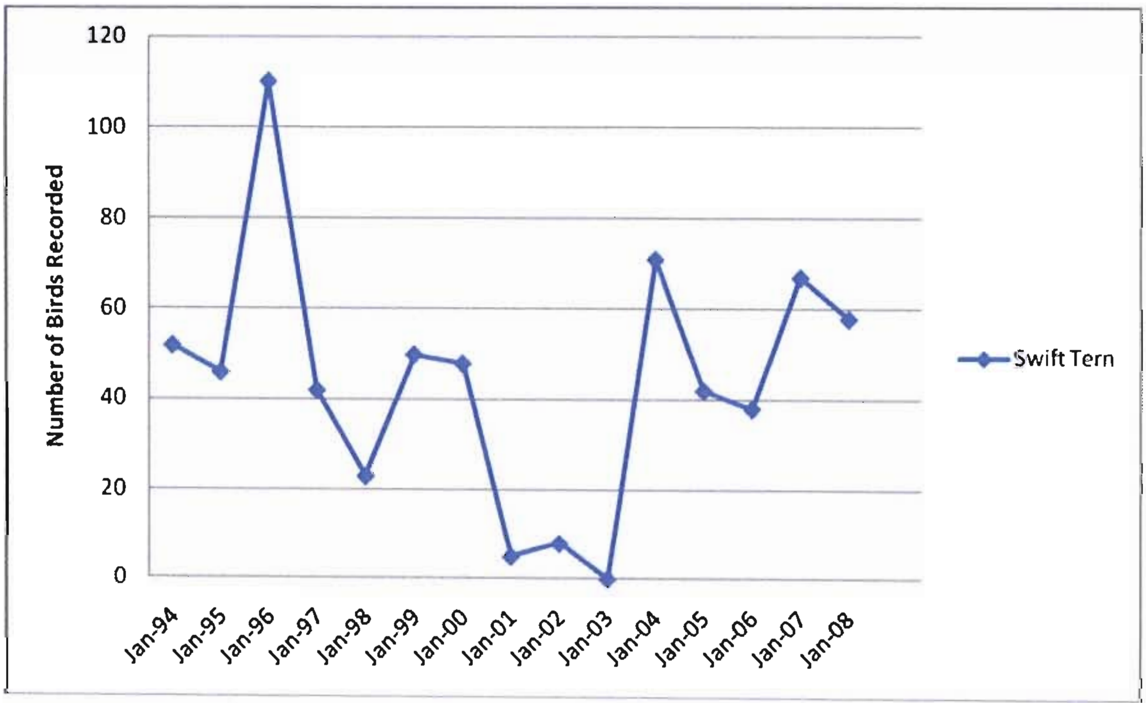

Figure 48: Summer Surveys - Swift Tern Population

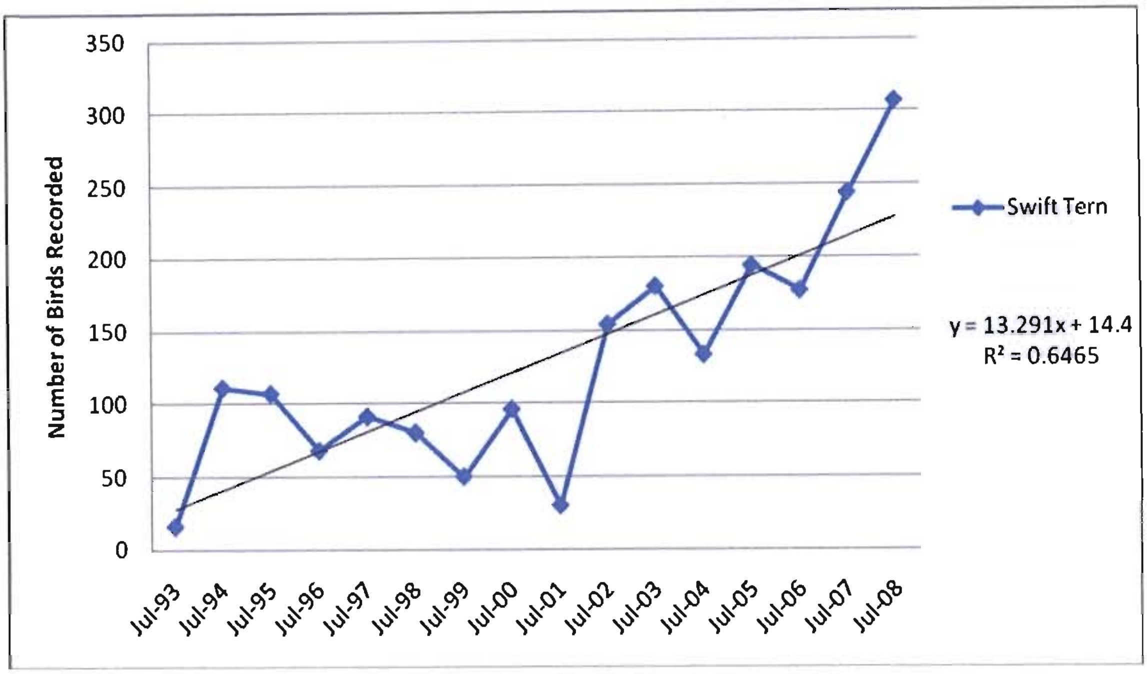

Figure 49: Winter Surveys - Increase in Swift Tern Population

5.17. Relationship between Changes in Land Cover and Avian Indicator Numbers

The comparison between *CWAC Wetland Bird Census* data and aerial imagery revealed several interesting trends, notably the decline in certain wetland bird indicators, and the decline in their preferred foraging, roosting and reproductive habitats within the Mgeni Estuary and Beachwood Mangrove Swamp study area; whereas other indicator species showed populations gradually increasing in relation to related land cover changes.

5.18. Stabilisation of Vegetated Islands and Shoreline Vegetation, and the Increase in Vegetable Areas and Shoreline Zone Indicator Bird Species

The examination and comparison of the aerial imagery against related avian census data, captured between 1991 and 2008, indicates that the increase in sightings of vegetation dependent water bird species within the study area can be linked to the stabilization of the estuarine shoreline and islands through the process of plant colonization, consolidation and expansion. Estuaries that are fringed by reed beds, marshes and mangrove swamps provide a valuable service to the estuarine ecosystem.

The water that drains from the Mgeni Catchment area carries suspended sediment and nutrients. This water eventually enters the Mgeni Estuary, and flows into the shallow water channels that dissect the chain of estuarine islands. The flat estuary is characterised by a lowering of the water velocity, and help reeds, grasses, sedges and mangrove tree clusters take root and filter out nutrients and sediment from the water (Gillard, 2008). Scientists indicate that mangrove tree roots assist in the removal of sediment and help protect the islands from water erosion and scouring flood waters. Mangrove vegetation helps stabilise the islands and allows other vegetation with shallower root systems to become established. Over time, the deposition of sediment decreases the depth of the river channels around the islands, forming new mudflats which are eventually colonized by reeds, sedge and grass species that in turn help prevent further erosion by stabilizing the growing shoreline (Garland and Moleko, 2000). This concept will be discussed in more detail later in this chapter.

Plates 44 and 48 graphically illustrate the land cover changes that have occurred within the Mgeni Estuary and Beachwood Swamp study area between 1991 and 2008. The comparative plates represent these changes in land cover increases or decreases, relative to the precise location of the 1991 land cover 'core' – the basis against which all land cover change can be measured. For example, the core of the mangrove forest is represented in pale green, whereas an area where the mangrove swamp has increased or decreased is represented by light green and red respectively. This method of mapping was developed to graphically represent significant changes in various land cover types during the study period. When such data is compared against avian census data, it is possible to correlate and interpret indicator bird population changes against related land cover trends during the study period.

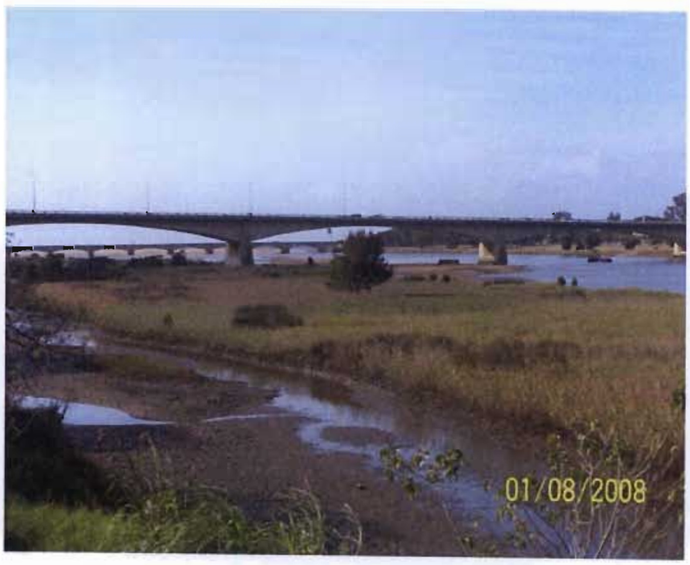

Plate 42: Mangrove Seedlings, Reeds and Grass Species on Island in the Mgeni Estuary

Island mangrove vegetation, reed beds, marshes and grasslands have all managed to successfully colonize, consolidate and expand their area coverage of the islands and estuarine shoreline along a significant portion of the Mgeni Estuary as seen in Figure 41. In 1991, Reed Beds and Grassland habitats covered 4.51 ha (2.8%) of the study area. However, by 2008 it covered 9.6 ha (6.0%) of the study area which is an increase in total land coverage of 4.8%. Reed Bed and Marsh habitats covered an estimated 10.64 ha (6.7%) of the study area in 1991. However, as reed beds and marshes progressively reverted to reed beds with mixed sedge and grass species, the area covered by this land cover type decreased to 9.60 ha (6.4%) of the study area.

Established vegetation also showed signs of densification. The increase in vegetation cover represented by the reed beds, grasslands and mangrove clusters on estuarine islands and along estuary shore lines, have all combined to create an ideal habitat for wetland bird species that primarily rely upon reed beds, marshes and other vegetated covers for roosting, foraging and procreation. This makes the Mgeni Estuary and adjacent Beachwood Mangrove Swamps study area an ideal habitat for skulking bird species such as Purple Heron and Water Dikkop (See Appendix F). These species spend much of their lives in structurally complex habitats such as reed beds, marshes and mangrove clusters that make locating and identifying them during census conditions challenging.

The Purple Heron is seldom seen because it tends to favour dense vegetation close to the water's edge, and prefers to forage within this habitat or along the channels and waterways flowing through such vegetation. The Purple Heron is rarely seen foraging for its prey out in the open like other heron species. Ornithologists mention that this species is particularly fond of *Phragmites* Reed beds found in abundance along the estuarine shoreline and island networks. Conversely, the Water Dikkop is a common nocturnal wetland bird species that is found along the banks of large rivers, lakes, dams, estuaries and lagoons where there is a dense fringe of vegetation. Water Dikkop can be found lying up during the day in reed beds, or underneath overhanging bushes, trees and other vegetation along the water's edge.

Examination of the avian census data indicated that numbers of Water Dikkop, Purple Heron and Woolly-Necked Storks (skulking bird species) observed and recorded within the Mgeni Estuary and Beachwood Mangrove Swamp had increased steadily between 1993 and 2008. The increase in the populations of these 3 species, strongly correlate to the noted increase in related vegetation cover on the estuary islands and shorelines.

Figures 50 below shows the number of Purple Herons recorded plotted against the area covered by reed beds, marshes and grassland land cover classes within the study area. It is obvious from examining the figure below that the Purple Heron numbers within the study area have remained relatively stable between 1991 and 2008. This indicates that the population of Purple Heron has not been positively or negatively affected by the increase in the area coverage of reed beds, marshes and grassland land cover classes within the study area.

Figure 51 graphically represents the number of Woolly-Necked Storks recorded within the study area plotted against the changes in the total area covered by reed beds, marshes and grassland land cover classes. The figure indicates a correlation coefficient of 0, thus changes in the variables are also random and unpredictable. Therefore, it is difficult to establish an indisputable link between changes in the area coverage of the land cover classes and the fluctuation in this avian indicator population.

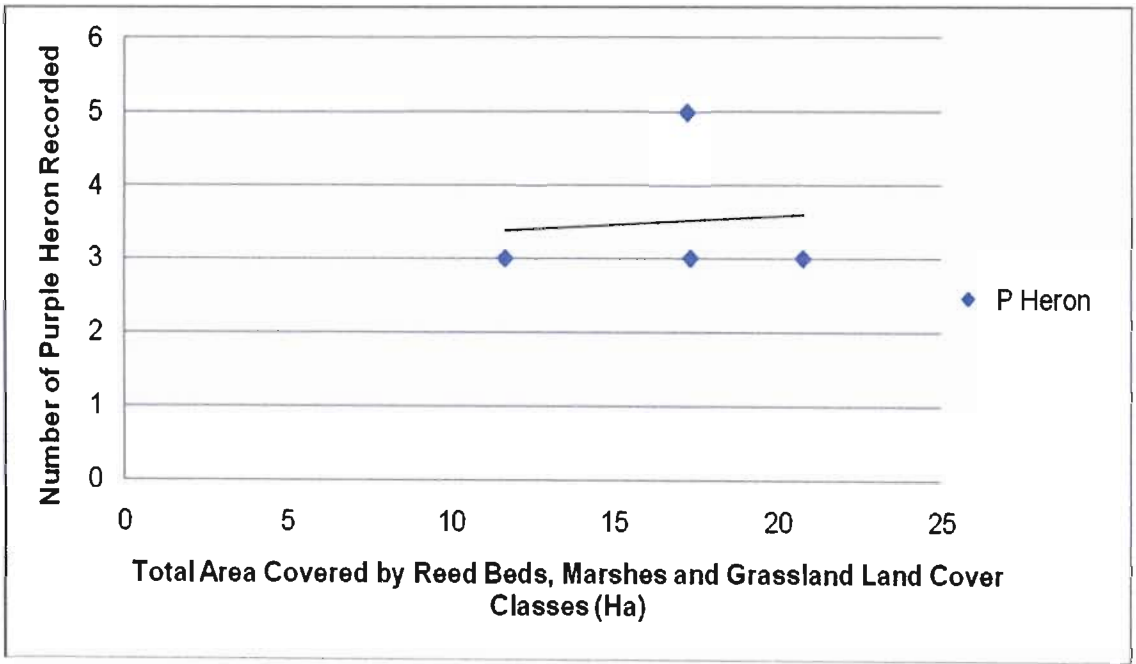

Figure 50: Correlation between Land Cover Change and Fluctuations in Purple Heron Populations

Table 26: Values of the Dependent and Independent Variables A

Variables	Years			
	1991	1997	2003	2008
Area Coverage of Reed Beds, Marshes and Grassland Land Cover Classes(Ha)	16.15	20.76	17.22	19.3
Number of Water Dikkop Recorded	2	16	3	17

Figure 52 illustrates plots the number of Water Dikkop recorded during avian surveys, against changes in the total area covered by reed beds, marshes and grassland habitats. Table 26 above illustrates the values of the dependent and independent variables. The figure displays a moderately positive linear trend with a regression equation of $\hat{y}= 1.5352x - 16.192$ with $R^2 = 0.5113$. A correlation coefficient of +0.5113 indicates that a change in the independent variable should result in a comparable increase in the dependent variable. Therefore, it can be reasonably deduced that the increase in the area covered by reed beds, marshes and grassland is contributing to an increase in the numbers of Water Dikkop within the study area.

Plate 43: Reed Beds on Mgeni Estuary Island

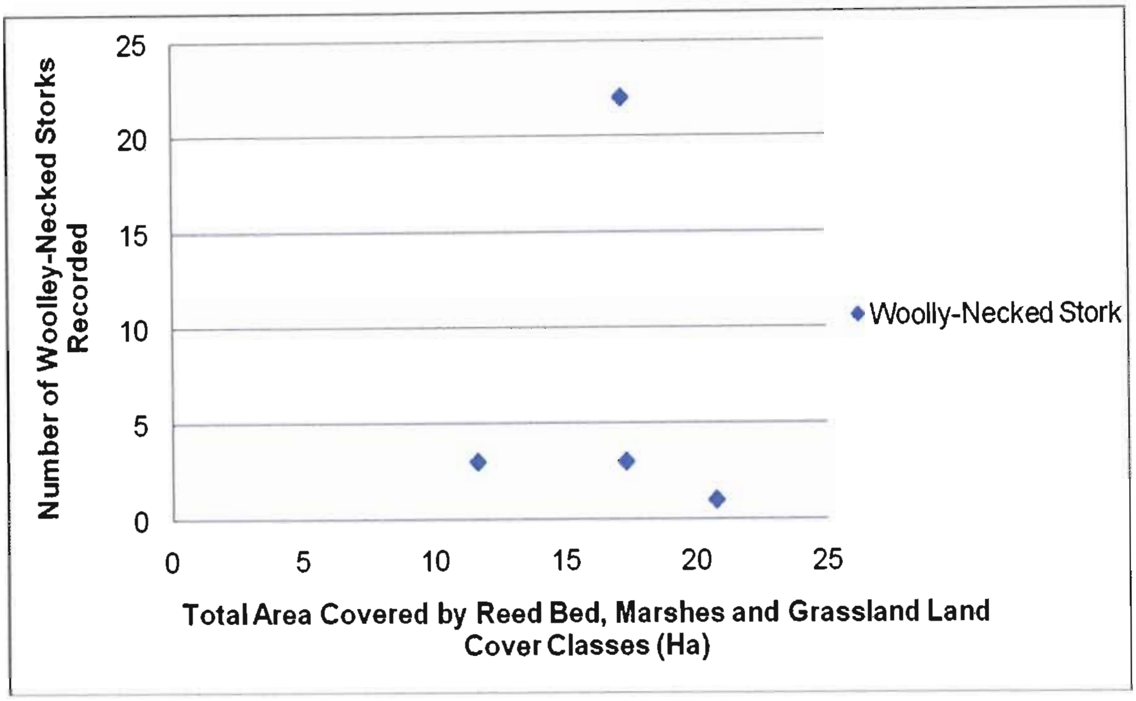

Figure 51: Correlation between Land Cover Change and Fluctuations in Woolley-Necked Stork Populations

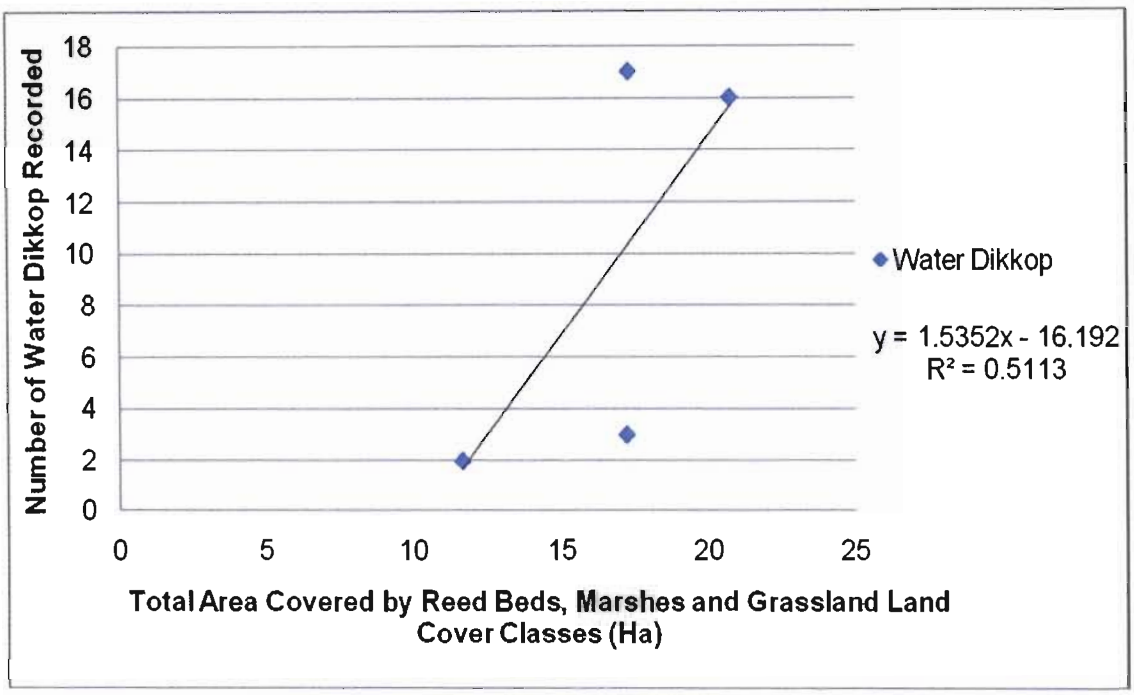

Figure 52: Correlation between Land Cover Change and Fluctuations in Water Dikkop Populations

In conclusion, the findings of this study indicate that Purple Heron population remained relatively constant and unaffected by the changes in the area coverage of reed beds, marshes and grassland land cover classes. In addition, fluctuations in the population of Woolley-Necked Storks cannot be indisputably linked to the changes in the area coverage of the land cover classes. However, evidence suggests that fluctuations in the Water Dikkop population were strongly linked to changes in the area covered by vegetated area land cover classes. This indicates that Water Dikkop are ideal reed bed, marsh and grassland indicator species.

5.19. Decline in Grassland and Scrub Land Cover Class

The grassland and scrub land cover class is showing signs of decline. As already noted, in 1991 this land cover class covered approximately 13.21 ha of the study area. This shrunk to just 3.52 ha by 2008. This decline is attributed to the expansion of woodland and coastal forest land cover classes into areas previous designated as grassland and scrub due to the absence of a regular fire regime and logging within the study area.

Table 27: Values of Dependent and Independent Variable B

Variables	Years			
	1991	**1997**	**2003**	**2008**
Area Coverage of Grassland and Scrub Land Cover Class (Ha)	13.21	11.51	3.47	3.52
Area Coverage of Coastal Forest Land Cover Class (Ha)	7.12	5.69	14.07	14.06
Area Coverage of Woodland Land Cover Class (Ha)	4.69	4.19	10.91	8.26

Figures 53 and 54 below illustrate changes in the total area of grassland and scrub plotted against changes in the total areas covered by woodland and coastal forest. Table 27 displays the values of the dependent and independent variables used to generate the figures below. Figure 53 displays a strong negative linear trend with a regression equation of $\hat{y}$ = -1.1171x + 19.361 and R^2 = 0.9309. This reveals that as coastal forest expands, grassland and scrub areas will decline.

Figure 54 plots changes in the total area covered by grassland and scrub land cover class against the changes in total area covered by woodland land cover class. The figure reveals a strong negative linear trend with an equation of $\hat{y}$ = -1.503x + 18.467 and R^2 = 0.8498. This figure illustrates a similar relationship as Figure 53, where the expansion of woodland areas within the study area is actually having a negative impact upon grassland and scrub habitats.

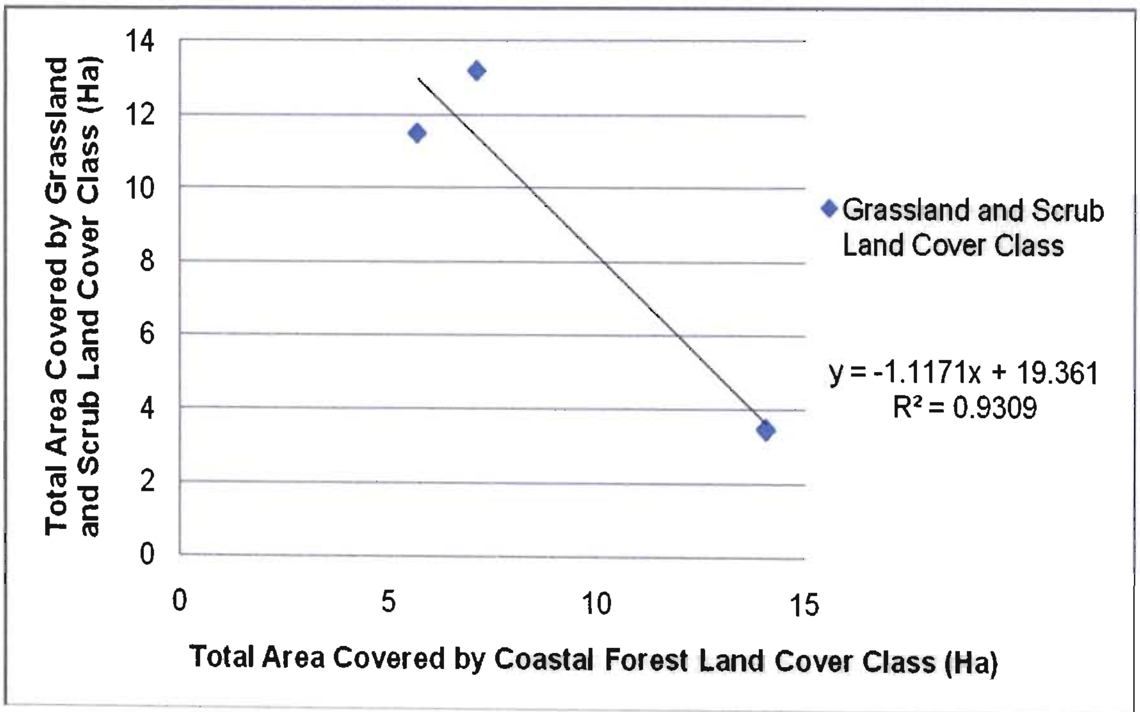

Figure 53: Illustrating Relationship between Changes in Land Cover Classes within Study Area (1991-2003)

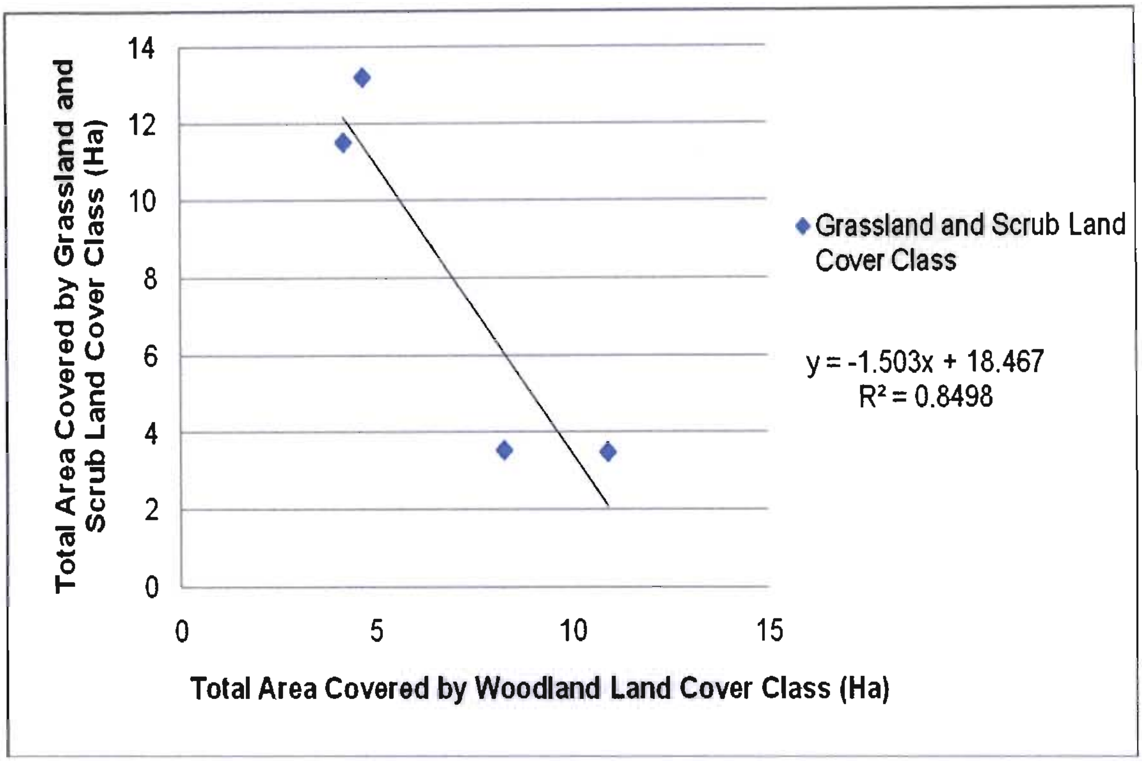

Figure 54: Illustrating Relationship between Changes in Land Cover Classes within Study Area (1991-2003)

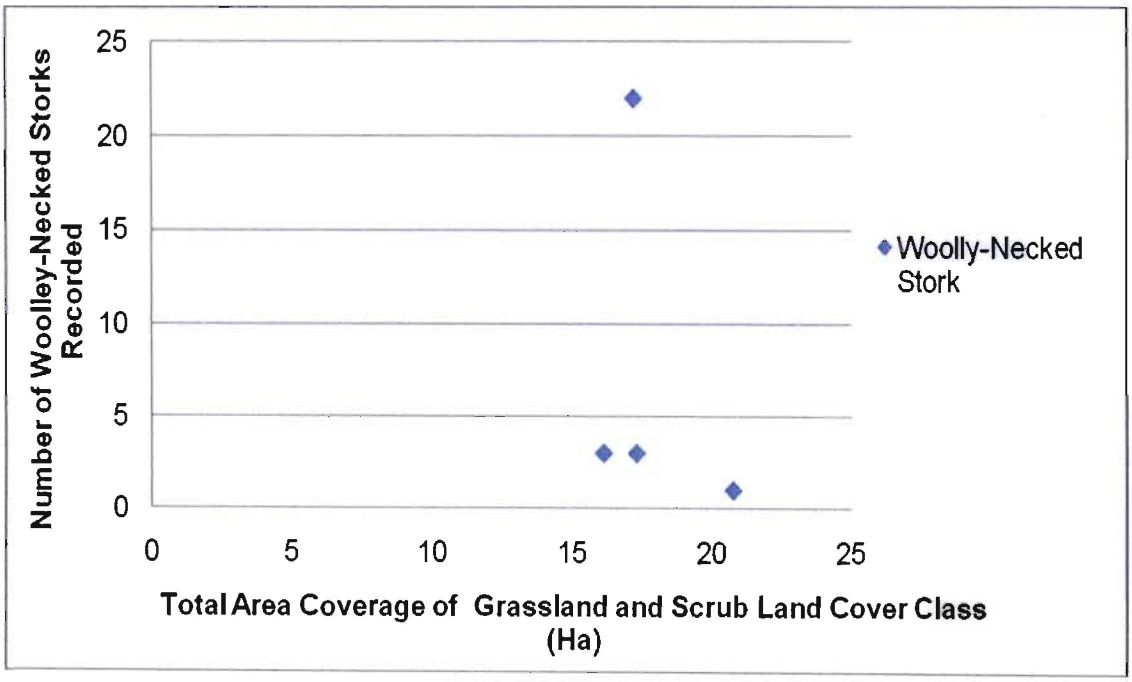

Figure 55: Illustrating Number of Woolley-Necked Stork Recorded Plotted Against Grassland and Scrub Land Cover Class (1991-2003)

Woolley-Necked Storks and Water Dikkop can often be observed in Grassland and Scrub habitats during visits to the Mgeni Estuary and Beachwood Mangrove Swamps. Storks and Dikkops tend to forage in open grass areas.

Figure 55 shows the number of Woolley-Necked Storks recorded plotted against the total area covered by the grassland and scrub land cover class. A correlation coefficient of 0 indicates that the changes that occur in the independent and dependent variables are random and unrelated. There is no relationship between the variables and thus no linear correlation.

Therefore, despite the decline in the area covered by grassland and scrub, Woolley-Necked Stork numbers are gradually increasing within the study area in which they do not roost and breed. This species simply visits vegetated areas within the study area because they are ideal foraging locations (See Appendix F). Therefore, land cover change within the study area would not have an impact on their population because of their ability to move freely between a wide variety of different land cover classes and sub-classes found in other grassland, riverine, estuarine and wetland ecosystems scattered throughout the greater eThekweni area. This suggests that this bird species is not a good indicator species.

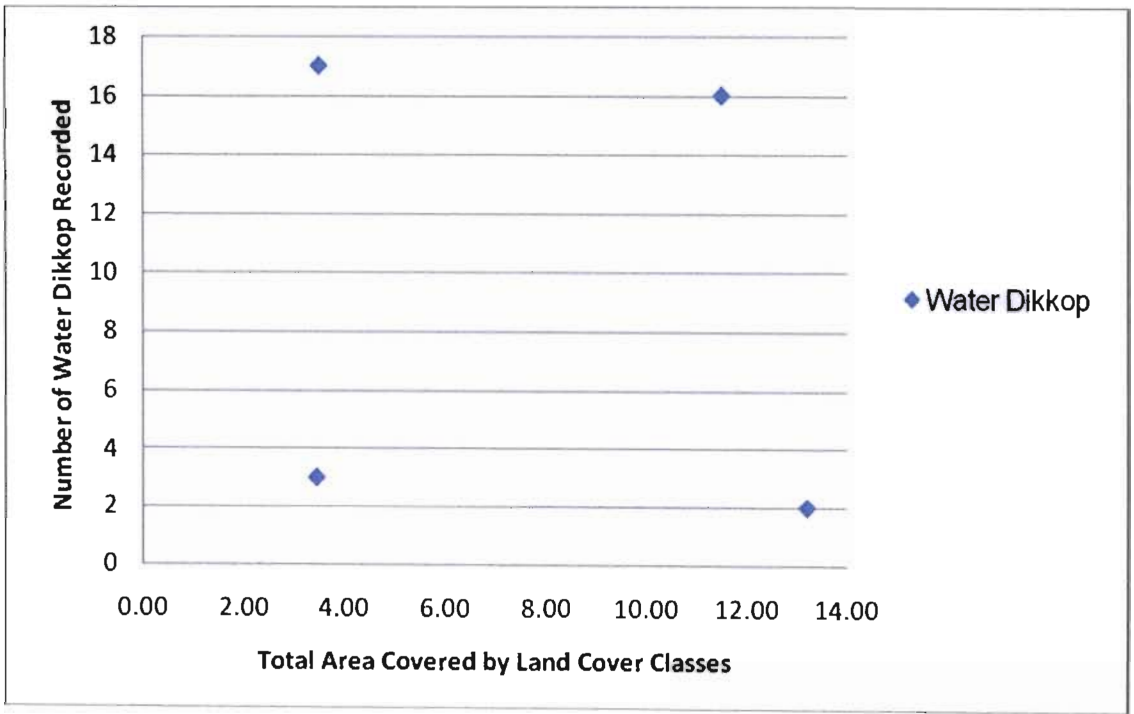

Figure 56: Illustrating Number of Water Dikkop Recorded Plotted Against Grassland and Scrub Land Cover Class (1991-2003)

Figure 56 above graphically illustrates the number of Water Dikkop counted during avian surveys plotted against the total area covered by the grassland and scrub land cover class. However, there is no strong linear correlation between the values which suggest that establishing a incontrovertible link between the flucutations in populations of Water Dikkop and changes in the area coverage of grassland and scrub land cover class is difficult.

The decline in the grassland and scrub land cover class did not had a negative impact on Woolley-Necked Stork and Water Dikkop indicator populations due to their use of a wide range of other land cover classes for foraging, roosting and reproduction within the study area. This suggests that these bird species that were selected as avian indicators for this particular land cover class, are adaptive and can utilise a wide vareity of different habitats. This means that these bird species are not good indicators species for this land cover class.

5.20. Expansion of Island Mangrove Land Cover Class and Impact of Vegetated Avian Indicator Populations

In 1991 island mangrove clusters scattered throughout the island chain, and along the shoreline of the ecosystems initially accounted for 1.38 ha (0.8%) of the study area. However, as conditions in the estuary and mangrove swamps became more idyllic for mangrove vegetation growth, island and shoreline mangrove clusters gradually increased to an area of 3.17 ha (2.0%). This represents a significant land cover change in terms of this study. Plates 44 and 48 clearly illustrate the expansion of these mangrove clusters within the study area between 1991 and 2003.

Table 28: The Values of the Dependent and Independent Variables C

Variables	**Years**			
	1991	**1997**	**2003**	**2008**
Area Coverage of Exposed Mudflat Land Cover Class (Ha)	16.51	14	11.54	4.25

Area Coverage of Island Mangrove Land Cover Class (Ha)	1.38	0.52	1.53	3.17

Figure 57 below illustrates the total area covered by island mangrove vegetation land cover class plotted against the total area covered by exposed mudflat land cover class. The figure shows a negative linear trend with a regression equation of $\hat{y} = -4.1372x + 18.401$ and $R^2 = 0.7497$. There is a negative correlation coefficient like -0.7497 which means that the two variables will respond in opposite directions. While the one increases, the other variable will decrease. Therefore, the decline in the area coverage of the exposed mudflat land cover class can be linked to the gradual expansion of island mangrove vegetation.

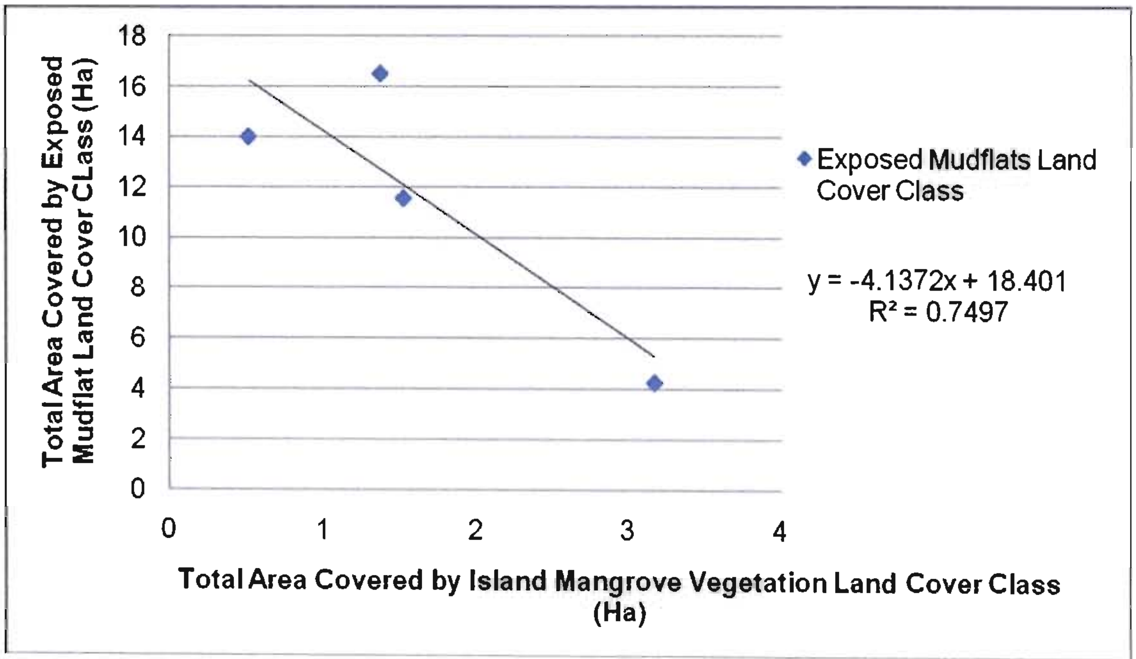

Figure 57: Island Mangrove Vegetation and Exposed Mudflat Land Coverage (1991-2008)

Figure 58 below shows the number of Purple Heron recorded plotted against the total area covered by island mangrove land cover class. The figure indicates that the Heron population has not fluctuated significantly and has remained relatively constant over the time period.

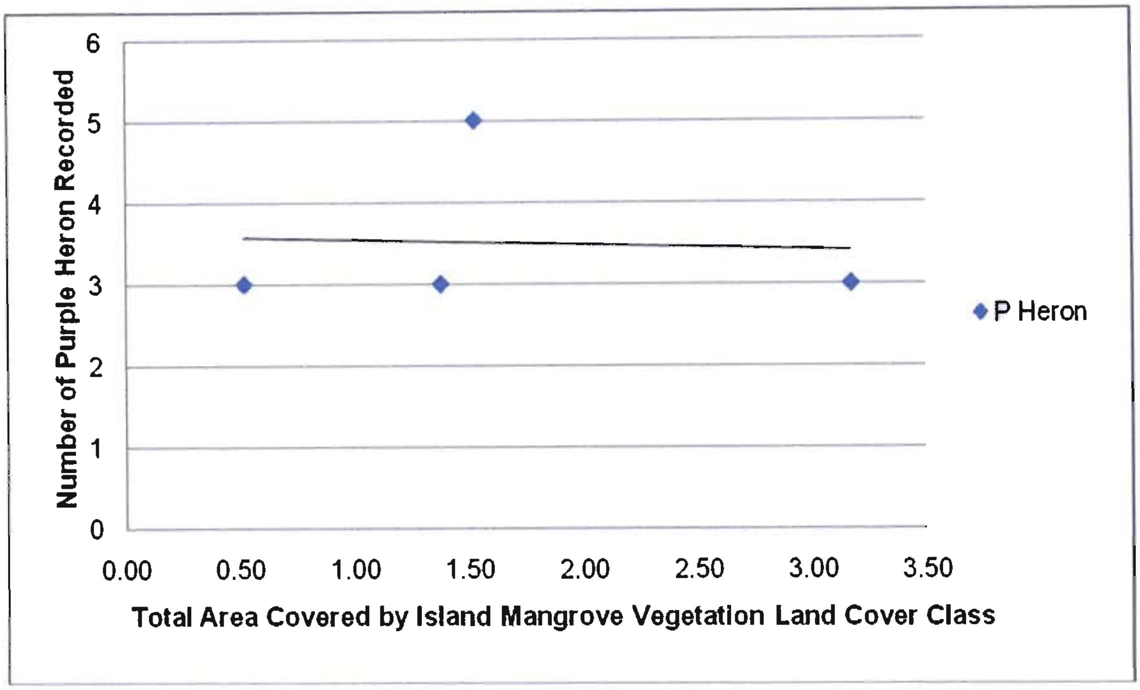

Figure 58: Correlation between Land Cover Change and Fluctuations in Purple Heron Population

Figure 59 indicates that the numbers of Woolly-Necked Storks seen within the study area have not fluctuated much over the last eighteen years. The population has remained relatively constant. Therefore, changes in the area coverage of island mangrove vegetation have not impacted upon the Woolley-Necked Stork population.

Figure 60, however, shows that changes in the variables (Water Dikkop numbers and area covered by island mangrove vegetation) appear to be random and no relationship exists between the values. It can therefore be assumed that there is no relationship between the increase in the area covered by island mangrove vegetation and the increase in vegetated area avian indicators.

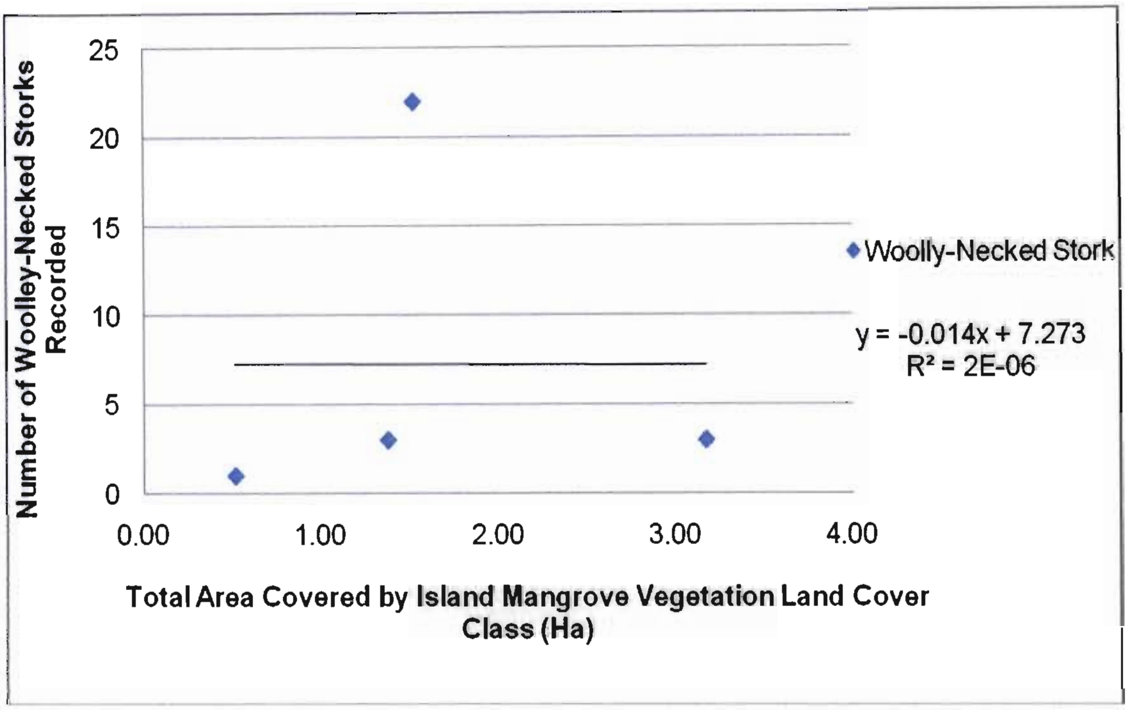

Figure 59: Correlation between Land Cover Change and Fluctuations in Woolley-Necked Stork Population

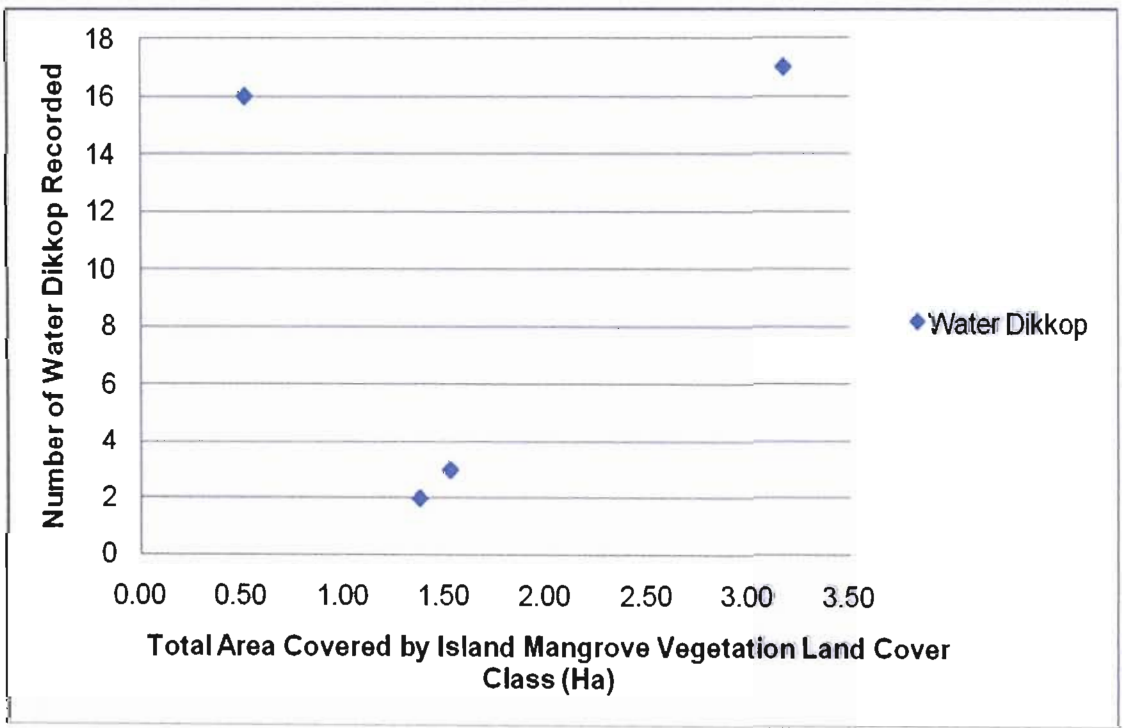

Figure 60: Correlation between Land Cover Change and Fluctuations in Water Dikkop Population

In conclusion, the expansion of mangrove vegetation is having a detrimental impact on the mudflat land cover class throughout the lower part of the Mgeni Estuary. The increase in the area covered by mangrove vegetation is clealry evident in Plates 43 and 46. Figure 57 graphically illustartes the decline of exposed mudflats due to the colonisation and expansion of mangrove vegetaion through the chain of isalnds and mudflats scattered throught the estuary.Further research found that Purple Heron and Woolley-Necked Stork numbers remain relatively stable and consistent throughout the study period, whilst the area covered by island mangrove vegetation expanded resulting in a decline in exposed mudlfats. This indicates that these avian indicator species were uneffected by the changes in land cover.In addition, the study was unable to provide indistuptable evidence to argue that there is a link between the increase in Water Dikkop populations and the increase in area coverage of island mangrove vegetation. Ornithologists and local conseration officals argue that the increase in the numbers of Water Dikkop within the study area could be a seasonal phenomenon.

5.21. Reduction in Sediment, and the Subsequent Impact on Mudflat, Dune and Shoreline Avian Indicators

The researcher concluded that the decrease in the total area covered by mudflats, beaches and sandbanks within the study area could be due to two factors. Firstly, several studies relating to the annual sediment yield of the Mgeni River were examined. The studies noted that the sediment yield of the river was approximately l-6x 10* tonnes (Garland and Moleko, 2000). However, the construction of five dams within the catchment area has drastically reduced the contemporary sediment yield to the coast. The catchments area below the four main dams that were completed prior to 1987 is estimated to be around 1700 Km2, and the total sediment yield from this area was calculated to be around 0-5 x 10* tonnes per year (Garland and Moleko, 2000).

The completion of the Inanda Dam in 1988 has only exacerbated the situation by altering bed load transportation and deposition. After the completion of the Inanda Dam, the mean annual discharge of the river was significantly reduced (4%). The establishment of a water release policy also had a major impact on the discharge regime which has led to an increase in competent discharge events (Gillard, 2008). Sediment continually builds up behind the dam wall, which has led to a notable reduction in available downstream sediment. Whereas the volume of sediment within the estuary has not changed since 1989, the sediment calibre has become much finer (McCally, 2007).

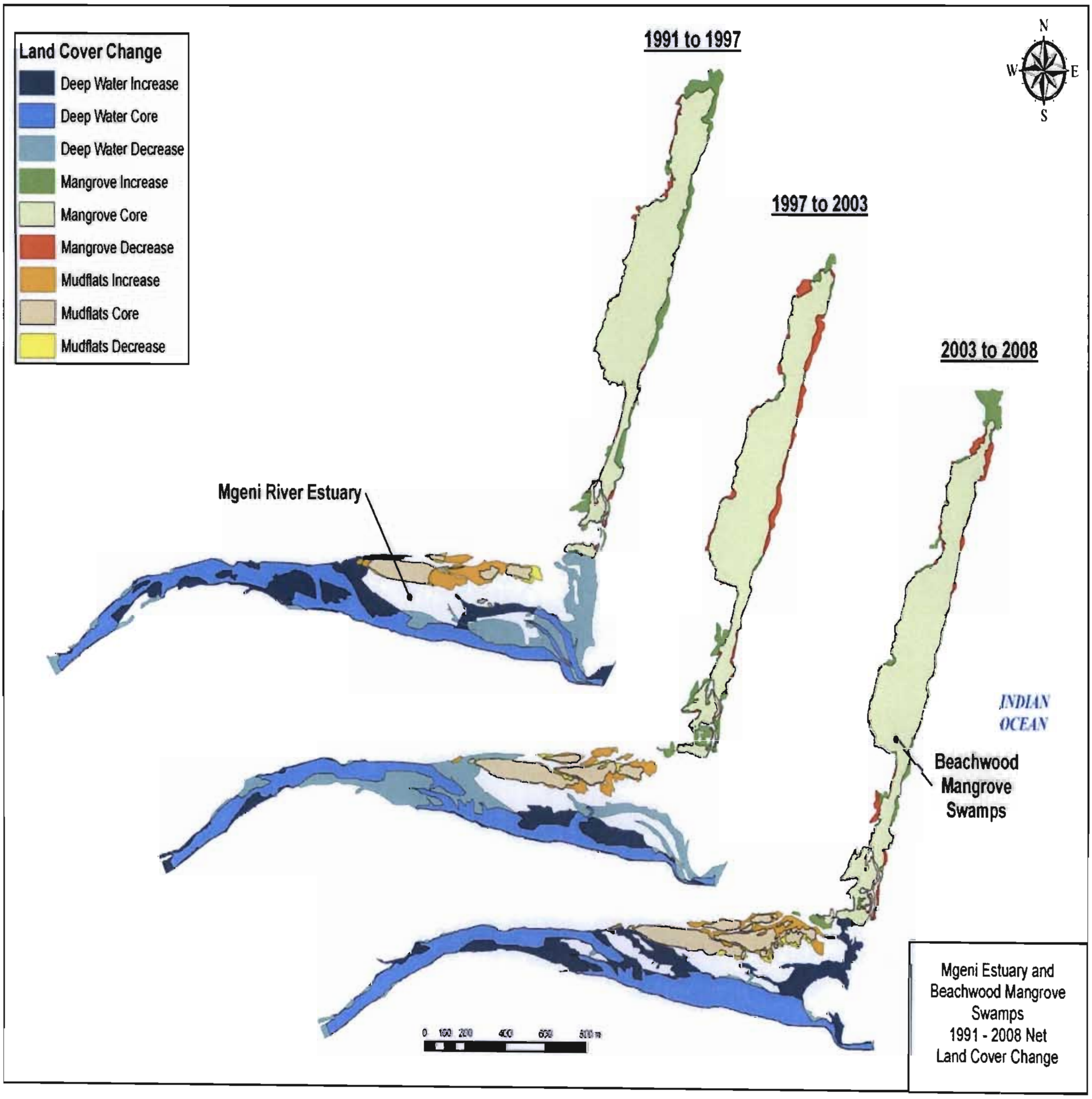

Plate 44: Significant Land Cover Change within the Mgeni Estuary and Beachwood Mangrove Swamps (1991-2008)

Plate 45: Beach near Beachwood Mangrove Swamps

Garland and Moleko (2000) also mentioned that without the natural replenishment of downstream sediment from the upper reaches of the Mgeni Catchment area, sand mining operations below the Inanda Dam will eventually cease. Such activities contribute to the reduction in the amount of sediment being transported downstream towards the Mgeni Estuary and the eThekwini beaches. Eventually, the estuary will begin to deepen, and the mudflats and sand banks will gradually disappear as the coarse pre-dam sediment is eventually flushed out into the Indian Ocean and is replaced by new sediment (Garland and Moleko, 2000). McCally (2007) also indicates that local eThekwini beaches will also be affected as their sediment supply is curtailed (Plate 45).

In 1991, the beach in the vicinity of the Beachwood Mangrove Swamps covered 18.67 ha (11.67%) of the study area. By 2008, the beach accounted for 11.23 ha (7.0%). This is a reduction in total land coverage of 4.67%. Sand Banks have steadily increased in terms of land coverage from 5.48 ha (3.42%) in 1991, to an estimated 8.75 ha (5.4%) in 2008. This is an increase of 1.98% over twenty years. However, when the beach and sand banks land coverage values are combined and analysed, it become apparent that these initial findings, when evaluating the decline of beaches and the progressive increase in the total land coverage of sand banks, do not accurately represent actual land cover changes and their impact on avian indicator species.

Table 29: The Values of Dependent and Independent Variables D

Variables	Years			
	1991	**1997**	**2003**	**2008**
Area Coverage of Exposed Mudflat Land Cover Class (Ha)	16.51	14	11.54	4.25
Number of Beach and Sandbank Avian Indicators Recorded	1063	668	827	611

Table 29 presents the values of the variables used in this Figure 61. This figure indicates that the beach and sand banks are declining slightly in terms of their total land coverage within the study area, and the dune and shoreline avian indicator species numbers also show a decline in population numbers, all of which is illustrated by the trend line in the graph below. This suggests a possible relationship between changes in area coverage of the land cover classes and the fluctuations in avian indicator populations.

The decline in the population of Caspian Terns and Grey Headed Gulls can be the result of a decrease in the quality and quantity of their preferred roosting habitats in the form of sand banks and beaches within the Mgeni Estuary and Beachwood Mangrove Swamp ecosystem. This could possibly be attributed to greater access by land-based predators (cats and dogs) to such beach locations as already stated (See Appendix F). The beaches in the vicinity of the study area are used for recreational purposes such as fishing, canoeing and walking. Such regular disturbances by humans travelling through the sensitive ecosystem may have resulted in indicator species moving away to undisturbed locations (Kalejta and Hockey, 1991).

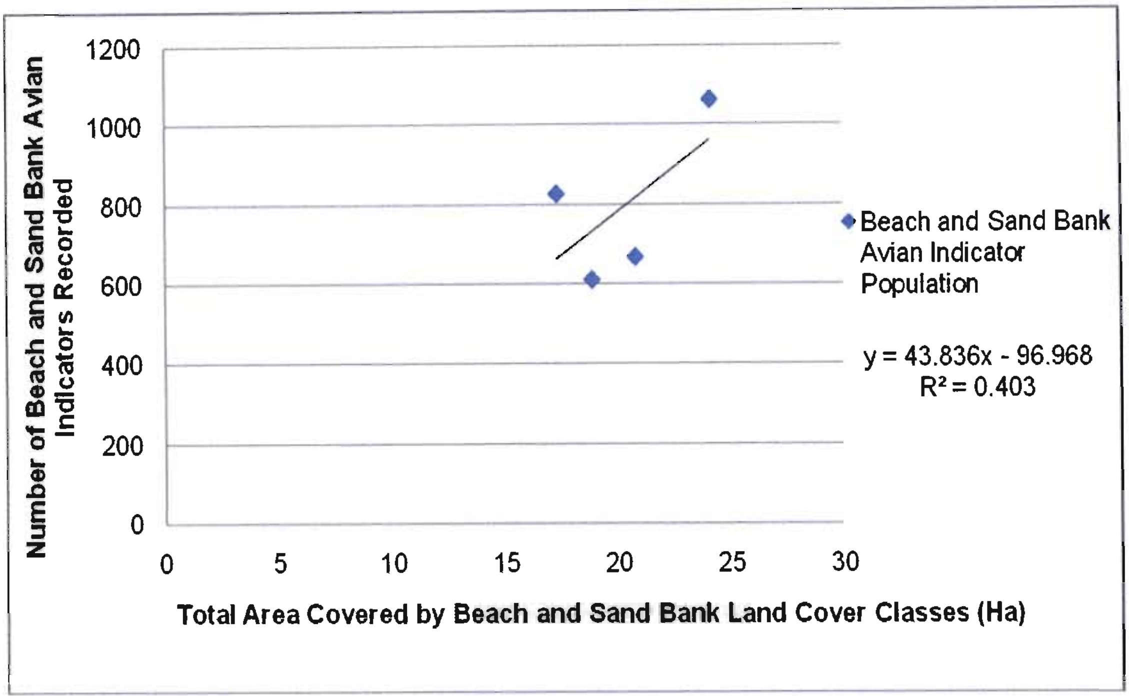

Figure 61: Number of Beach and Sand Bank Avian Indicators Recorded plotted against Total Area Covered by Beach and Sand Bank Land Cover Classes (1991-2008)

Figure 62 graphically represents the number of beach and sand bank avian indicators plotted against the total area covered by beach and sand bank land cover classes between 1991 and 2008. The figure has a moderately strong positive linear trend with a regression equation of $\hat{y} = 43.836x - 96.968$ and $R^2 = 0.403$. This illustrates that there is indeed a possible relationship between the decline in the land cover classes and populations of avian indicators.

The figures below seek to determine if there is a link between the changes in these land cover classes and fluctuations of avian indicator species. Figure 62 displays the number of Caspian Terns recorded plotted against the total area covered by beach and sand bank land cover classes within the study area. However, the figure shows that the variables are random and there is no relationship between them, which means there is no linear correlation.

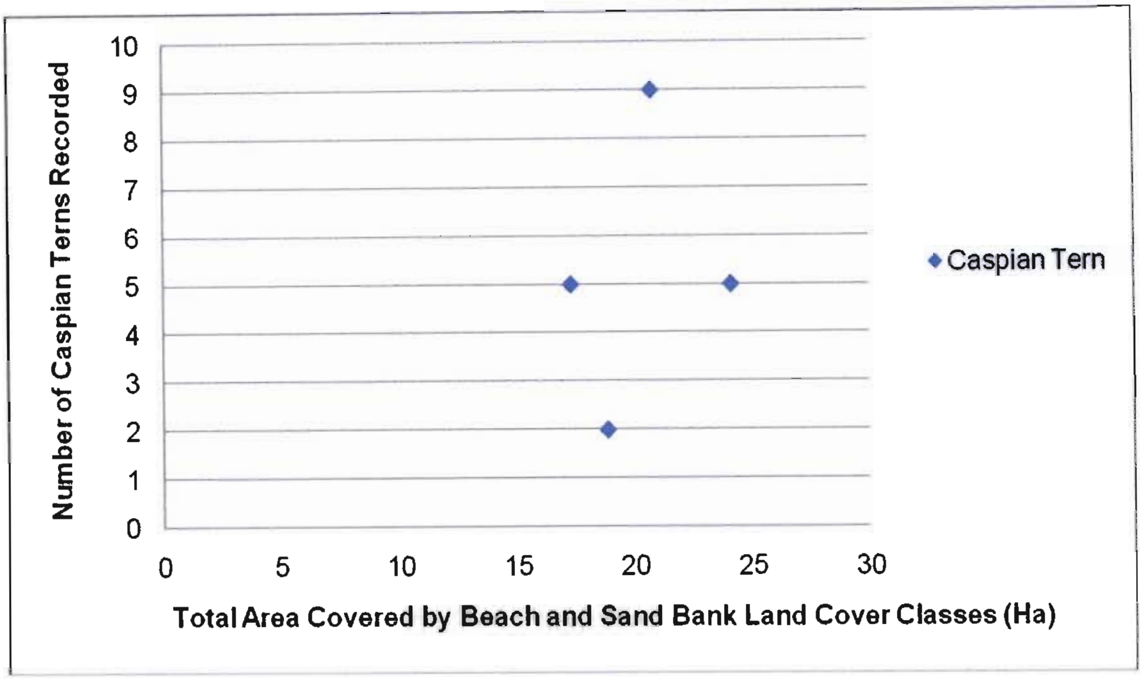

Figure 62: Correlation between Land Cover Change and Fluctuations in Caspian Tern Population

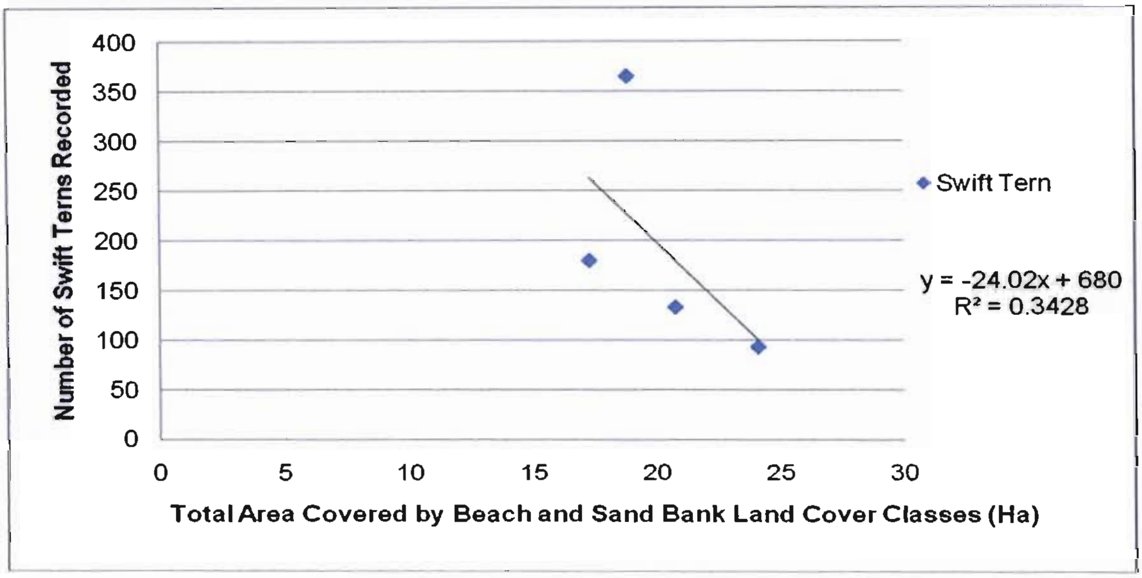

Figure 63: Correlation between Land Cover Change and Swift Tern Population

Table 30: The Values of the Dependent and Independent Variables E

Variables	Years			
	1991	1997	2003	2008
Area Coverage of Beach and Sand Bank Land Cover Classes(Ha)	24.13	20.8	17.33	19.98
Number of Grey-Headed Gull Recorded	965	526	642	224
Number of Swift Tern Recorded	93	133	180	365

The table above shows the values of the dependent and independent values used to create the following figures. Figure 63 represents the number of Swift Terns recorded plotted against changes in the total area of the beach and sand bank land cover classes. This figure displays a weak negative linear trend. The regression equation for this figure is $\hat{y} = -24.02x + 680$ and the $R^2 = 0.3428$. Therefore changes in one variable are reflected by changes in the second variable in the other direction. Therefore, the decline in Beaches and Sand Bank habitats is not having a negative impact on Swift Tern populations. In fact, Swift Tern numbers are increasing in the study area.

Figure 64 represents the number of Grey-Headed Gulls plotted against changes in the total area of the beach and sand bank land cover classes. The figure displays a positive linear trend with a regression equation of $\hat{y} = 67.613x - 777.27$ and $R^2 = 0.4409$. This means that changes in the one variable result in similar changes in the other variable. The positive correlation between its variables, which indicates that there is a possible relationship between the decline in Grey-Headed Gull populations and the decline in these land cover classes within the Mgeni Estuary and Beachwood Mangrove Swamp study area. This indicates that there is a possible relationship between the decline in the area covered by beach and sand bank land cover classes and the decline in avian indicator species.

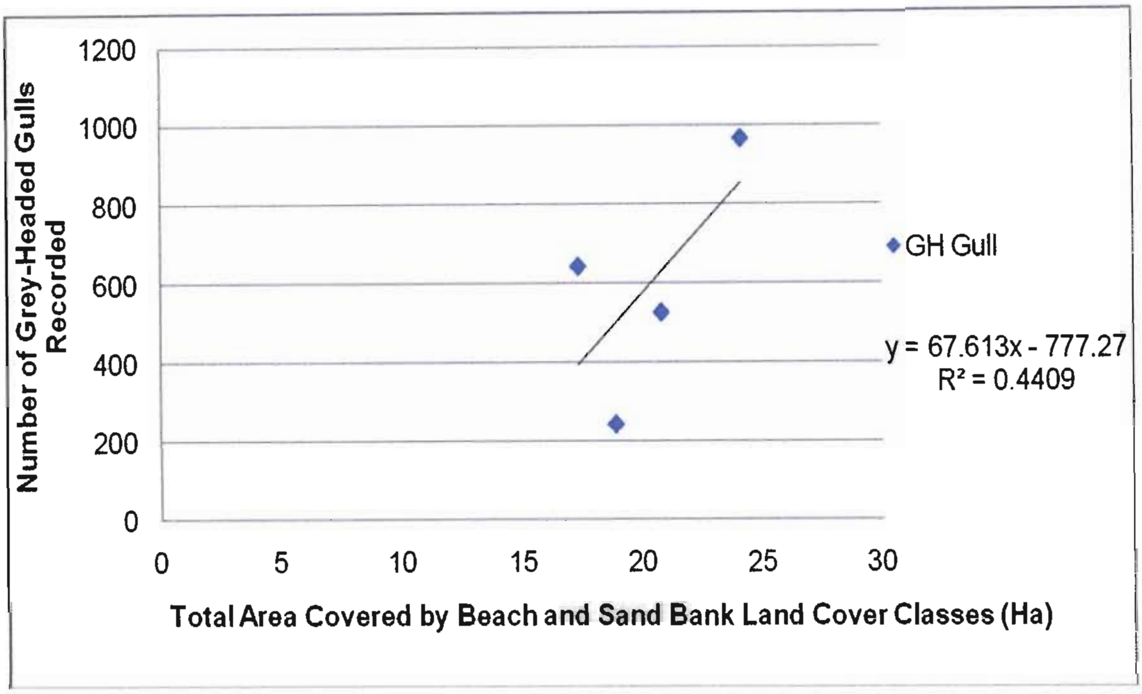

Figure 64: Correlation between Land Cover Change and Fluctuations in Grey-Headed Gull Population

In conclusion, on closer examination of the figures, it has been determined that there is some degree of correlation between changes in these beach and sand bank land cover classes and the fluctuations in the populations of Gull and Tern species. This is despite inconsistencies and irregularities in the avian census data used to produce these findings. For example, there is a moderately strong correlation between the decline in the Grey-Headed Gull population and the decline in the area coverage of beach and sand bank land cover classes between 1991 and 2008.

5.22. Mangrove Vegetation Expansion and the Decline of Mudflat Habitats and Avian Indicators

Another factor contributing to the steady disappearance of the mudflats is the following: Closer examination of the mudflats and islands in aerial imagery, taken of the Mgeni Estuary and Beachwood Mangrove Swamp study area over the last two decades, has revealed the progressive expansion of the mangrove community into the estuary and the lower reaches of river estuarine ecosystem as seen in Plate 44 and 48 (Gillard, 2008).

The figures below clearly illustrate the link between the two habitat land cover types. In 1991, mangroves covered 25.85 ha (16.16%) of the study area and during the same period mudflats cover 20.65 ha (12.91%). As the mangrove community expanded and consolidated its position within the study area, gradually mudflat habitats began to decline. In 2008, the mangrove community covered 29.81 ha (18.40%) of the study area, whereas the mudflats only covered 2.52 ha (3.99%) in 2008. This represents an increase in mangrove coverage of 6.04%, and a decrease in mudflat coverage of 16.66%. However, the changes in land coverage of exposed mudflats have to be considered in the light of the natural tidal fluctuations that occur within the Mgeni estuarine ecosystem. Plate 47 illustrates the land cover changes that have occurred within the study area since 1991.

Table 31: The Values of the Dependent and Independent Variables F

Variables	**Years**			
	1991	**1997**	**2003**	**2008**
Area Coverage of Exposed Mudflat Land Cover Class (Ha)	16.51	14	11.54	4.25
Area Coverage of Mangrove Vegetation Land Cover Class (Ha)	26.23	28.57	29.35	32.98

Table 30 above presents the values of the dependent and independent variables used to generate Figure 65 below. Figure 65 graphically illustrates the total area covered by mangrove vegetation land cover class plotted against the total area covered by exposed mudflat land cover class. The figure has a moderately strong negative linear trend with a regression equation of $\hat{y} = -1.8671x + 66.247$ and and $R^2 = 0.9765$. This means that the variables will respond in opposite directions. While one variable increases, the other variable will decrease. This means that the expansion of the mangrove vegetation land cover class is causing a reduction in the area coverage of the exposed mudflat land cover class within the study area.

Tidal fluctuation assists in the dispersal of seeds from the Beachwood Mangrove Swamp Nature Reserve which has allowed *Avicennia germinans* (Black Mangrove) and *Laguncularia racemosa* (white mangrove) to spread and be established within the lower estuarine and river ecosystems. This has led to a gradual disappearance of the mudflat habitat within the lower estuarine and river ecosystem as seen in Plates 44 and 48. As a result, wading bird populations (mudflat avian indicator species) have steadily declined because of their reliance on these habitat systems (Gillard, 2008).

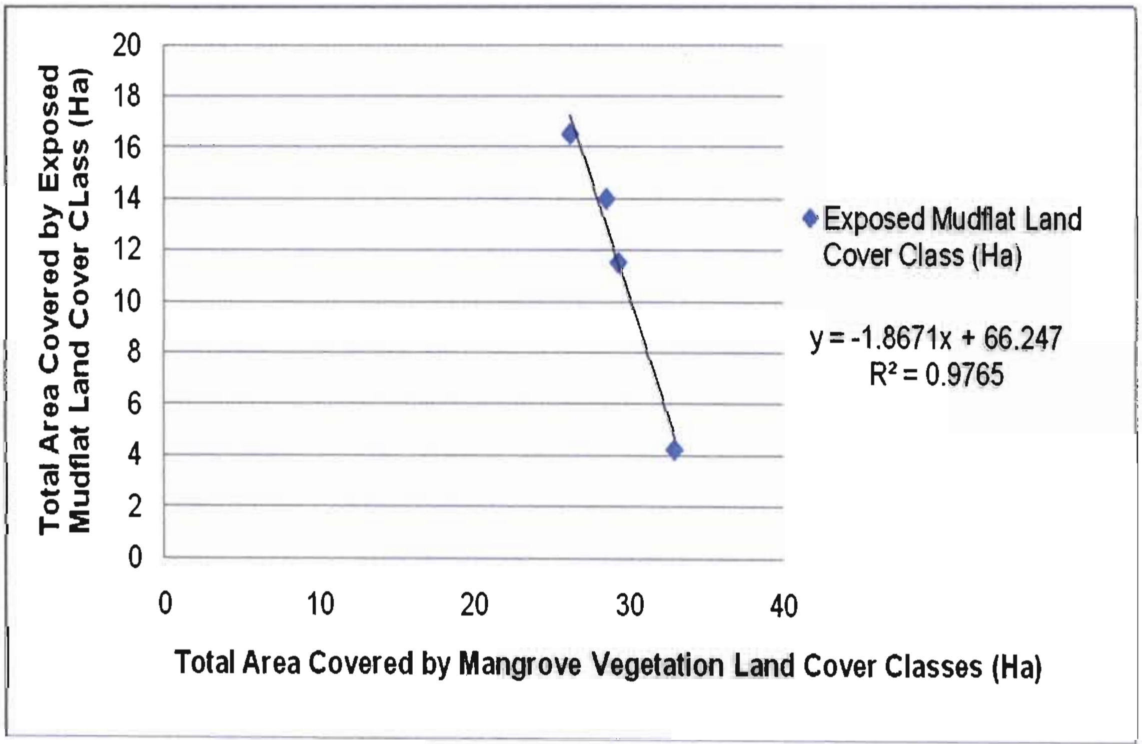

Figure 65: Mangrove Vegetation and Exposed Mudflat Land Coverage (1991-2008)

The *Avicennia germinans* (Black Mangrove) and *Laguncularia racemosa* (White Mangrove) species are pioneering plants that colonize muddy and sandy banks of estuaries and other inlets. As mentioned previously *Avicennia germinans* has managed to successfully establish itself in reasonable numbers on the majority of estuarine islands scattered throughout the Mgeni Estuary and river system (Gillard, 2008). Aerial imagery of the study area also indicates that *Avicennia germinans* has also managed to colonize large portions of the once prominent mudflats. This has been confirmed by a series of field surveys. If mangrove trees are allowed to establish themselves, the mudflats will be held together by extensive mangrove trees root systems. The roots gradually stabilise the mudflats by holding the poorly-consolidated silt, and by protecting it from being easily washed away or oozing erratically (Berjack *et al.,* 1981).

The deposition of sediment is increasing at a rapid rate, and the sediment will become finer as the roots of the pioneer *Avicennia germinans* and *Laguncularia racemosa* perform the role of water flow breakers and subduing the rush of the tide (Gillard, 2008). This allows the smaller sediment particles to be deposited. Berjack *et al.* (1981) indicated that the coarser sediment will be covered by silt and clay while there is a stabilizing mangrove community. As the soil becomes firmer and stabilises, conditions favour the establishment of Brugueira and consequently, the Rhizophora is replaced by Brugueira.

Plate 46: Dense cluster of Avicennia Seedlings south of Athlone Bridge

(Lower Estuary)

This deposition of silt by the Mgeni River is essential for the establishment of the mangrove community. The collection and deposition of silt by mangrove root systems can lead to the rise in land level and in some cases the actual extension of the shoreline (Gillard, 2008). If the process continues indefinitely, the mangrove community might advance into the water of the estuary resulting in the alteration of tidal boundaries. In some instances this may leave the landward edge and actually expand the strip of developed soil that is fully terrestrial and reclaim land from the sea itself (Berjack *et al.,* 1981). This expansion of the mangrove community into the Mgeni Estuary would eventually reduce the total area covered by mudflats and other estuarine habitats. The disappearance of the mudflats from the estuary ecosystem would have a negative impact on wading bird species that rely upon such habitat systems as a source of nutrients.

Researchers established that the mangrove community within the Mgeni Estuary covered an area of 44 ha. Historical records indicate that the silt deposits that formed due to dredging were colonized by young mangroves during the early 1980s (Begg, 1978). Begg (1978) also mentioned that seed dispersal from the Beachwood Reserve allowed mangrove trees to spread and become established throughout the estuarine and river ecosystems (See Plate 51). In addition, the City Council was prepared to facilitate and assist with the spread of the mangroves by actively planting trees in areas where the banks were being eroded which further expanded the range of mangrove trees within the estuary system (Gillard, 2008). Mangrove vegetation has managed to establish a large cluster of trees approximately 10 metres from the western end of the Athlone Bridge, and the inlet close to the estuary mouth. The clump that has established itself close to the Athlone Bridge has grown over the last decade into a dense stand of mangrove trees that have reclaimed a significant portion of the mudflat and islands (Plates 46, 47 and 49).

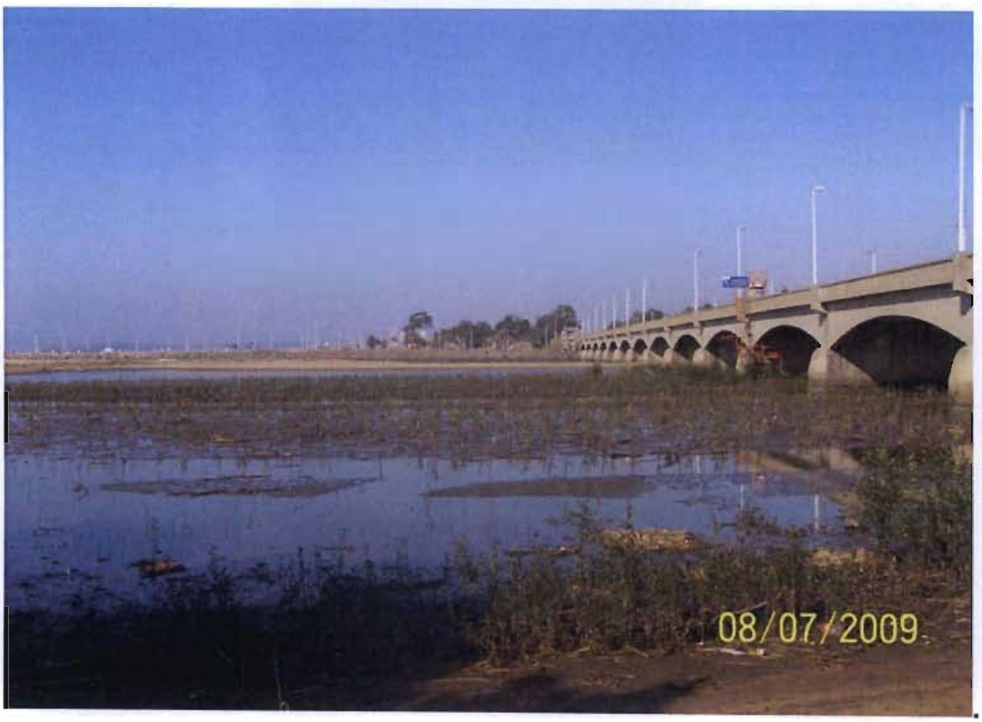

Plate 47: Mangrove Seedlings Established on Mudflats near Mgeni Estuary Mouth

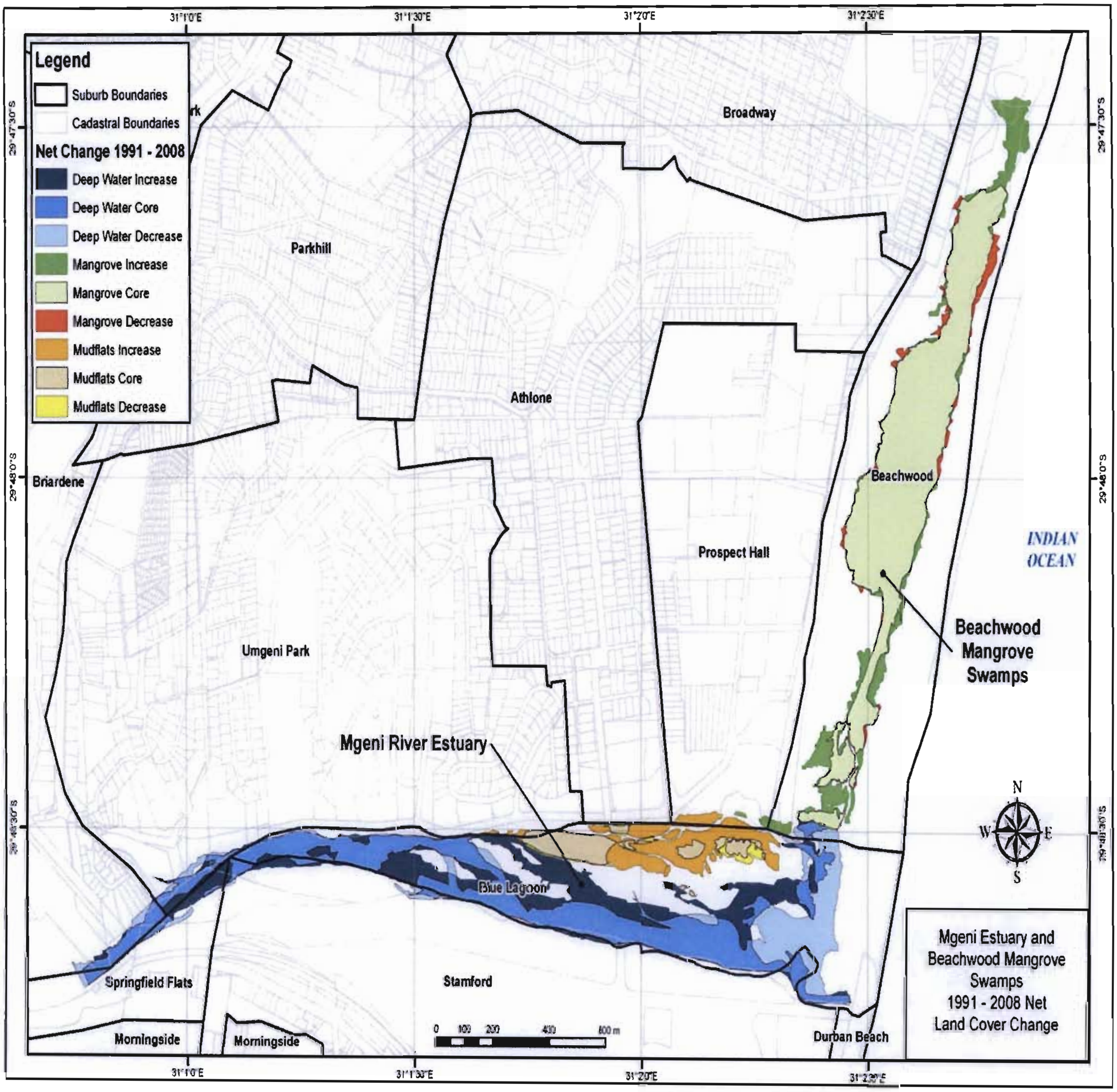

Plate 48: Mgeni Estuary and Beachwood Mangrove Swamps Land Cover Changes (1991-2008)

The researcher also identified other locations where the mangrove succession process is still in its early stages. The seaward side of the Mgeni Estuary is renowned for its mudflats and sandbanks. The latest aerial imagery and field surveys indicate a gradual colonization of the mudflats by the pioneer mangrove species *Avicennia germinans* and *Laguncularia racemosa.* Currently, the mudflats are covered in relatively young *Avicennia germinans* and *Laguncularia racemosa* seedlings of various heights, which have not yet managed to establish deep anchoring root systems that can retain and retain silt. It can only be assumed that under ideal conditions, these seedlings will grow rapidly and eventually completely cover the mudflats of the Mgeni Estuary.

The expansion of mangrove coverage and the deepening of the estuary could eventually reduce mudflat areas, resulting in a significant decline in wading bird species due to them not being able to forage for aquatic invertebrates within the Mgeni Estuary. Wading bird species forage for aquatic invertebrates which are found close to the surface of the inter-tidal mudflats by pecking or shallow water probing. These birds normally identify their prey by sight. However, Summers (1977) indicated that wading birds can also locate prey by secondary clues such as surface casts of poychaetete worms, and the movement of prawns as they irrigate their burrows on exposed mudflats (Smith, 1975). This means that the range of foraging habitats is limited by their morphology, as well as the range of prey they can locate and consume (Allen, 2008).

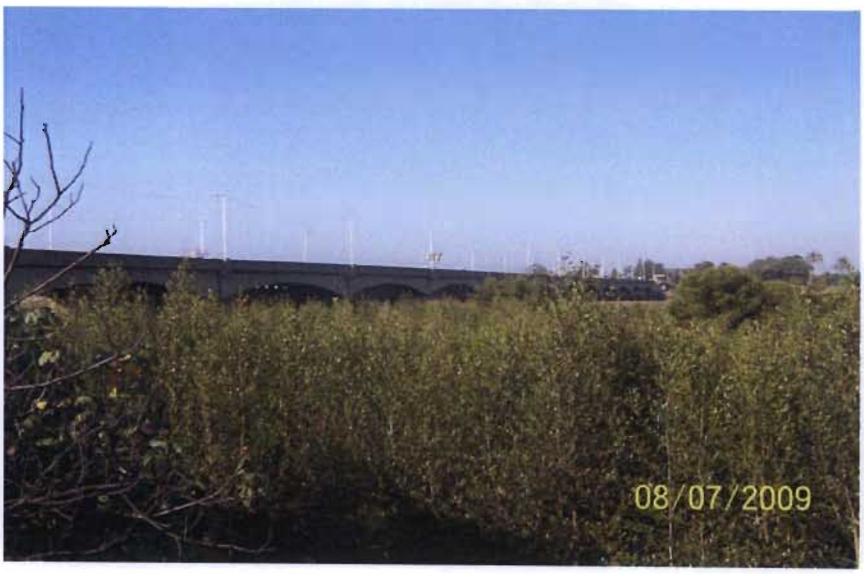

Plate 49: Expansion of Mangrove Vegetation near Athlone Bridge

(Connaught Bridge Side)

The Little Stint, which is the smallest wading bird in Southern Africa, is primarily adapted to hunting for its prey on exposed mudflats, salt marshes and along the water's edge. The bird's legs are too small to wade into deeper water, and its beak is too short to probe far beneath the surface of the mud. Therefore, this species is morphologically not adapted to foraging in mangrove habitats, and its prey would probably also be displaced by the habitat change. Scolopacid waders such as Curlews and Sandpipers have a larger body size to correlate with their larger beak and longer legs adapted to wading into deeper water (Velásquez and Hockey *et al.,* 1992). These waders are also visual foragers; but their longer bills enable them to probe deep into the mud to catch prey. However, ornithologists also indicate that they use chemoseception and mechanoreception to locate and recognize their prey (Allen, 2008).

The series of figures below display the relationship between land cover changes in terms of the Exposed Mudflat Land Cover Class and fluctuations in Mudflat Avian Indicator Populations within the Mgeni Estuary and Beachwood Mangrove Swamps.

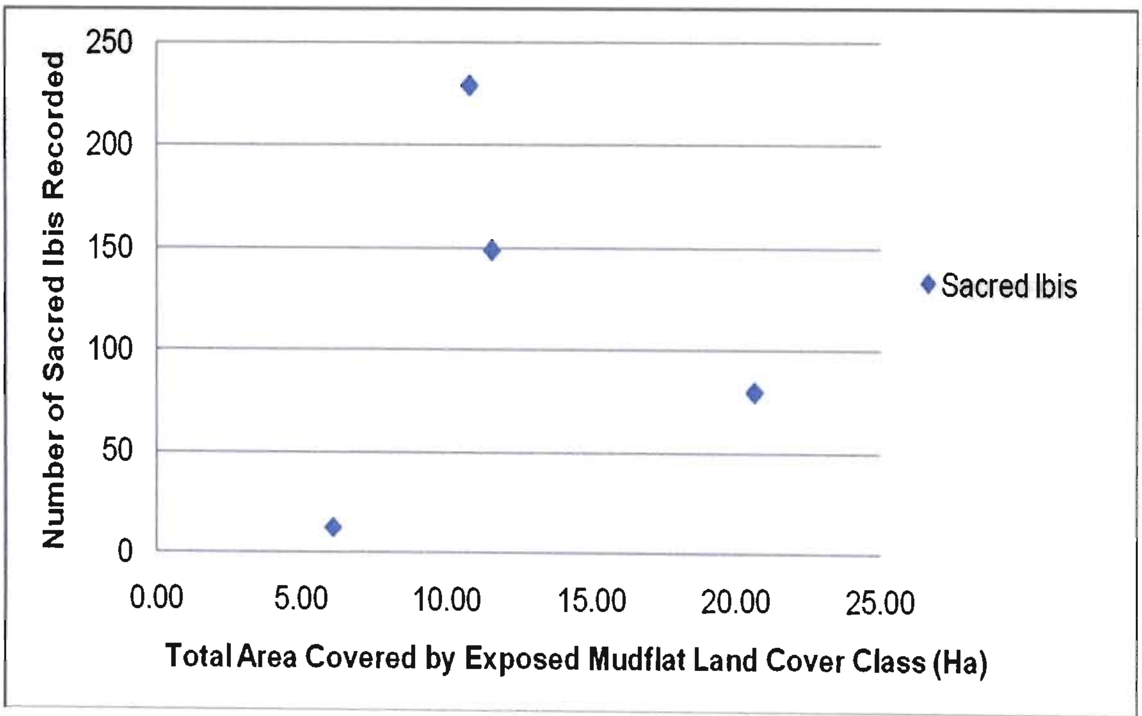

Figure 66: Correlation between Land Cover Change and Fluctuations in Sacred Ibis Populations

Figure 66 above shows the number of Sacred Ibis recorded plotted against the total area of exposed mudflat land cover class within the study area. This indicates that the changes in the independent and dependent variables are haphazard and completely unrelated. In other words there is no relationship between the variables and thus there is no linear correlation. For further information about the decline in Sacred Ibis populations within the study area please see Figure C2 in Appendix C.

Table 32: The Values of the Dependent and Independent Variables G

Variables	Years			
	1991	**1997**	**2003**	**2008**
Area Coverage of Exposed Mudflat Land Cover Class (Ha)	16.51	14	11.54	4.25
Number of Little Stint Recorded	138	38	0	3
Number of Curlew Sandpiper Recorded	224	170	0	162
Number of Black-Smith Plover Recorded	54	99	158	173

Table 31 illustrates the values of the dependent and independent variables used to form the following series of figures. Figure 67 below represents the number of Curlew Sandpipers recorded plotted against the total area of exposed mudflat land cover class .However, it is evident that there was no association between the variables.

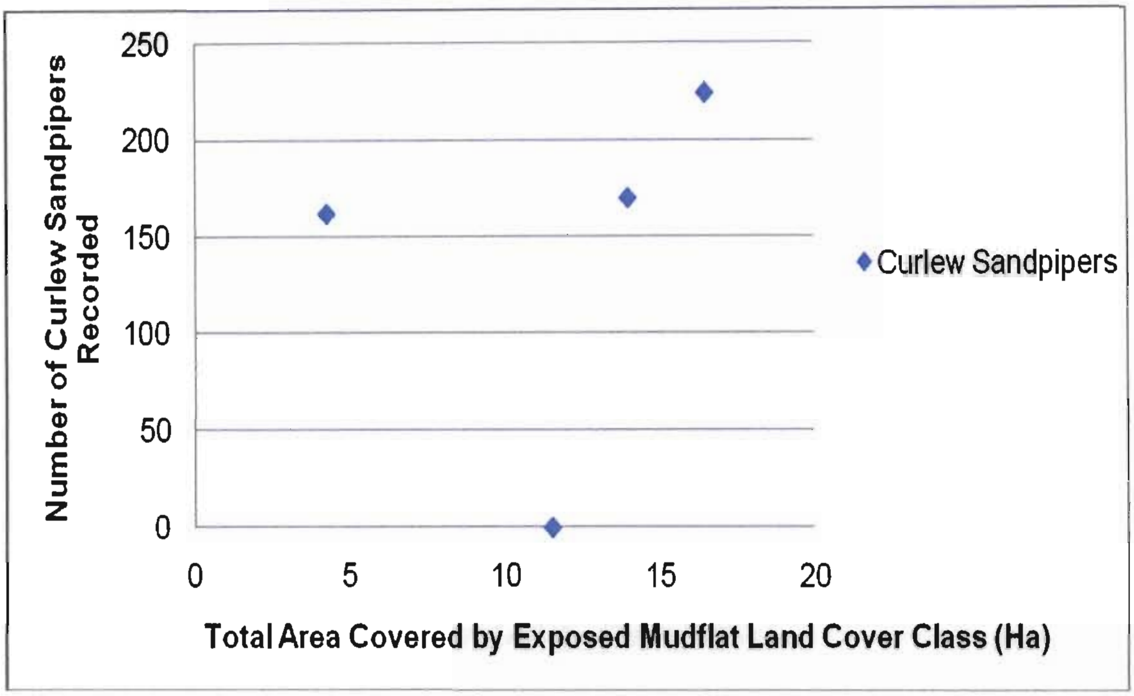

Figure 67: Correlation between Land Cover Change and Fluctuations in Curlew Sandpiper Population

Plate 50: Mangrove Vegatation Expansion- Former Mudflat Area

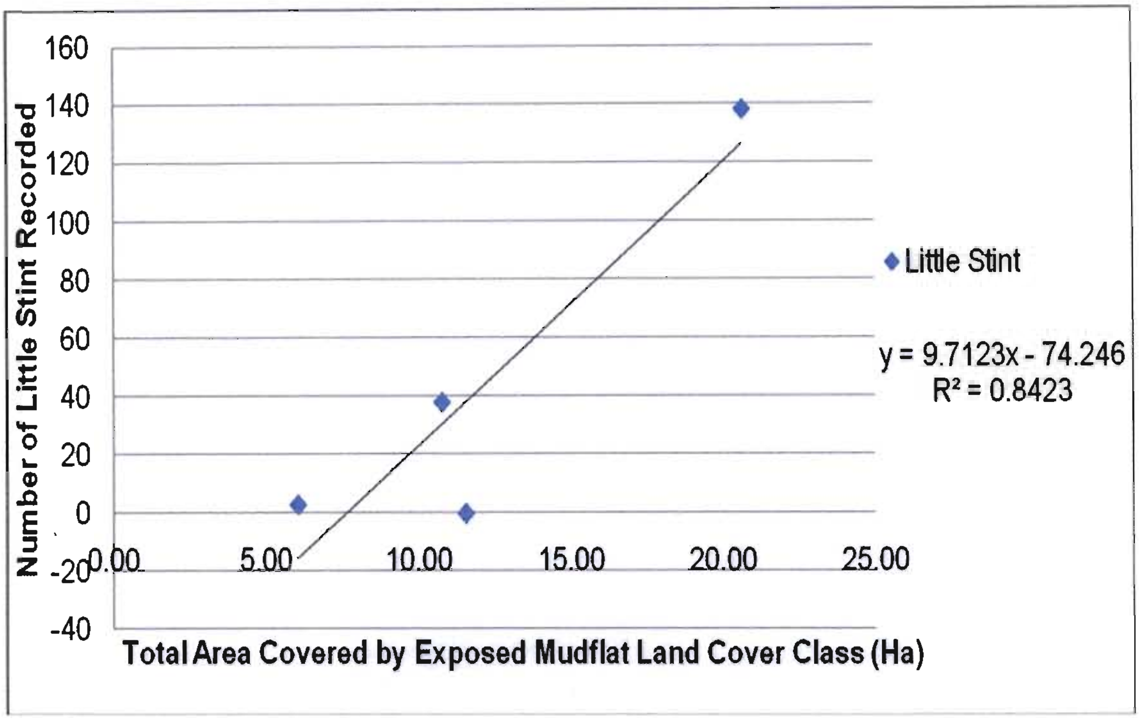

Figure 68: Correlation between Land Cover Change and Fluctuations in Little Stint Populations

Figure 68 displays a strong positive linear trend with a regression equation of $\hat{y} = 9.7123x - 74.246$ and $R^2 = 0.8423$. This means that there is a strong relationship between the independent variable and the dependent variable, and that changes in the one variable are reflected by comparable changes in the other variable, which indicates the decline in the number of Little Stints recorded within the study area could be linked to the decline in the exposed mudflat land cover class.

Plate 51: Mangove Tree Seeds

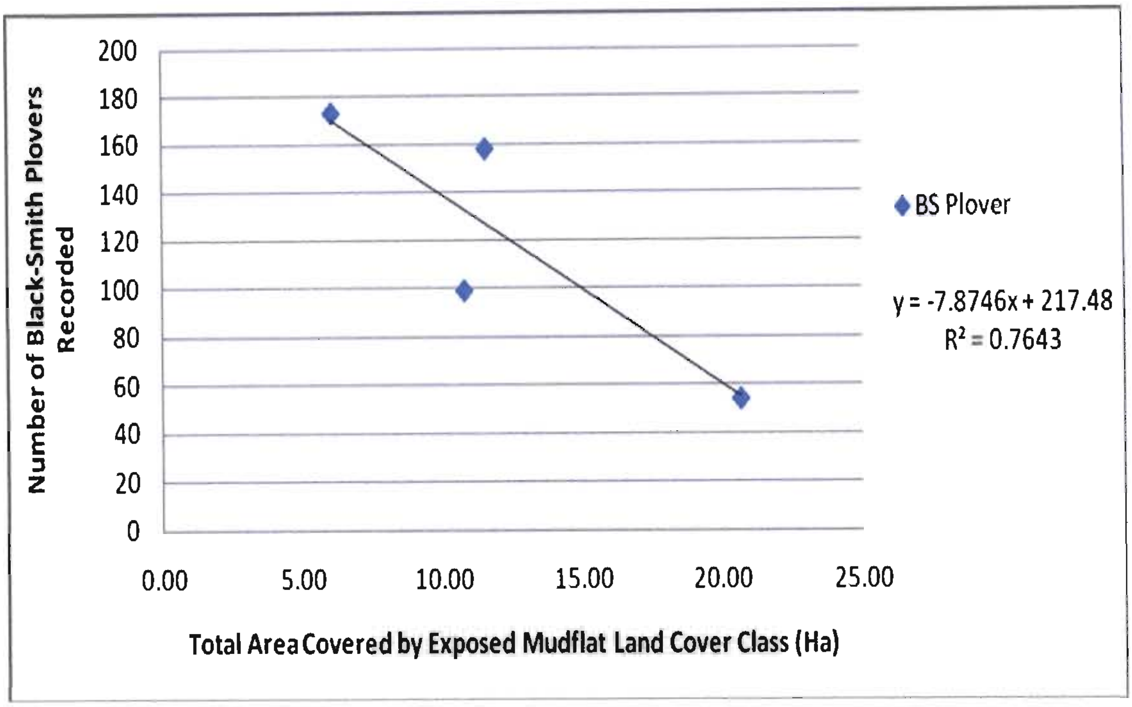

Figure 69: Correlation between Land Cover Change and Fluctuations in Black-Smith Plover Population

Figure 69 displays the number of Black-Smith Plovers recorded plotted against the total area covered by exposed mudflat land cover class. There is a strong negative linear trend displayed in the figure with a regression equation of $\hat{y} = -7.8746x + 217.48$ and $R^2 = 0.7643$. This indicates that changes in the one variable (Exposed Mudflats) are reflected in changes in the other variable (Avian Indicators) in the opposite direction. This indicates that the Black-Smith Plover population has increased despite the decline in the area coverage of the exposed mudflat land cover class.

Examination of the avian census data indicates that the number of Sanderlings is increasing within the Mgeni Estuary and Beachwood Mangrove Swamps despite the decline in the area covered by exposed mudflat habitats. This land cover class has been identified as the most important foraging and roosting habitat for these couple of wading bird species. However, the decline in exposed mudflat habitats appears not to be having a negative impact on the Sanderling population (Plate 47). No figure was produced because Sanderlings are summer migrants that visit the study area for a short period during the year, and large numbers of these small wading birds only started to make regularly visits to the study area during the late 1990s. Prior to this, there are inconsistent sightings of Sanderlings in small numbers within the study area which were discounted.

In conclusion, the decline in the area coverage of the exposed mudflat land covers class is undeniably linked to the expansion of mangrove vegetation into areas previously designated as mudflat habitats. The decline in the area coverage of the exposed mudflats has also been identified as the main cause behind the gradual decline in mudflat avian indicator populations of Little Stints that rely on these exposed mudflat habitats for foraging and roosting locations. This makes Little Stints ideal avian indicator species for this particular land cover class. Further research discovered that the populations of other mudflat avian indicator species were unaffected by the decline exposed mudflats and as a result they cannot be considered as mudflat avian indicators in future studies. For example, Black-Smith Plover numbers continued to increase despite the decline in the exposed mudflat land cover class. This indicates that Black-Smith Plovers are not as reliant on mudflat habitats for foraging and roosting as other mudflat avian indicator species because they have adapted to a wider range of land cover classes.

5.23. Water Land Cover Classes within the Mgeni Estuary and Beachwood Mangrove Swamps

The researcher selected Pink-Backed Pelicans, White-Breasted Cormorants, and African Darters as preferred indicators species for open water areas; and Goliath Herons and Little Egrets as effective indicator species for shallow water areas. According to *CWAC Bird Census Data,* Goliath Herons and Little Egret populations have increased between 1993 and 2008. This is seen in Figure B2 in the Appendix B.

Goliath Herons and Little Egrets have similar foraging techniques, whereby the bird wades steadily through the shallows moving their feet in the mud and vegetation on the estuary floor to tease out fish, amphibians and other prey species. White Egrets tend to forage in shallow water of an average depth of 100mm for their prey (See Appendix F). The reed beds and aquatic vegetation along the edge of the water provide shelter for small fish seeking refuge from aerial and surface predators. Fish make up a large portion of the Little Egrets diet. The larger Goliath Heron can be found foraging in water of a depth of 325mm hunting for larger fish species and amphibians (Velásquez and Hockey, 1992). Therefore, the reduction in medium and deep water levels within the study area has led to an increase in shallow water zones. This should stimulate an increase in Goliath Herons and Little Egrets populations because conditions are more ideal for their foraging techniques. Neither species swims or dives to catch their preferred prey (Plate 52).

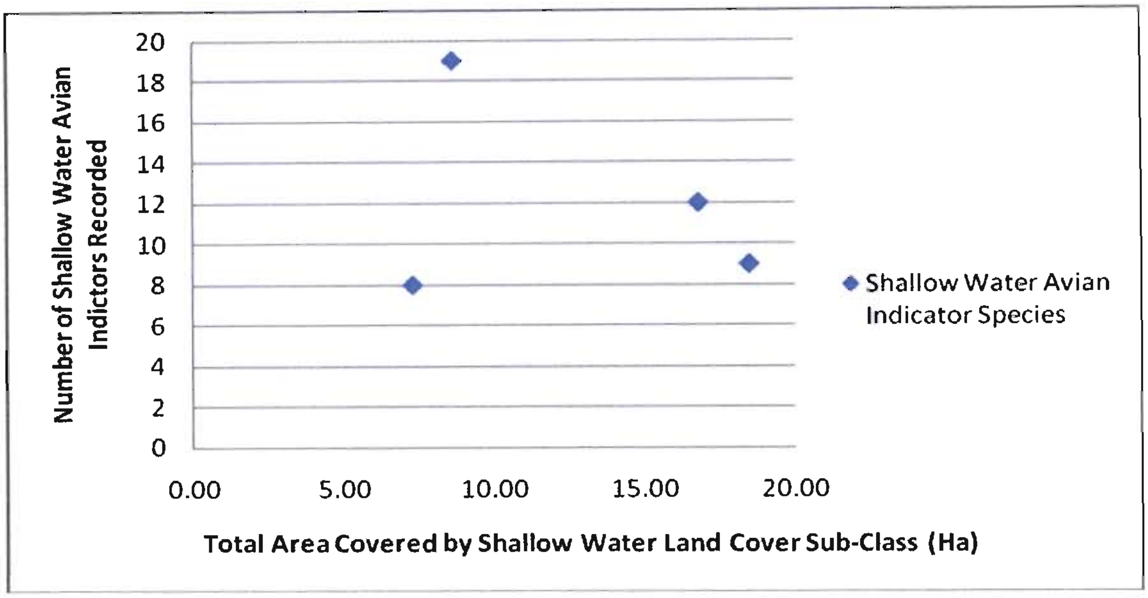

Figure 70: Correlation between Increasing Shallow Water Zone Indicator Species and the Increase in Shallow Water Zones within Study Area (1991-2008)

Figures 70 above shows the number of shallow water avian indicators recorded within the study area plotted against the total area covered by the shallow water land cover class between 1991 and 2008. It is evident that changes in the independent and dependent variables are random and unrelated. There is no linear correlation and that this indicates that changes in the populations of shallow water avian indicators cannot be incontrovertibly linked to changes in the area coverage of the shallow water land cover sub-class.

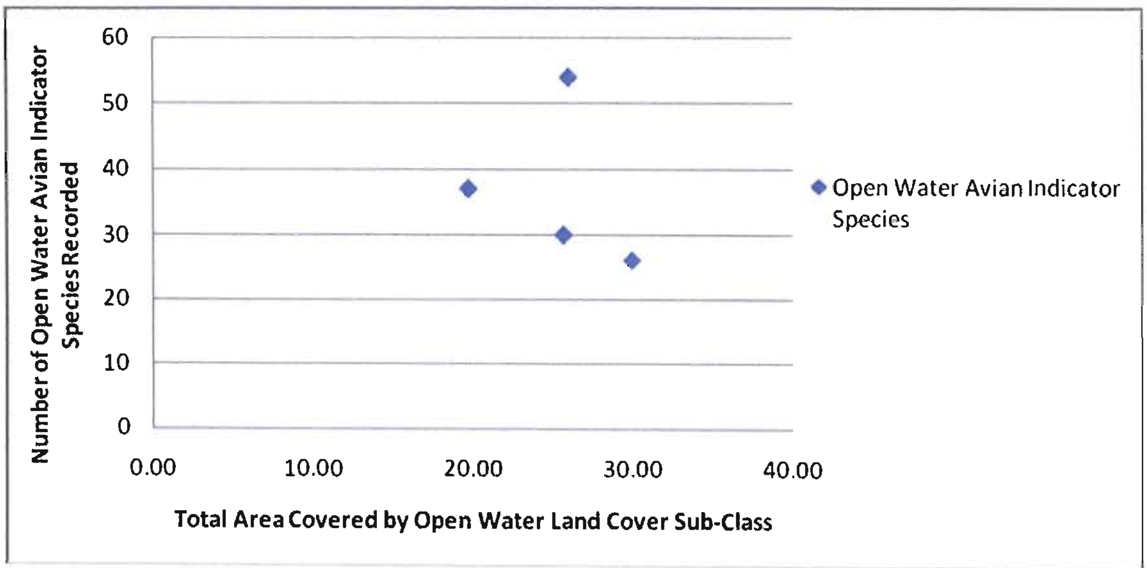

Figure 71: Correlation between Decreasing Open Water Land Cover Sub-Class and the Decline in Open Water Avian Indicator Species

Meanwhile, the open water avian indicators species such as the Cormorants and Darters forage by diving beneath the water's surface, hunting for fish amongst submerged logs and other obstacles below the surface. They will forage in shallow water when necessary. However, Cormorants and Darters tend to prefer deeper water. Pelicans will swim along in deeper water and catch prey close to the water's surface. These three indicator species tend to favour open water areas for foraging (See Appendix F). The gradual reduction of preferred forging habitats within the estuary and mangrove swamp system should stimulate a steady decline of these wetland bird populations. Where their preferred habitat has been compromised, these water indicator bird species will seek out other more suitable habitats such as deeper estuaries, river systems and dams. Birds might also move between different water habitats, perhaps returning to the estuary during the evening to roost.

Figure 71 above displays the number of open water avian indicator species recorded plotted against the total area covered by the shallow water land cover sub-class. Examination of the figure indicates a similar relationship between the variables as seen in Figure 70. Therefore, there is no relationship between the change in one variable and that of the other. This means that there is no relationship between the decline in open water avian indicator populations and the decline in the area coverage of open water land cover classes as previously predicted.

Plate 52: Little Egret Hunting in Shallow Water Zone

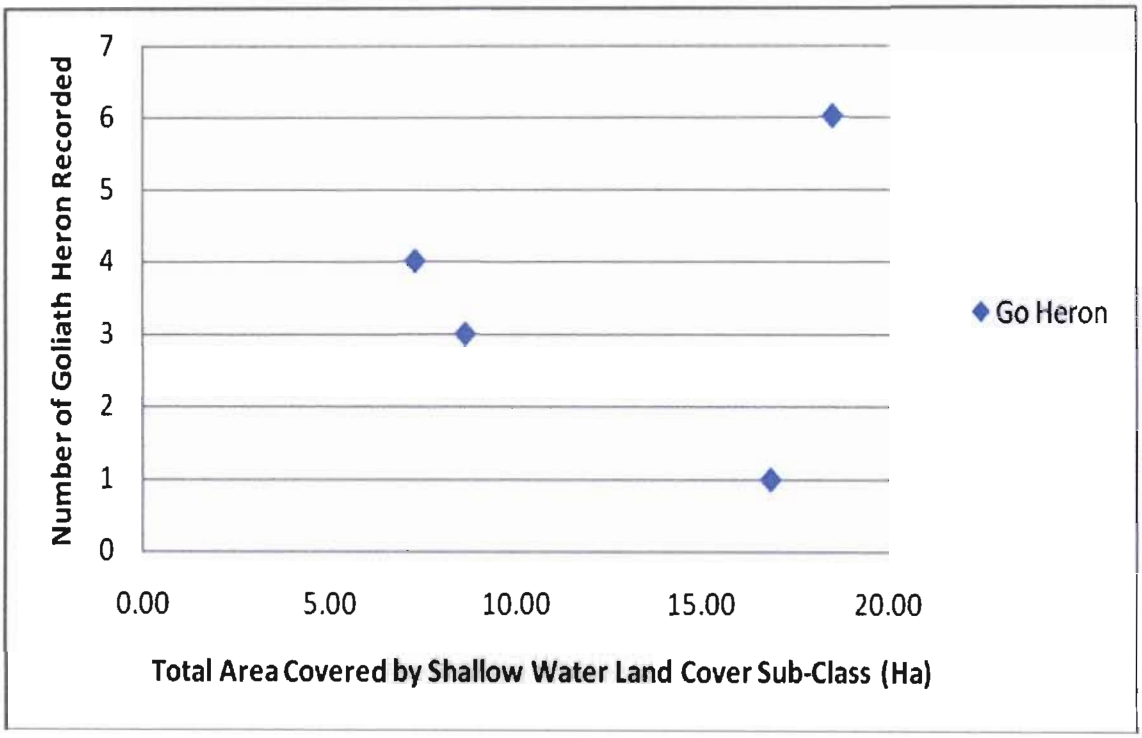

Figure 72: Correlation between Land Cover Change and Fluctuations in Goliath Heron Population

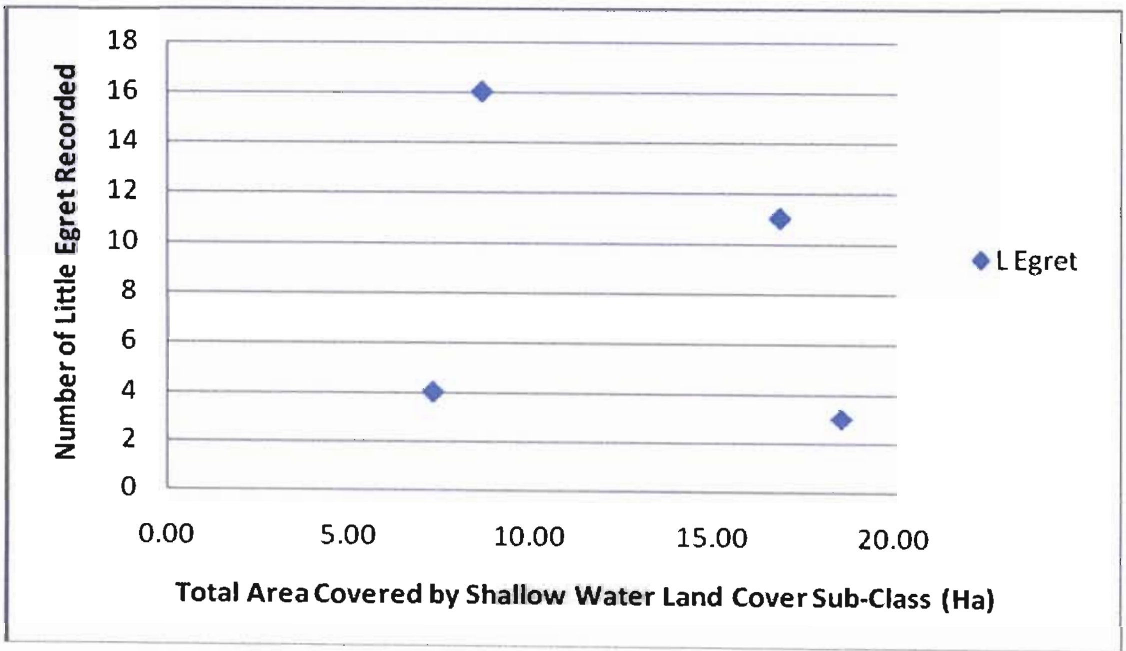

Figure 73: Correlation between Land Cover Change and Fluctuations in Little Egret Population

Figures 72 and 73 both also demonstrates a situation where the variables do change, but the changes that occur are unrelated and unpredictable. It is difficult to determine whether there is a relationship between the variables and as a result it is impossible to establish if changes in avian indicator populations are indeed the result of changes in the shallow water land cover sub-class.

Table 33: The Values of the Dependent and Independent Variables H

Variables	Years			
	1991	1997	2003	2008
Area Coverage of Open Water Land Cover Sub-Class (Ha)	26.00	25.69	19.75	25.99
Number of Pink-Backed Pelican Recorded	0	1	3	1
Number of African Darter Recorded	4	5	1	2

Figure 74 above graphically illustrates the number of Pink-Backed Pelicans plotted against the total area covered by the open water land cover class. The figure presents a strong negative linear trend with a regression equation of $\hat{y} = -0.3827x + 10.573$ and $R^2 = 0.8749$. This indicates that there is a possible relationship between the decline in the Pelican population and the decline in the area coverage of the open water land cover sub-class.

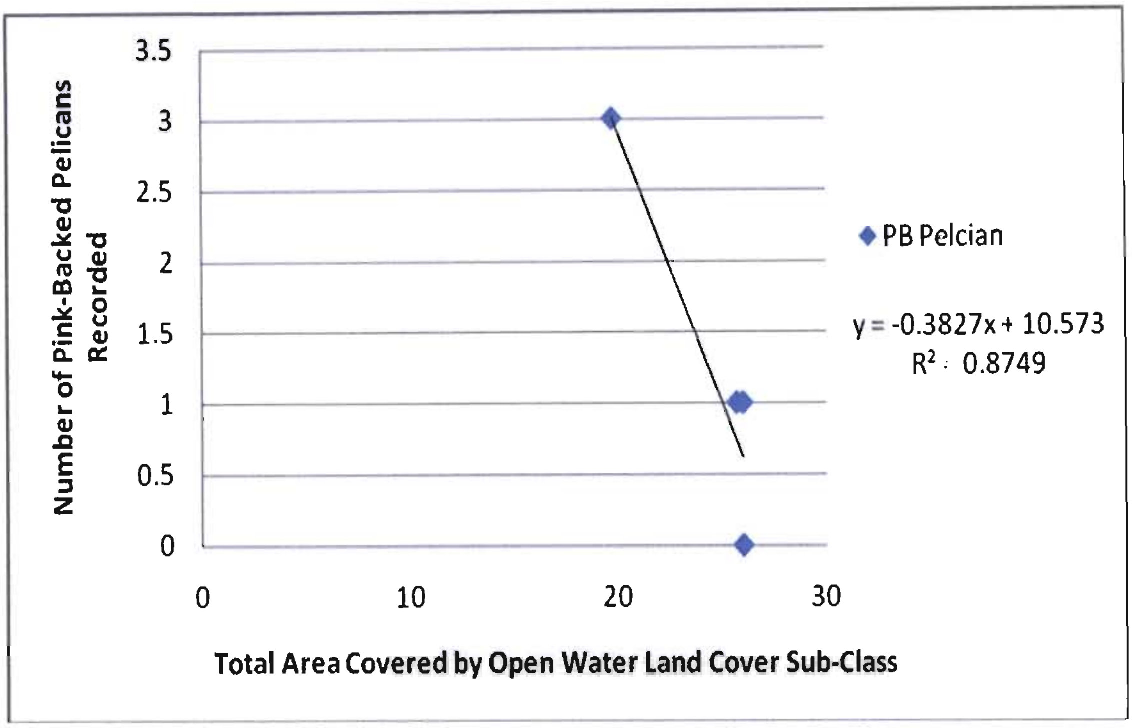

Figure 74: Correlation between Land Cover Change and Fluctuations in Pink-Backed Pelican Population

Figure 75 below shows the number of White-Breasted Cormorant recorded plotted against the area covered by the open water land cover sub-class. It is evident that the changes in the independent and dependent variable appear to be arbitrary and completely unrelated to each other. Therefore, there is no relationship between the decline in the area coverage of open water areas and the gradual disappearance of White-Breasted Cormorants.

Figure 76 below is displays a moderately strong positive linear trend with a regression equation of $\hat{y} = 0.4191x - 7.2093$ and $R^2 = 0.4984$. A correlation coefficient of +0.4984 indicates that a decrease in the independent variable should result in a comparable decrease in the dependent variable. Therefore, the decline in the area coverage of the open water land cover sub-class might be responsible for the decline in the population of African Darter.

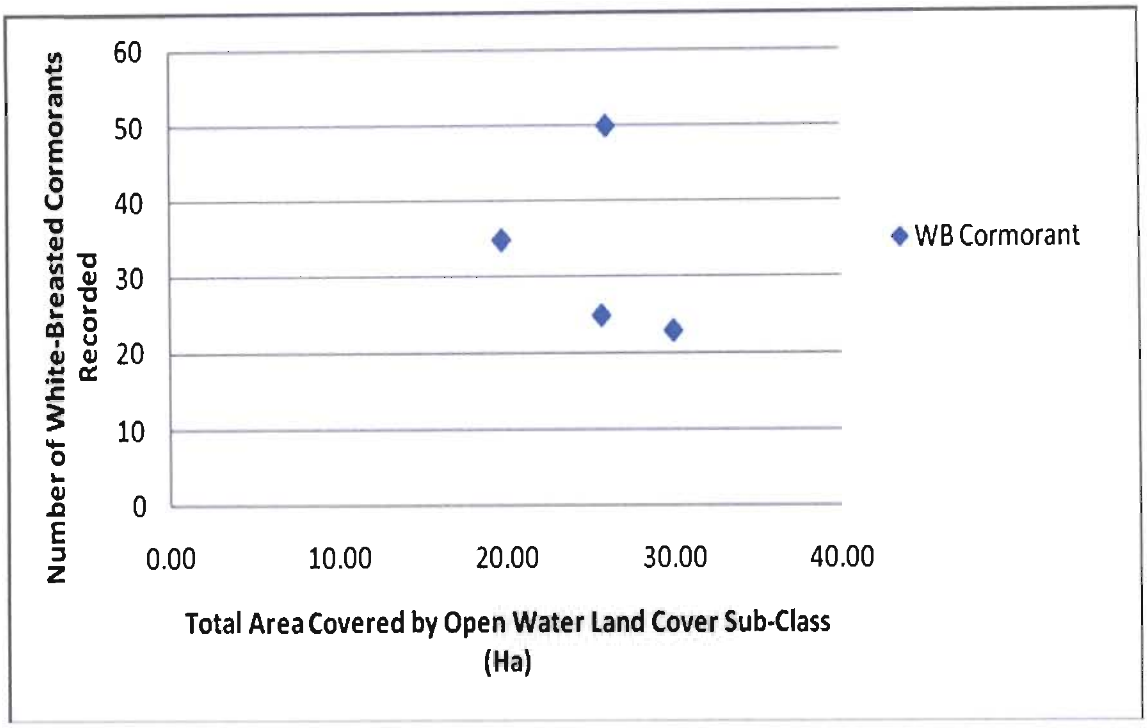

Figure 75: Correlation between Land Cover Change and Fluctuations in White-Breasted Cormorant Population

In summary this section has established that the decline in the Pink-Backed Pelican and African Darter populations could be associated with the decline in the area coverage of the open water land cover sub-class within the study area. In addition, due to the limited availability of avian census data for several water avian indicator species, it cannot be conclusively shown that there is an effective link between fluctuations in other avian indicator populations and changes in area coverage of water land cover sub-classes. Further research is required to establish indisputable evidence of the relationship between these variables.

Plate 53: Shallow Water in the Mgeni Estuary

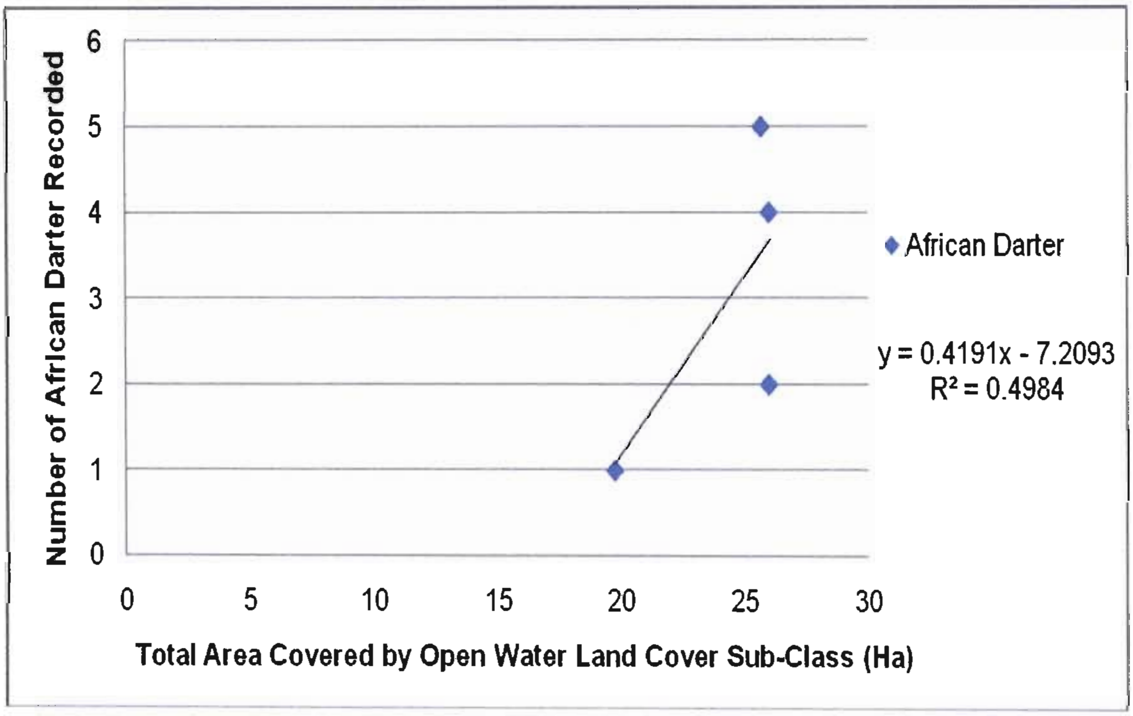

Figure 76: Correlation between Land Cover Change and Fluctuations in African Darter Population

Chapter Six

Conclusion and Recommendations

6.1. Inconsistencies in the Avian Census Data Set Acknowledged

Whereas the land cover data was gathered and processed by the researcher off aerial survey imagery using GIS software tools; the avian census data was the result of Waterbird Counts (CWAC) project field surveys undertaken by the University of Cape Town's Avian Demographic Unit, and over which the researcher had absolutely no control (Wheeler, 2008). This study therefore had no other option but to utilise the only credible avian census data – the Waterbird Counts (CWAC) project - with all its potential limitations.

A review of the study findings has demonstrated that the limited counts on certain bird species in some instances undermined the statistical validation process. The basic rule of all research is to obtain the largest set of data samples possible to ensure that the statistical accuracy of the information is enhanced. Conversely, a limited set of sample data could compromise the scientific accuracy or relevancy of the eventual findings of any given study. In this instance certain wetland avian indicator counts were either too sparse, or in other instances leaned towards a potential for human error. The Coordinated Waterbird Counts (CWAC) project undertook regular mid-summer and mid-winter censuses of wetland sites all around South Africa, including the Mgeni Study Area. Wheeler (2008) indicates that the regular six-monthly counts are conducted by groups of experienced ornithologists and 'volunteers'. This study has shown that more frequent avian counts, with less potential human inaccuracies would clearly enhance the validity of future study conclusions.

There are two main criteria used for evaluating the quality of avian data sets used during a particular study. Each of these criteria actually relates most strongly to the quality of the process by which data is collected, and the methods used during the process of collecting the data (Rumsey, 2003). However, the available avian data sets used for the study area are limited to the findings of two potentially biased bi annual surveys. As such it is impractical to precisely determine changes in avian populations based on partially compromised avian data sets.

Firstly, the researcher suspected that the avian census was biased, being data that is occasionally over measured or under measures the true result (Rumsey, 2003). Bias can occur anywhere during the design or implementation of a particular study. Bias can be caused by a bad measurement techniques or human error (Rumsey, 2003). Basic human error has been identified as the most obvious cause of irregularities and inconsistencies in the avian census data used. Counters are responsible for the identification and recording of the number of birds sighted during field surveys. The Counters have a varying degree of avian knowledge, practically amongst part-time bird enthusiasts and volunteers, which can lead to mistakes during identification and the recording of sightings. Mistakes do occur on a regular basis according to ornithologists (Allen, 2008; Gillard, 2008). This can lead to a false representation of the numbers of wetland birds within the study area, especially when one is using only two counts annually.

The CWAC guidelines state that numbers of birds should be estimated when the numbers are relatively large (+/- 1000), the birds are moving rapidly or flying, there is a chance of a disturbance or birds are crowded and not all the birds are clearly visible. Ornithologists and experienced Counters promote the use of a method for estimating numbers of birds in large flocks, either in flight or on the ground, known as the "Block Method". Basically, this method involves the super imposing of a fictional or actual block of a certain size onto or within a large flock of birds (Wheeler, 2008). Each block should have 10, 20, 100 or some other round number of individual birds assigned to it. However, inexperienced Counters tend to underestimate the number of birds present within a block when they are estimating the size of a large flock of birds (+/- 100 individuals). Wheeler (2008) states that experience is vitally important during the application of this counting method in the field, and regular practise is require perfecting this method.

Given the background as set out above, the researcher assessed the available data sets and disregarded potentially flawed data in favour of data which appeared to have a reasonable and acceptable consistency. The researcher did not totally disregard the flawed data sets, but allowed himself to be influenced by the general trend identified, accepting that the results were not necessarily statistically validated. Had more frequent surveys been undertaken, the validity of the study results would have certainly been enhanced.

The more reliable data sets utilised in reaching a conclusion generally supported the thesis that changes in land cover can be linked to a corresponding fluctuation in wetland avian species, the basic premise of this study. Therefore it can be stated that specific wetland avian bird species have the potential to be utilised as an effective monitoring tool with which to help assess and predict land cover changes within estuarine and mangrove swamps within Southern Africa.

6.2. General Conclusion

Estuaries and mangrove swamps are recognised as valuable ecosystems because of the variety of ecological and economic functions they perform. These ecosystems benefit the natural environment and mankind and deserve appropriate management and conservation. Scientists, biologists, physicists and other academics all recognize the need for an effective method of monitoring the health and integrity of estuarine and mangrove swamp ecosystems to ensure that these ecosystems are conserved and managed appropriately for the benefit of future generations.

This study sought to establish whether wetland indicator bird species could be used as an effective monitoring system to help assess and predict land cover changes within estuaries and mangrove swamps within Southern Africa. The Mgeni Estuary and adjacent Beachwood Mangrove Swamps were chosen as an appropriate study area. The researcher recognized there were several potential problems that might arise due to the effects of tidal fluctuation within the Mgeni Estuary and Beachwood Mangrove Swamp study area, and issues of reliability arising from irregularities in the avian census database. These problems could have undermined the legitimacy of the study if appropriate measures had not been introduced to ensure they were addressed effectively. This process provided the researcher with a solid platform upon which to develop a substantial argument in favour of the relationship between estuarine and mangrove swamp land cover change, and the effects of such land cover change on wetland avian indicator populations.

Fluctuations in the populations of wetland avian indicator species were investigated by this study. It was discovered that that bird populations fluctuated significantly over time within the Mgeni Estuary and Beachwood Mangrove Swamp study area. Further research determined that the prevalence of specific indicator species was associated with seasonality rather than land cover change. However, other species showed signs of population decline that could be linked to changes in a particular land cover classes. These assumptions were verified through statistical analysis known as correlation coefficiency. This is the measure of how closely two variables change in relationship to each other. In this case, the number of birds recorded plotted against the time index. Finally, the researcher concluded that merely assessing and interpreting fluctuations in bird populations identified in avian census data was not sufficient enough to provide accurate and reliable data on wetland bird populations. An effort should be made to supplement these data sets with long term data on reproductive success and demographic traits according to local ornithologists (Allen, 2008).

Changes in land cover classes and sub-classes were investigated during this study. The Mgeni Estuary and adjacent Beachwood Mangrove Swamps are dynamic ecosystems that are affected by natural phenomena, and human activities throughout the entire river catchment area. This study focused primarily on the immediate vicinity of the estuary and the mangrove swamps. However, outside influences could not be totally ignored when examining the causes of land cover change. The study attempted to identify significant land cover change within the study area over the past eighteen years through the assessment of a series of aerial survey imagery. GIS analysis of aerial imagery allowed the researcher to successfully categorize and map different land cover types within the study area, and was used to calculate the total area covered by each land cover class and sub-class, in relation to the fixed total coverage of the study area. This provided the opportunity for the examination and recording of changes in terms of land cover within the study area, within a specific study period, all relative to a fixed area base. Once again, the researcher clarified the findings by attempting to discover the correlation between the total area covered by the land cover classes, and sub-classes, plotted against the time index. In conclusion, the study established that changes in specific adjacent land cover classes and sub-classes; were the result of the opportunity created by changes in adjacent land cover classes. For example, coastal forest and woodland which had an impact upon adjacent grassland and scrubland areas, or the expansion of mangroves which resulted in the colonisation of mudflats. One example of significant human intervention would be the restricted water flow and sediment load due to a controlled outflow program introduced by Inanda Dam management.

This study provided sufficient evidence to suggest that both human and naturally induced changes within the estuarine and mangrove ecosystems, as reflected by changes in some land cover classes, had an impact on specific wetland bird populations. However, to confirm this theory, the researcher correlated the number of avian indicators recorded against the total area covered by the specific land cover class, or sub-class, considered by the researcher and ornithologists to be their ideal foraging, roosting or breeding habitats. This assisted in validating the theory that, for instance, the decline in the exposed mudflat land cover class was linked to the expansion of the mangrove vegetation land cover class and island mangrove vegetation land cover sub-classes, and was directly responsible for the gradual decline in, for instance, the Little Stint population. On the otherhand, the increase in the population of the Water Dikkop is reflected in the increased area of reed beds, marshes and grassland land cover classes within the study period.

Secondly, a close examination of aerial imagery revealed the progressive expansion of the mangrove community into the estuary and the lower reaches of Mgeni river ecosystem. The researcher recorded that the pioneering mangrove species, *Avicennia germinans* (Black Mangrove) and *Laguncularia racemosa* (White Mangrove), have managed to steadily colonize large portions of the once prominent mudflats during several field surveys. This significant change in land cover within the study area has impacted on mudflat avian indicator populations. Mudflat indicator species, or wading bird species, cannot forage for aquatic invertebrates in open water or densely vegetated habitats. Wading bird species are adapted to foraging for aquatic invertebrates which are found close to the surface of the intertidal mudflats. This steady land cover change will inevitably lead to a decline in mudflat habitats, and a consequent reduction of the wading bird species which are especially dependent upon such habitats.

Certain avian indicator species proved to be very effective in their designated role as indicator species; others indicated potential given an acceptable level of avian census data; whilst others appeared to be ineffective, perhaps due to a greater level of environmental adaptability – see Appendix I.

However, after careful analysis of the eventual findings of this study, the researcher has concluded that despite a robust and rigorous assessment of all assessable avian census databases, and the examination and processing of relevant aerial imagery, further in-depth research is required to establish an meaningful link between land cover change, and the fluctuations of wetland bird populations with the estuarine ecosystem.

In conclusion, this study has merely touched the surface of an interesting field of research, the results of which suggested a need to delve deeper in order to establish indisputable evidence confirming that a direct link exists between land cover change, resulting in fluctuations in wetland avian populations. However, before further research is undertaken into the utilization of bird species as environmental monitoring tools, a more concise and extensive avian census database must be developed to provide researchers with an appropriate avian census data set. Recent work undertaken by the Avian Demographic Unit at the University of Cape Town is a significant step in the right direction.

6.3. Future Applications of this Study

This study has provided a spatial and descriptive historical land cover database of the Mgeni Estuary and Beachwood Mangrove Swamps over the past eighteen years. This baseline information can assist in the development of an improved environmental management regime for other estuarine and mangrove ecosystems throughout Southern Africa. The study has successfully shown that wetland avian species can be used to monitor environmental changes within the Mgeni Estuary and adjacent Beachwood Mangrove Swamps.

By highlighting the value for regular monitoring of wetland avian species populations within estuarine and mangrove ecosystems, this research has contributed to the body of local knowledge surrounding methods of conservation management and the protection of an environmentally sensitive ecosystem type. It was this desire to help make a contribution to the conservation of natural ecosystems which inspired the researcher to embark upon this study within the Mgeni Estuarine and Beachwood Mangrove Swamp ecosystem.

The land cover database, and the use of wetland bird species as a system of monitoring land cover change within an ecosystem, as developed during this study, can also be used in the following applications:

- The concepts developed by this study can be applied as an environmental tool. The results of this study can be applied during environmental management such as the analysis of further changes of habitats within the study area. The data base that has been developed during this course of this study can be used by the eThekwini Municipal Environmental division who require reliable information on land cover changes taking place within protected DMOSS areas within the City.

- The historical land cover data base that was developed during this study can be utilised by both the public and private sectors in environmental planning work within the Mgeni Estuary and Beachwood Mangrove Swamp study area and the surrounding area.

- The land cover data base developed during this study can be combined with other studies undertaken in the Albert Falls area by Yemane (2003), Midmar Dam sub-catchment by Rivers-Moore (1997) and the Karkloof sub-catchment area by Weyer (2000) to model land cover change within the entire Mgeni catchment area

- This study further reaffirmed the usefulness of avian indicator species within natural ecosystems. The United States Environmental Protection Agency has been utilising various bird species as a monitoring tool within a wide variety of different habitats for decades.
- In addition, the study contributed to the greater body of knowledge about tools and methods that enviromentalists can use to monitor the health and integrity of our natural world.

This dissertation on land cover change within the Mgeni Estuary and Beachwood Mangrove Swamps, and the use of wetland avian indicator species to monitor such changes, will be made available to other researchers and decision makers interested in environmental management planning and policy making within the Mgeni Estuary and Beachwood Mangrove Swamps.

6.4. Recommendations

As a result of this study the following are recommended:

- That environmental departments, boards and organisations implement a systematic policy of monitoring wetland bird populations as indicators of environmental change within wetland and estuarine ecosystems as part environmental management plan for both local and national levels.
- That organisations and groups that are responsible for the collection of the *CWAC Wetland Bird Survey* data should be encouraged by these departments, boards and other organisations to undertake more regular surveys throughout the year. If surveys were conducted in such a manner, this would provide a better overall understanding of the fluctuations in wetland bird populations throughout Southern Africa and provide a more reliable source of avian data.
- That the more sensitive ecosystems should be subjected to more regular structured aerial surveys to help provide essential raw data for monitoring purposes.
- That Environmental Planners should consider using avian indicators more regularly to assist with the assessment of the health and integrity of natural ecosystems.
- That, during similar land covers use and cover change analysis studies, the researcher should gather and analyse all available remote sensing data. Satellite

imagery has several advantages over aerial imagery in the future. These include the following:

1. Commercially available to general public
2. Greater aerial extent and accuracy than aerial photographs.
3. Satellite imagery comes in a digital format.
4. Satellite imagery allows regular repetitive coverage, while aerial surveys are infrequent.
5. Regular and predicable distortion.
6. A greater wavelength range.

- That locally manufactured remote controlled air vehicles (drones) equipped with cameras and other sensors should be used to enable them to cheaply and easily conduct aerial surveys on a regular basis. The capture of aerial imagery from aircraft is expensive and undertaken on an irregular basis.

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Appendix A

Land Cover Class and Sub-Class Figures

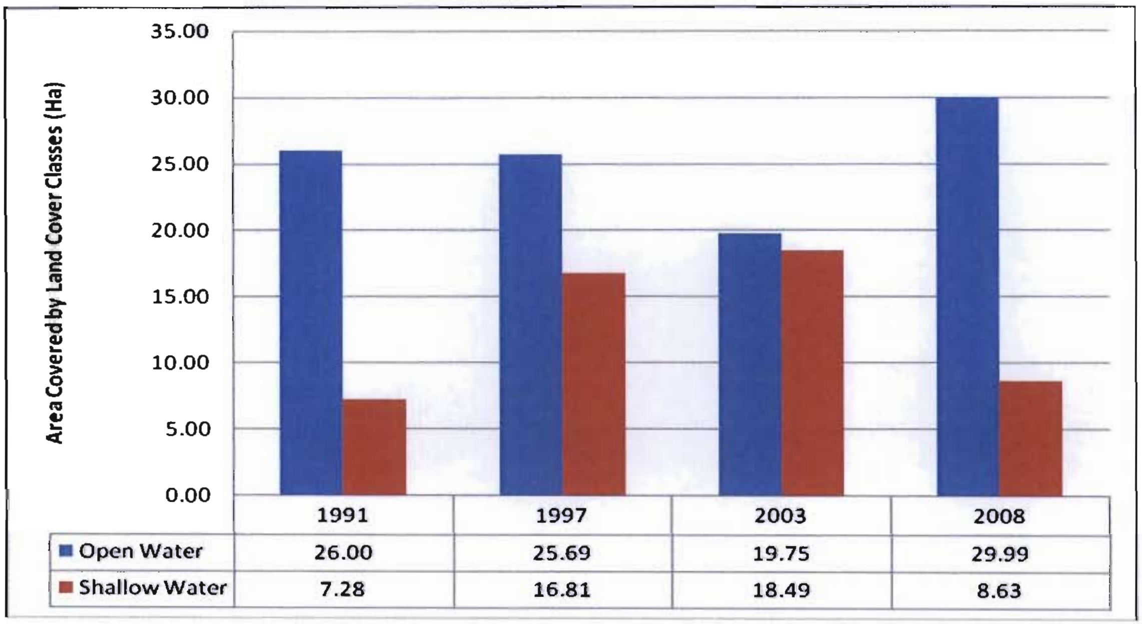


Figure A1: Changes in Water Bodies within Mgeni Estuary and Beachwood Mangrove Swamps

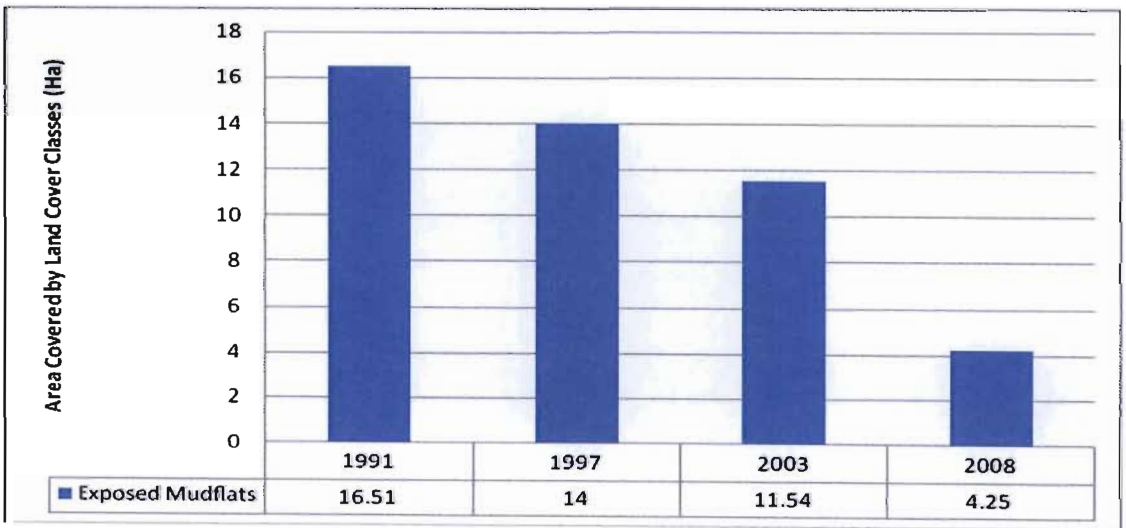
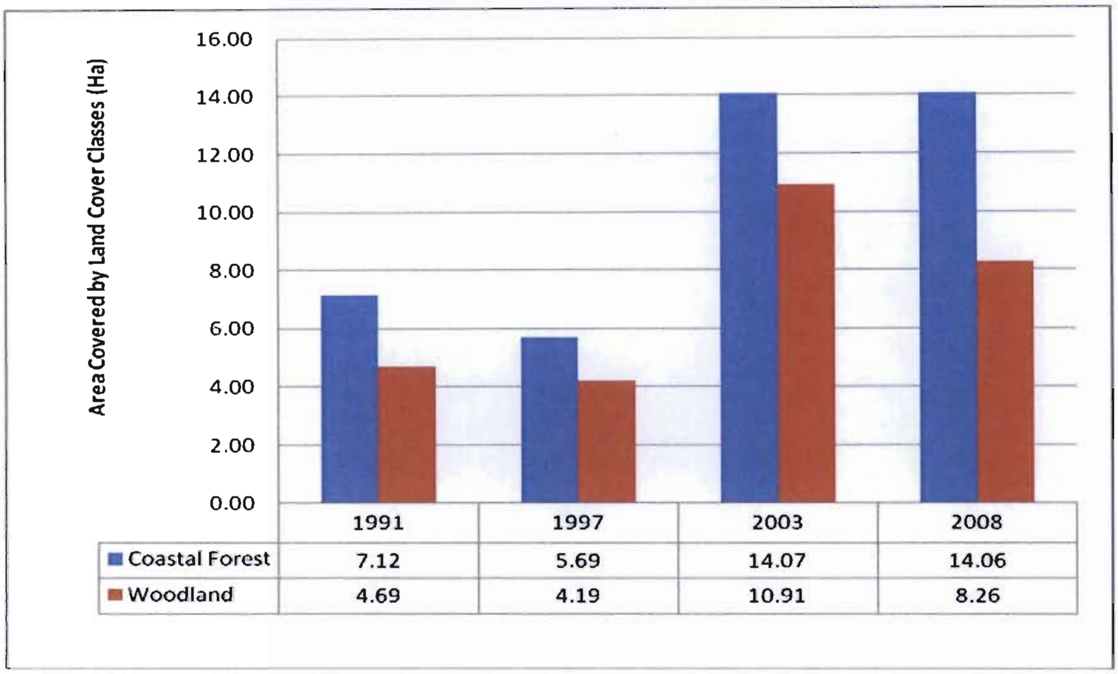
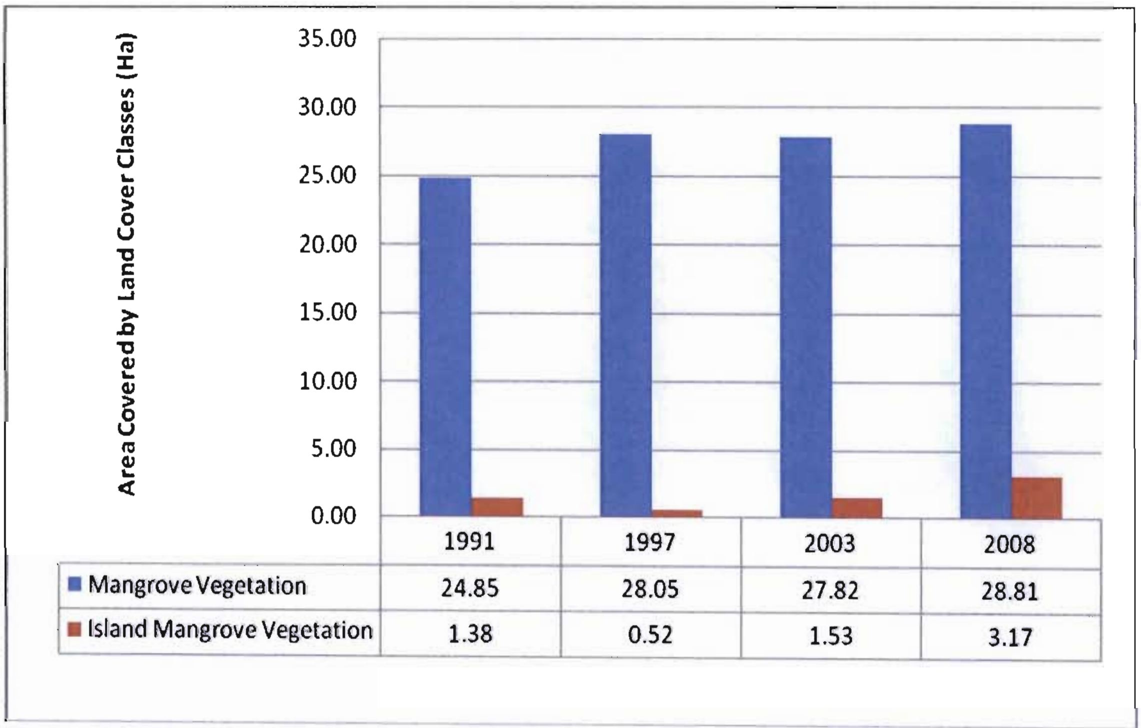


Figure A2: Changes in Exposed Mudflats within Mgeni Estuary and Beachwood Mangrove Swamps



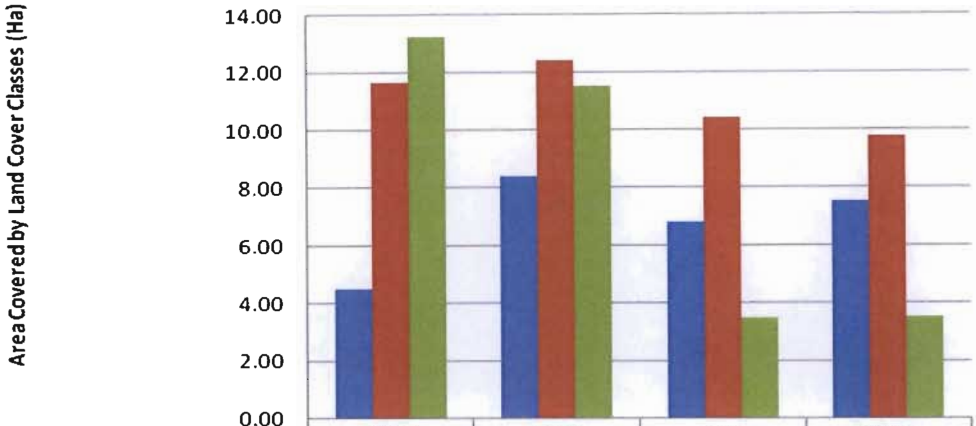
	1991	1997	2003	2008
Coastal Forest	7.12	5.69	14.07	14.06
Woodland	4.69	4.19	10.91	8.26

Figure A3: Changes in Coastal Forest and Woodland within Mgeni Estuary and Beachwood Mangrove Swamps



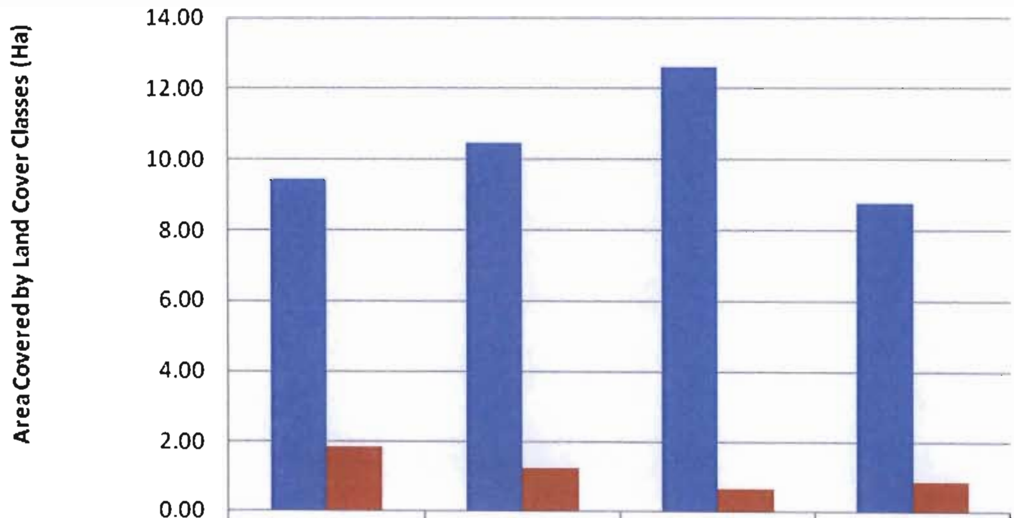
	1991	1997	2003	2008
Mangrove Vegetation	24.85	28.05	27.82	28.81
Island Mangrove Vegetation	1.38	0.52	1.53	3.17

Figure A4: Changes in Mangrove Forest and Island Mangrove Clusters within Mgeni Estuary and Beachwood Mangrove Swamps



	1991	1997	2003	2008
Reed Beds and Grasslands	4.51	8.38	6.79	7.54
Reed Beds and Marsh	11.64	12.38	10.43	9.78
Grassland and Scrub	13.21	11.51	3.47	3.52

Figure A5: Changes in Reed Beds, Marshes and Grassland within the Mgeni Estuary and Beachwood Mangrove Swamps



	1991	1997	2003	2008
Dune Vegetation	9.43	10.46	12.60	8.78
Salt Marsh	1.85	1.27	0.68	0.88

Figure A6: Changes in Dune Vegetation and Salt Marsh within the Mgeni Estuary and Beachwood Mangrove Swamps

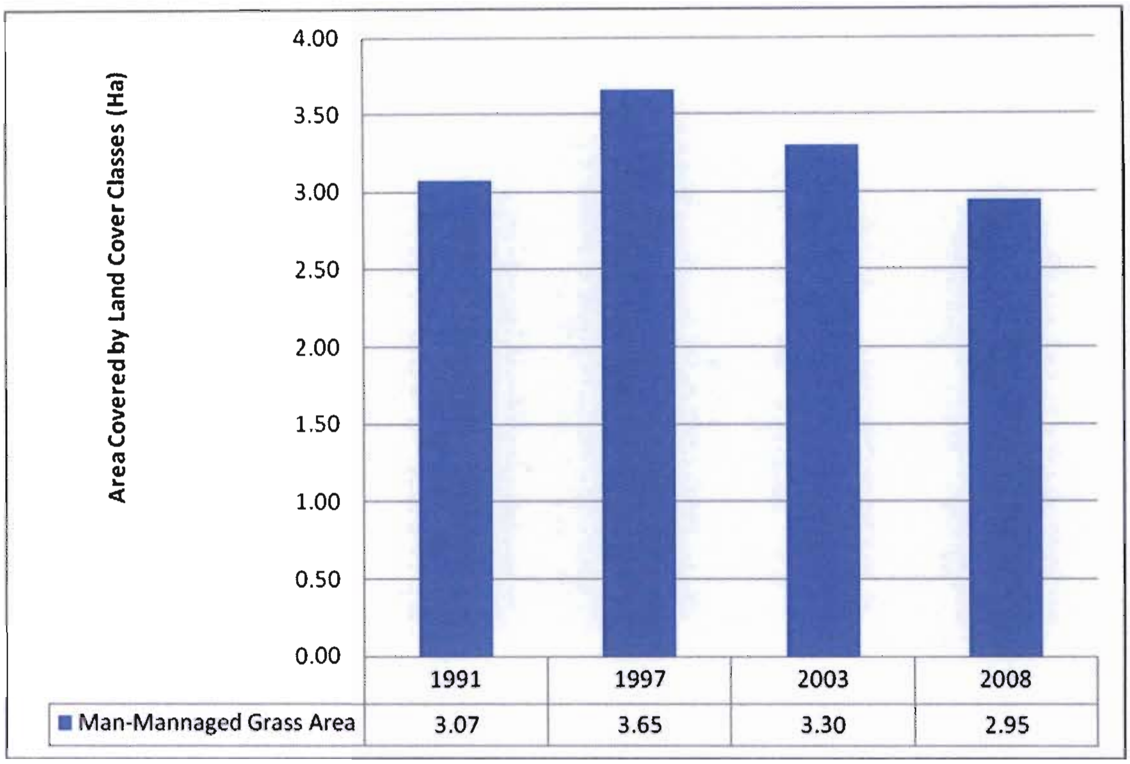


Figure A7: Changes in Man-Managed Grass Area within the Mgeni Estuary and Beachwood Mangrove Swamps

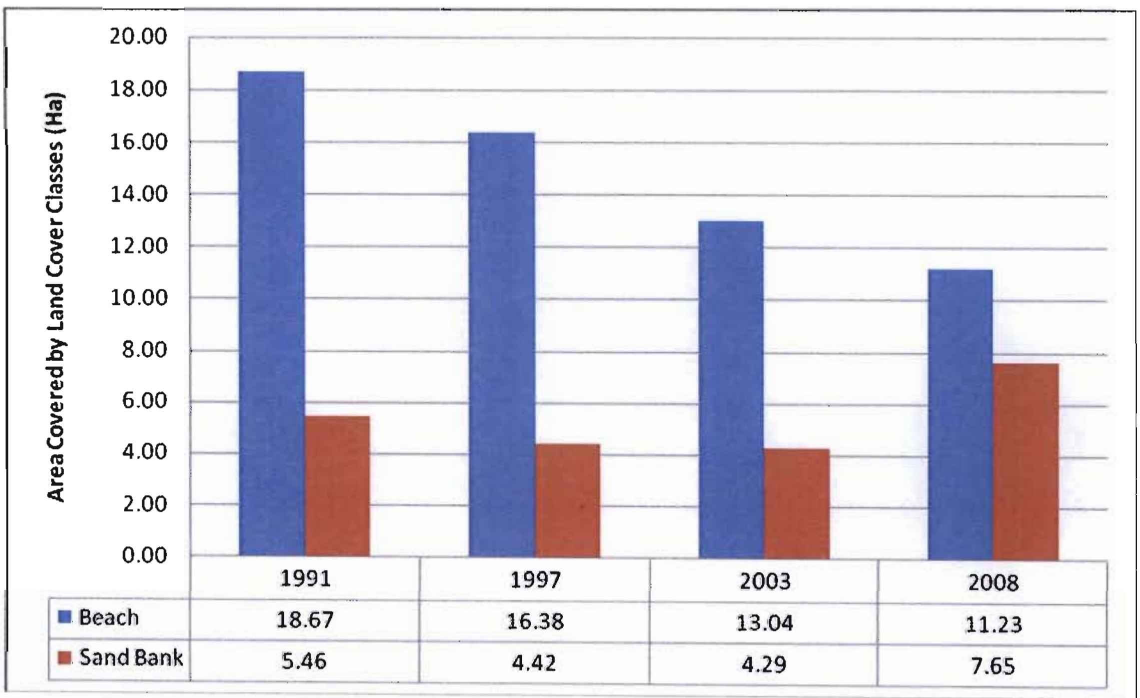


Figure A8: Changes in Sand Banks and Beaches within the Mgeni Estuary and Beachwood Mangrove Swamps

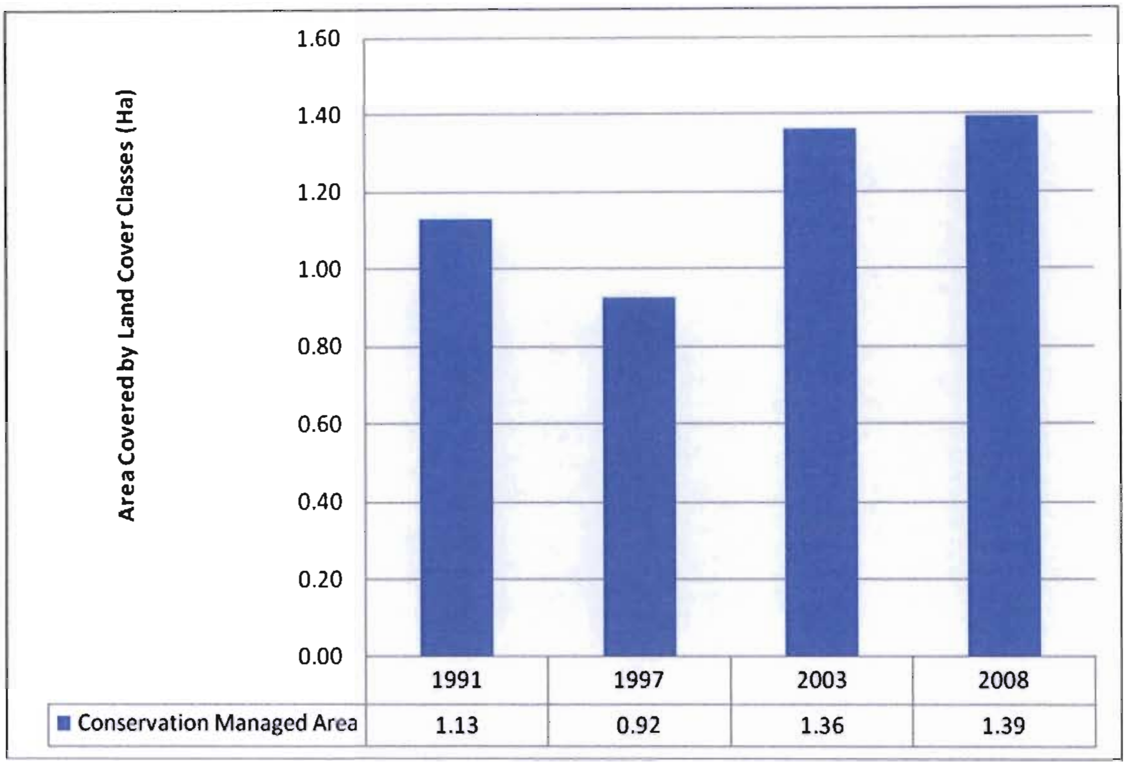
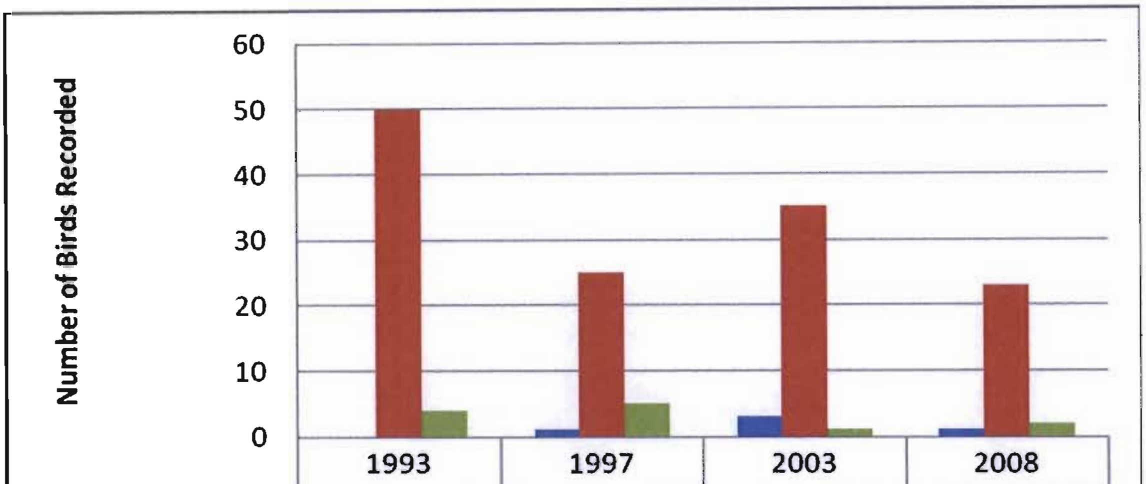


Figure A9: Changes in Conservation Managed Area within the Mgeni Estuary and Beachwood Mangrove Swamps

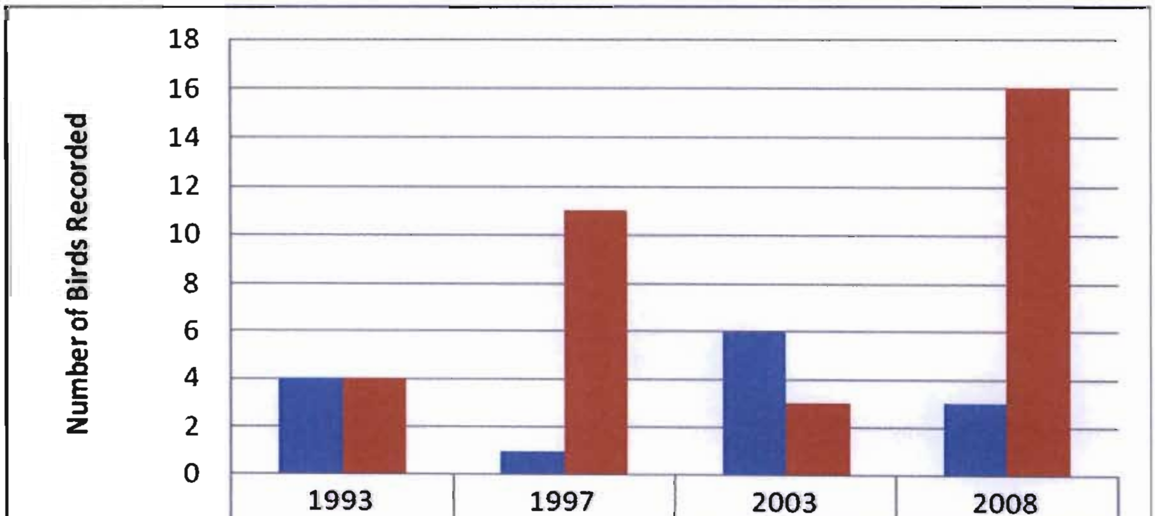
Appendix B

Comparison between Avian Indicator Populations (1993-2008)



	1993	1997	2003	2008
PB Pelican	0	1	3	1
WB Cormorant	50	25	35	23
African Darter	4	5	1	2

Figure B1: Decline in Open Water Avian Indicator Species in Study Area (1993-2008)



	1993	1997	2003	2008
Go Heron	4	1	6	3
L Egret	4	11	3	16

Figure B2: Increase in Shallow Water Avian Indicator Species in the Study Area (1993-2008)

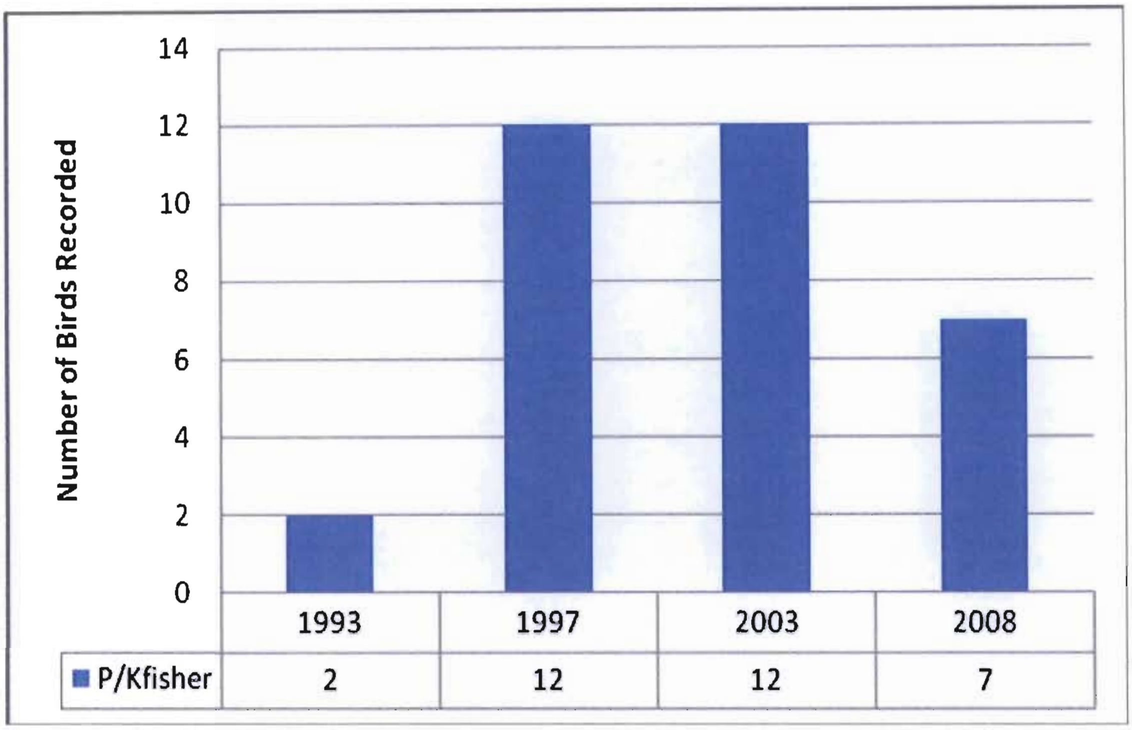


Figure B3: Pied Kingfisher Populations in the Study Area (1993-2008)

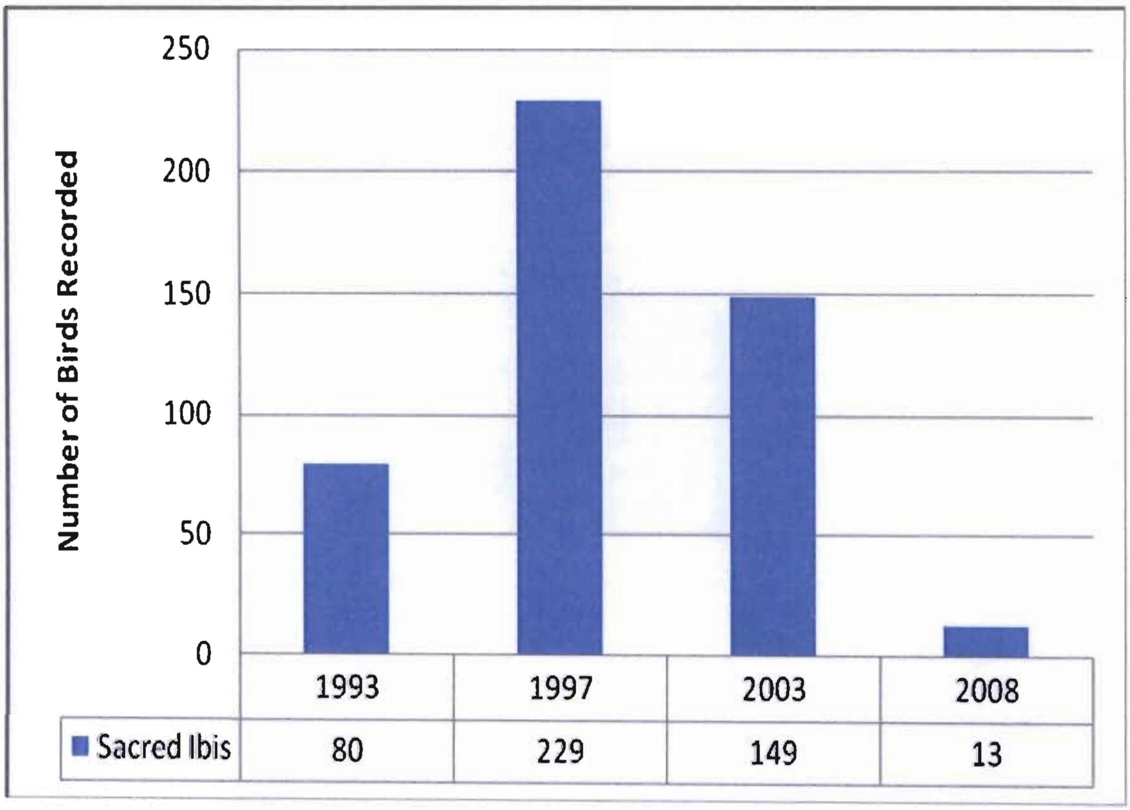


Figure B4: Declines in Sacred Ibis Population in Study Area (1993-2008)

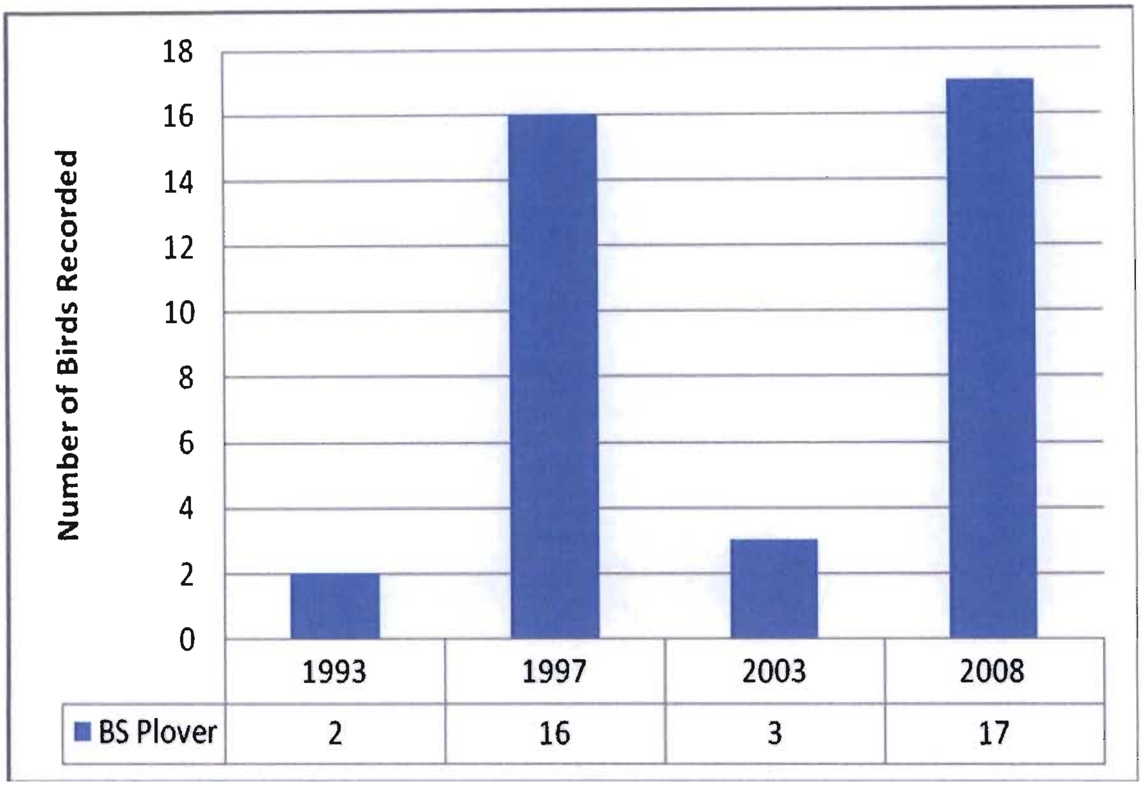


Figure B5: Increase in Blacksmith Plover Population in the Study Area (1993-2008)

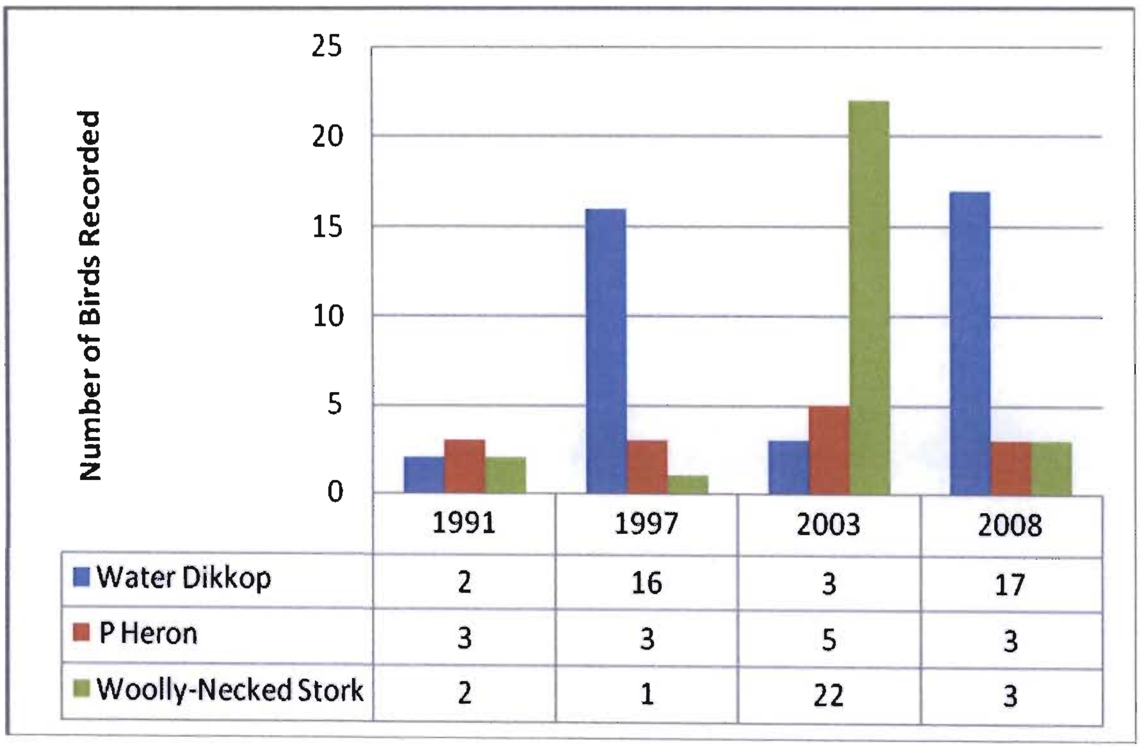
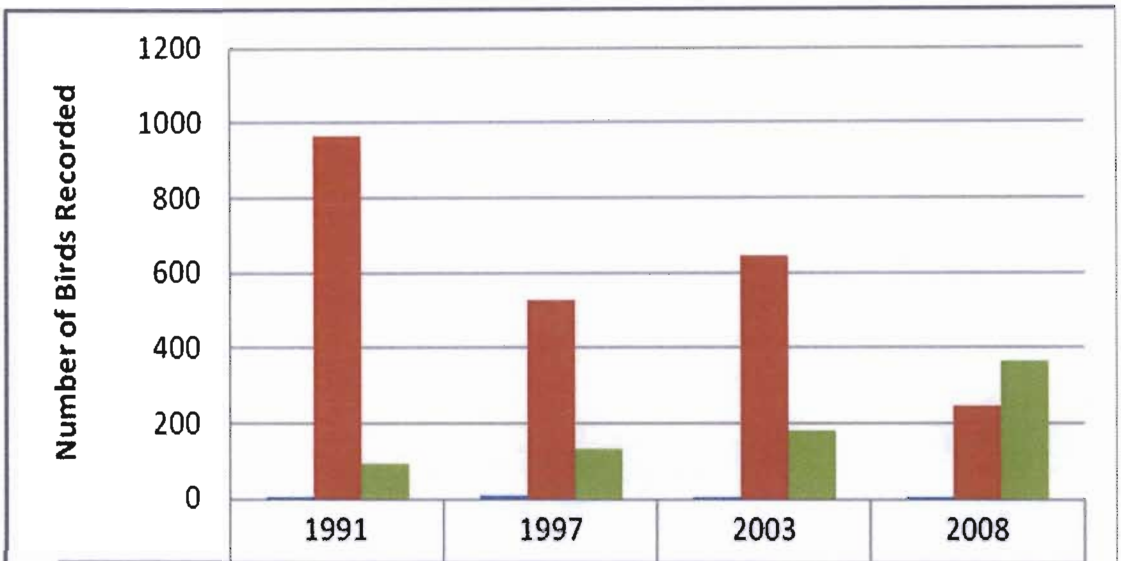


Figure B6: Increase in Vegetated Areas Indicator Species in the Study Area (1993-2008)



	1991	1997	2003	2008
Caspian	5	9	5	2
GH Gull	965	526	642	244
Swift Tern	93	133	180	365

Figure B7: Decline in Beach and Sand Bank Indicators in the Study Area (1993-2008)

Appendix C

Wetland Avian Indicator Species

The figures below represent the number of birds of each indicator species counted in the vicinity of the Mgeni Estuary and Beachwood Mangrove Swamps during CWAC Wetland Bird Surveys between 1993 and 2008.

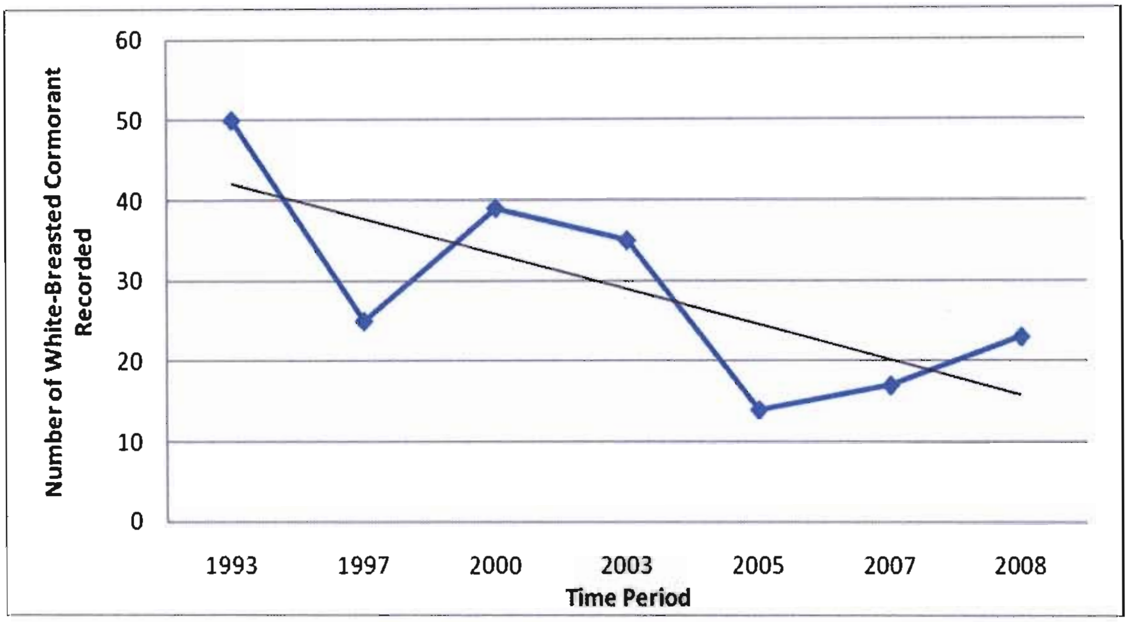


Figure C1: CWAC Wetland Avian Census Data for WB Cormorant (1993-2008

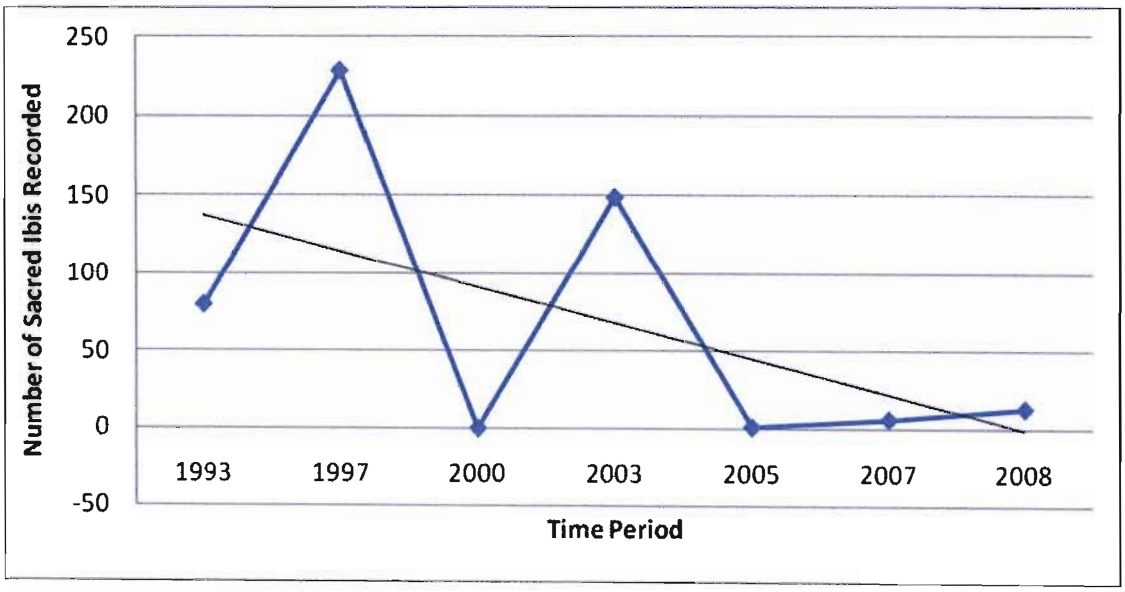


Figure C2: CWAC Wetland Avian Cencus Data for Sacred Ibis (1993-2008)

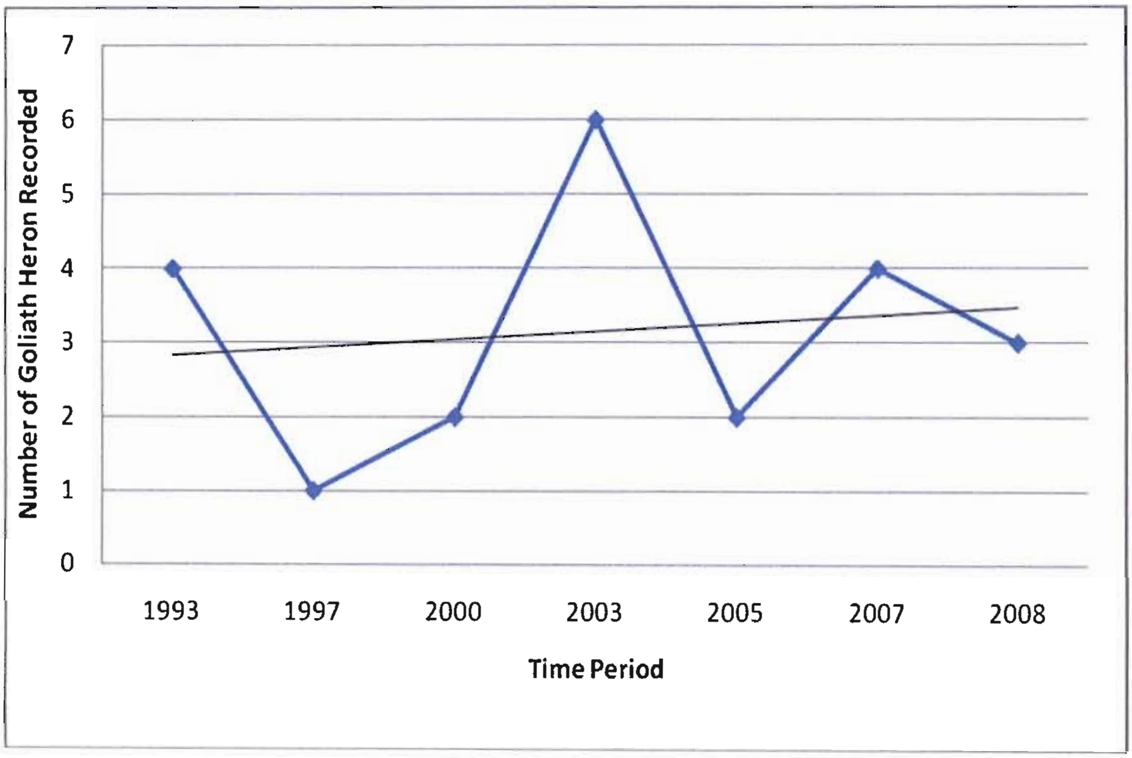


Figure C3: CWAC Wetland Avian Census Data for Goliath Heron (1993-2008)

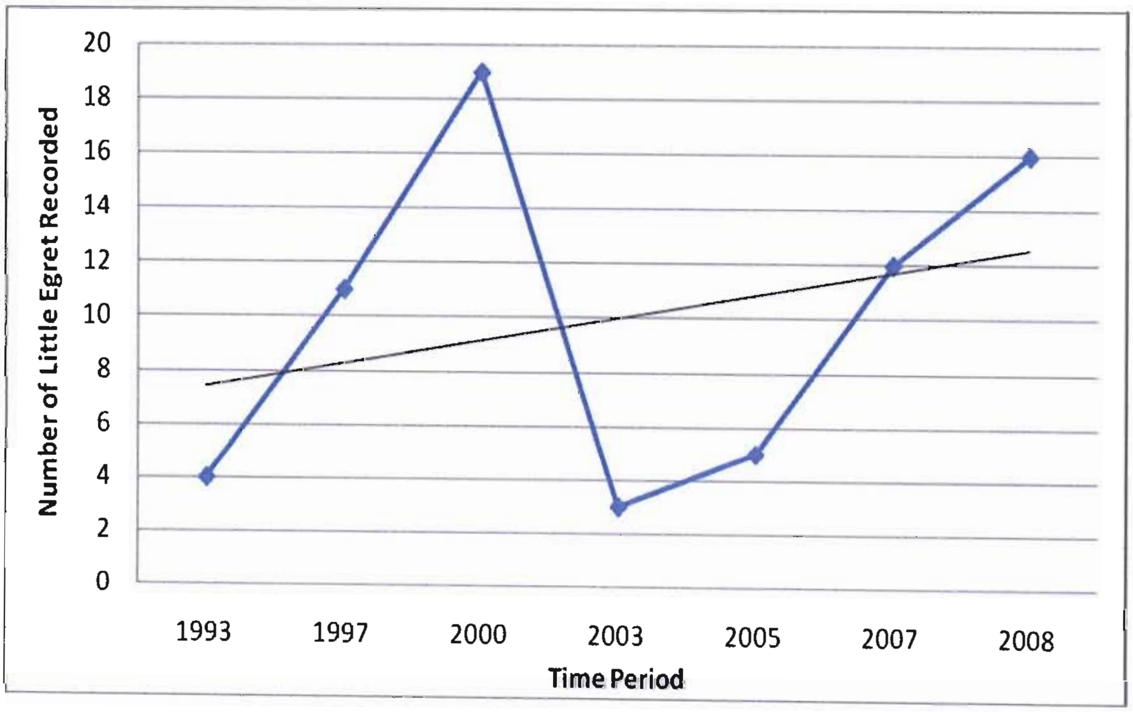


Figure C4: CWAC Wetland Avian Census Data for Little Egret (1993-2008)

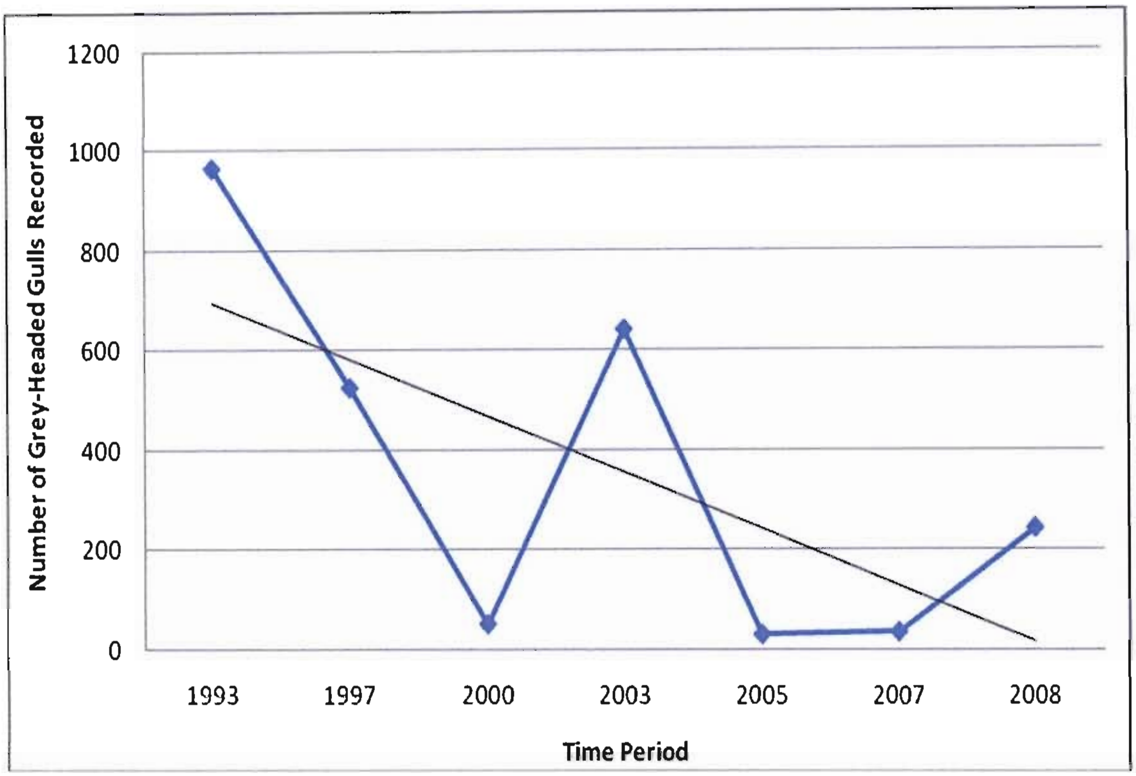


Figure C5: CWAC Wetland Avian Census Data for Grey-Headed Gulls (1993-2008)

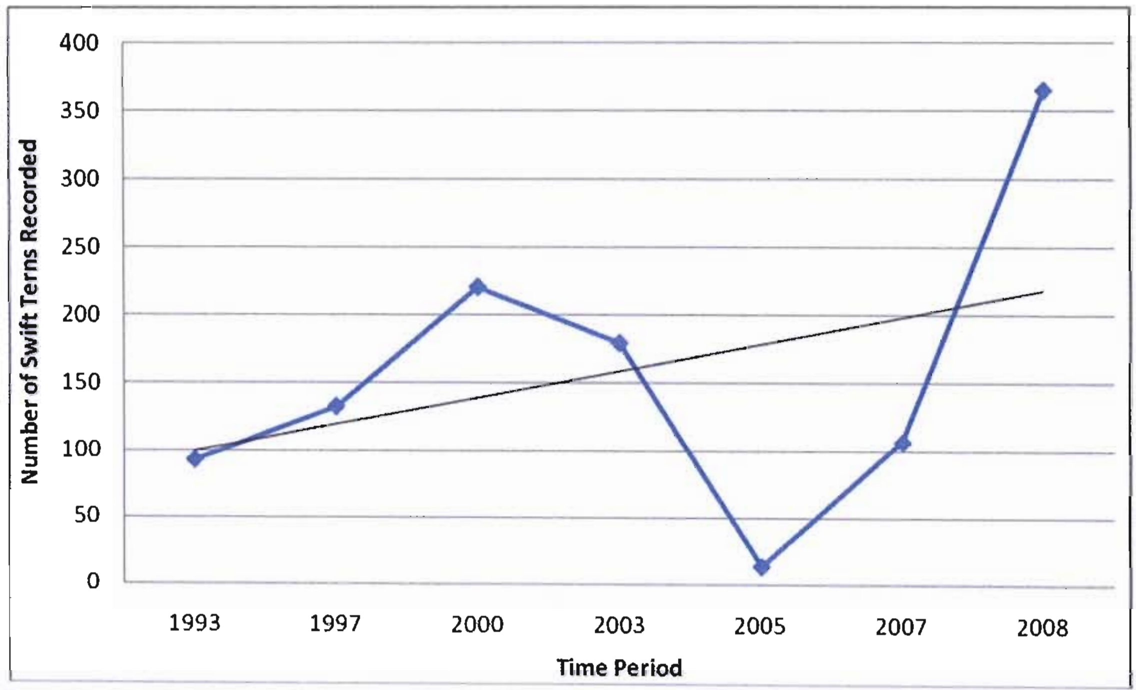


Figure C6: CWAC Wetland Avian Cencus Data for Swift Terns (1993-2008)

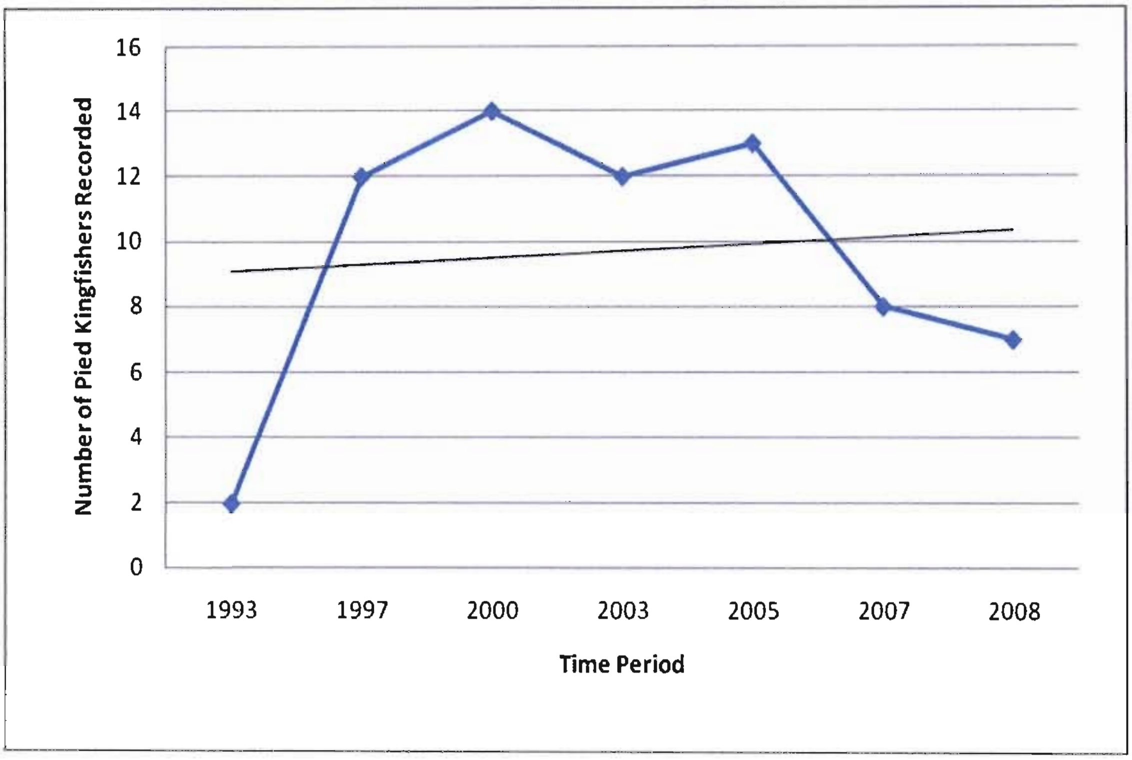
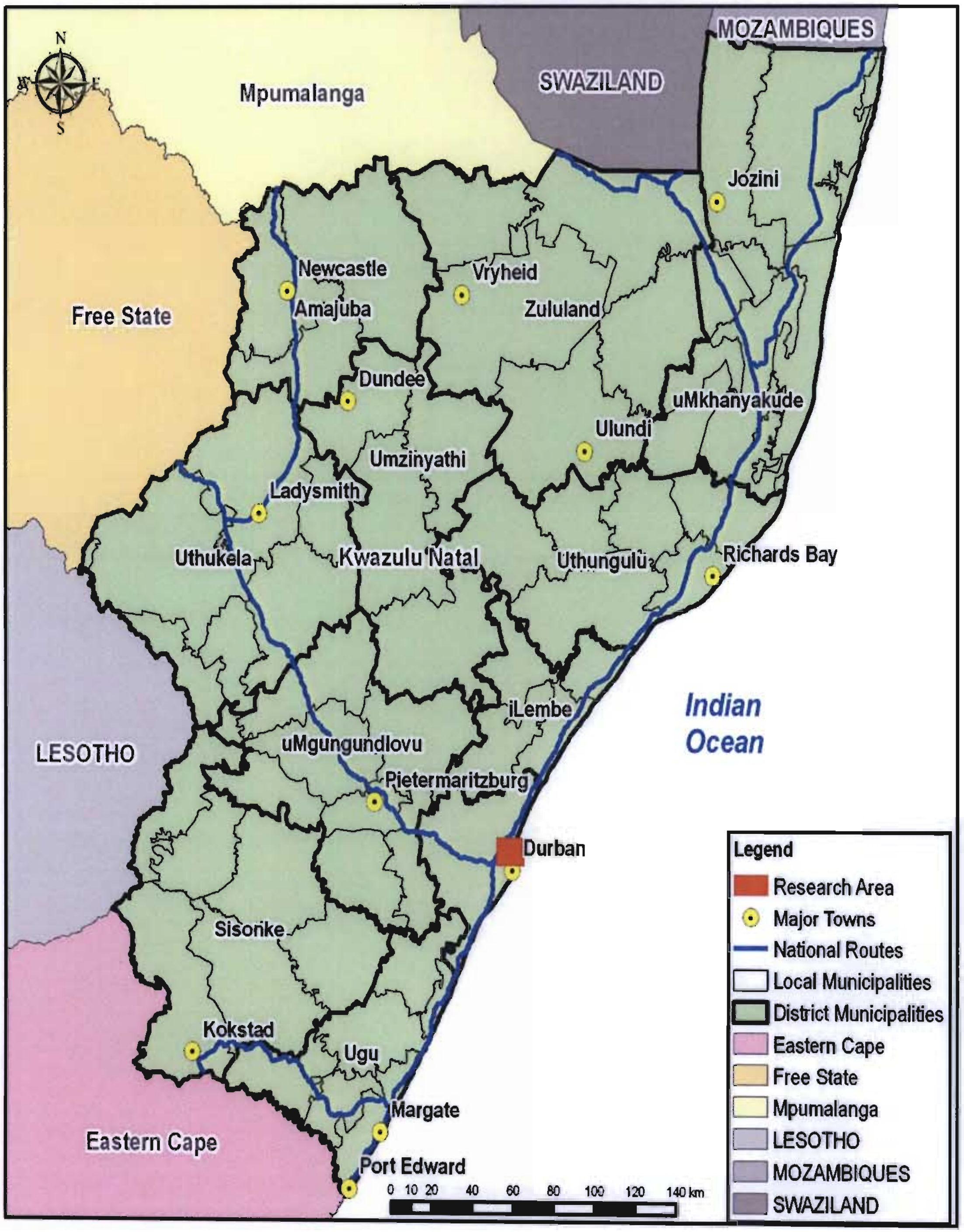


Figure C7: CWAC Wetland Avian Census Data for Pied Kingfisher (1993-2008)

Appendix D

Orientation Map



Appendix E

Estuarine and Mangrove Avian Indicator Species Provided by David Allen

Open and Shallow Water Avian Indicators

Pink Backed Pelican (*Pelecanus rufescens*)

Status:

Uncommon Resident

Description:

It is described as having grey under parts and a greyish white head and under parts during the non-breeding season. It has a pale yellow bill with a pink tip. The legs are yellow in colour. Breeding birds have a yellow bill pouch and the bill has a pink edge. The legs turn an orange yellow and there are pinkish feathers sprouting from the birds back.

Habitat:

Pink Backed Pelicans can be seen in small groups or large flocks either drying themselves on mudflats, or hunting for schools of fish in moderately to deep water.

Diet:

Small to Medium Size Fish

African Darter (*Anhinga melanogaster*)

Status:

Common resident

Description:

This species of waterbird has a long, thin neck and a 'kink', straight (not hooked) bill. The bird's plumage is rufous in colour and the body is generally slender in appearance (Newman, 1996). Males are normally blacker in colour and have visible long beige plumes on their mantles during the breeding season (Newman, 1996).

Habitat:

Inland and coastal waters, this species can be seen sun bathing on mud-flats and tree trunks in the Mgeni Estuary.

Diet:

Darters prey on fish of various different species and sizes and will forage in shallow, medium and deep water.

Whitebreasted Cormorant (*Phalacrocorax carbo*)

Status:

Localized resident

Description:

Whitebreasted Cormorants are large waterbirds with a white throat and breast area. Immature birds are normally identifiable because they have entirely white under parts according to Newman (1996).

Habitat:

This species consumes various different species of fish found within coastal waters, estuaries, lagoons and inland waters. This species is comfortable hunting for its prey in various different water depths, however, they prefer medium to deep water habitats. Visitors to the Mgeni Estuary will often see large flocks of Whitebreasted Cormorants drying themselves on mud-flats or trees (Newman, 1996).

Diet:

Small to medium size fish

Goliath Heron (*Ardea goliath*)

Status:

Common Resident

Description:

It is a robust bird with slated-grey upperparts and rich rufous under parts (Newman, 1996)

Habitat:

This species of heron can be found near rivers, lakes, pans and estuaries.

Diet:

The species will also move slowly along the shoreline hunting for frogs, mice, rats, snakes and other vertebrates. The Goliath Heron can frequently seen hunting in the deeper water of the Mgeni Estuary, standing motionless for long period waiting for its prey to come into range of its long, sharp bill (Newman, 1996).

Important Fact:

This species of heron is the largest of all herons.

Little Egret (*Egretta garzetta*)

Status:

Common Resident

Description:

This species of egret has a larger, longer neck than other species and the bill and legs are longer and black. The feet are yellow. The species can be identified easily by its unmistakable white head plumes (Newman, 1996).

Habitat:

Inland waters, estuaries and coastal pools (Newman, 1996).

Diet:

This species is a common resident often seen standing motionless in the shallows or walk forward slowly, stealthily hunting for small fish and aquatic and terrestrial invertebrates.

Pied Kingfisher (Ceryle Rudis)

Status:

Common Resident

Description:

The Pied Kingfisher is entirely black and white in colour.

Habitat:

This species of kingfisher often can be found in pairs or small parties inland on rivers or dams and at coastal lagoons and estuaries (Newman, 1996). The Mgeni Estuary and Beachwood Mangrove Swamps have a high population density of Pied Kingfishers due to the suitableness of shallow water habitats which are rich in small fish and invertebrates. However, Pied Kingfishers often can be seen hovering over deep water while fishing, then plunging into the water to seize their prey (Newman, 1996).

Diet:

Small fish and Aquatic and terrestrial invertebrates

Beach and Sand Bank Avian Indicators

Swift Tern (*Sterna bengii*)

Status:

Common Resident

Description:

This is the intermediate size to the Caspian tern. This species has a yellow bill and distinctive whitish grey plumage.

Habitat:

They occur in small groups in coastal waters and can be seen roosting on beaches and exposed mudflats of estuaries.

Diet:

Small fish

Caspian Tern (*Hydroprogne caspia*)

Status:

Common Species

Description:

They have a massive red bill and their overall size makes them unmistakable. These are the largest tern species in the region.

Habitat:

This is a common species of tern which can be found in pairs or small groups around large inland waters and lagoons.

Diet:

Small Fish

Grey Headed Gull (*Larus cirrocephalus)*

Status:

Common Resident

Description:

Distinctive grey hood and the bill, legs and feet are bright red. The eyes are yellowish white with a red ring around them.

Habitat:

Coastal habitats and inland water sources such as dams, rivers and lakes.

Diet:

Aquatic and terrestrial invertebrates, frogs and fish

Vegetable Area Avian Indicators

Water Dikkop (*Burhinus vericulatus*)

Status:

Common Resident

Description:

Pale grey wing panels with a narrow white bar that separates it from the Spotted Dikkop. Upperparts of adult birds are streaked.

Habitat:

Nocturnal species that can be found inhabiting the banks of large rivers, lakes, dams, estuaries and lagoons where there is a fringe of vegetation. This species can be found lying up during the day in reed beds or underneath overhanging bushes, trees and other vegetation.

Diet:

A dikkop's diet normally consists of invertebrates and foraging normally takes place at night.

Purple Heron (*Ardea purpurea*)

Status:

Nomadic Species

Description:

The Purple Heron is often mistaken for a Grey Heron at a distance. However, the two species are completely different in appearance and behaviour. The Purple Heron is smaller than the Grey Heron, and has a slender neck and thinner bill.

Habitat:

It prefers to seek shelter amongst dense vegetation along the shoreline along rivers and dams. Prefers dense reedbeds of Phragmites Reeds.

Diet:

Fish, amphibians, reptiles, invertebrates and small birds.

Interesting Fact:

This species is solitary and secretive.

Woolly-Necked Stork (*Ciconia episcopus*)

Status:

Common Resident and visitor

Description:

This large stork species has a woolly white neck and a head with a black face (Newman, 1996). The plumage on their wings and lower body is a dark brownish-black.

Habitat:

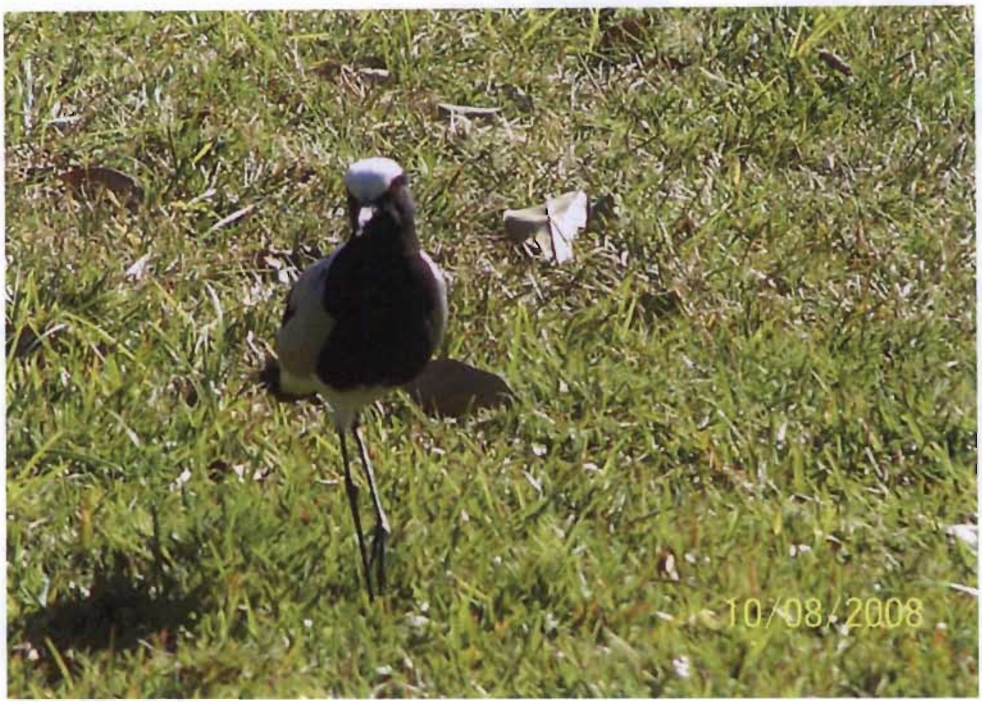
Woolly-Necked Storks can be found foraging in open grassland and marshy areas in small groups. However, large flocks have been recorded in the past.

Diet:

Prey normally considers of insects, amphibians and small mammals.

Mud Flat/ Wading Avian Indicator

Blacksmith Plover (Vanellus armatus)



Status:

Common Resident

Description:

Blacksmith Plovers have a pied appearance with grey wings and mantle (Newman, 1996).

Habitat:

The Blacksmith Plover is a common resident species which can be found in pairs and as scattered individuals (Newman, 1996). This species can be seen in a wide variety of different habitats raging from inland waters, coastal waters, estuaries and lagoons. Blacksmith Plovers can often be seen foraging in marshy areas, flooded fields, mud-flats and shallow water.

Diet:

Invertebrates and fish

Sanderling (*Calidris alba*)

Status:

Common Migrant

Description:

This is a small shorebird which is white in appearance with darker shoulder-patches. It has a short, thick bill which is used to probe the mud for worms and other organisms.

Habitat:

Found in estuarine habitats, in particular along the shoreline and on mud-flats. Sanderlings run along the water's edge at speed and feeding where the waves and water recede which is a characteristic of this species. A regular visitor to the Mgeni Estuary, the Sanderling is one of the most common summer migrants to Kwa-Zulu Natal's shores.

Diet:

Invertebrates

Curlew Sandpiper (*Calidris ferruginea*)

Status:

Common Migrant. This species is abundant during the summer months within the Mgeni Estuary and Beachwood Mangrove Swamp Ecosystems.

Description:

It is described as a common, small, curved-billed wading species. Curlew Sandpiper during the breeding season has a blotched rump and the underpants and face of the bird will become rufous. The male is generally brighter appearance than the female.

Habitat:

The Curlew Sandpiper forages and roosts within estuarine and mangrove ecosystems. Curlew Sandpipers can be observed forging in large flocks along the shoreline, wading into shallow water to consume small invertebrates. This species generally roosts on mud-flats according to ornithologists.

Diet:

Invertebrates

Little Stint (*Calidris minuta*)

Status:

Common summer visitor

Description:

This common visitor can be identified by their long slender bill and heavily blotched upperparts (Newman, 1996).

Habitat:

Little Stints have a sharp *'chit'* or rapid *'chitchitchit...'* call which can be heard while they forage along the shoreline and in the shallows in a hunched, head down posture which is characteristic of this species (Newman, 1996). This species can be found singly or in flocks at coastal estuaries, lagoons and inland water sources.

Diet:

Invertebrates

Sacred Ibis (*Threskiornis aethiopicus*)

Status:

Common Resident

Description:

The body is covered in white plumage whilst the head, neck and legs are black. It has a long curved black which is ideal for forging in the mud for invertebrates.

Habitat:

Sacred Ibises forage in large flocks in marshy area, dams and along the shoreline of rivers and estuaries.

Diet:

Sacred Ibises have been recorded consuming fish, vegetation and vertebrates. This species is a regular visitor to local rubbish dumps.

Appendix F

Ornithologist Report on Avian Indicator Species

Summary of Habitats, Diets, Roosting and Breeding Requirements Developed following Interviews with Local Ornithologists

Species	Habitat	Requirements		
		Dietary	Roosting	Breeding
Pink-Backed Pelican	Open Medium to Deep Water of estuaries, lagoons, lakes, dams and river systems. Mudflats and Sandbanks	Medium to Large Fish	Generally roost on secure mudflats and sandbanks in surrounded by water.	Breed in colonies on islands. PB Pelicans currently nesting at Botanical Gardens, Durban. Close proximity to water.
White-Breasted Cormorant	Open Medium to Deep Water of estuaries, lagoons, lakes, dams and river systems. Mudflats and Sandbanks	Medium to Large Fish	Generally roost on secure mudflats and sandbanks in surrounded by water. Will roost in trees and other foliage along water's edge.	Breed in colonies on island. Construct platform nests in trees. Close proximity to water.
African Darter	Open Medium to Deep Water of estuaries, lagoons, lakes, dams and river systems. Mudflats and Sandbanks	Medium to Large Fish	Generally roost on secure mudflats and sandbanks in surrounded by water. Will roost in trees and other foliage along water's edge.	Construct platform nests in trees. Normally breed in mixed bird colonies. Close proximity to water.

Goliath Heron	Open Medium to Deep Water of estuaries, lagoons, lakes, dams and river systems. Mudflats reedbeds, grassland, sandbanks and shoreline.	Invertebrates Medium to Large Fish Amphibians Reptiles Small birds and mammals	Generally roost on secure mudflats and sandbanks in surrounded by water. Will roost in trees and other foliage along water's edge.	Construct platform nests in trees. Normally breed in mixed bird colonies. Close proximity to water.
Purple Heron	Open Medium to Deep Water of estuaries, lagoons, lakes, dams and river systems. Heavily Vegetated reedbeds, marshes and mangrove swamps	Invertebrates Medium to Large Fish Amphibians Reptiles Small birds and mammals	Roosts amongst dense vegetation at ground level or roost in trees and other foliage along water's edge.	Nest singly as pairs in dense reedbeds and marsh habitat. Have been recorded building platform nest in trees. Close proximity to water.
Little Egret	Shallow water and pools. Found near estuaries, lagoons, lakes, dams and river systems. Mudflats reedbeds, grassland, sandbanks and shoreline.	Invertebrates Small Fish Amphibians Reptiles	Roosts amongst dense vegetation at ground level or roost in trees and other foliage along water's edge. Mudflats and Sandbanks	Construct platform nests in trees. Normally breed in mixed bird colonies. Close proximity to water.
Woolly-Necked Stork	Medium to shallow water of estuaries, lagoons, lakes, dams and river systems. Grasslands, marshes, reedbeds and other open areas.	Invertebrates Medium to Large Fish Amphibians Reptiles Small birds and mammals	Generally roost on secure mudflats and sandbanks in surrounded by water. Will roost in trees and other foliage.	Construct platform nests in trees. Breed as single pairs.
Water Dikkop	Grasslands, reedbeds, marshes and any vegetated cover in the vicinity of water bodies such as estuaries, lagoons, lakes,	Invertebrates Small Fish Amphibians Reptiles	Roosts amongst dense vegetation at ground level.	Nest in a scrap in the ground amongst dense vegetation.

	dams and river systems.			
Pied Kingfisher	Water bodies such as estuaries, lagoons, lakes, dams and river systems.	Invertebrates Small Fish Amphibians Reptiles	Roosts in trees and other foliage along water's edge.	Nests in hollowed out sandbanks and tree trunks.
Little Stint	Mudflats, sandbanks and shoreline of estuaries, lagoons, lakes dams and river systems.	Invertebrates Small Fish	Generally roost on secure mudflats and sandbanks surrounded by water.	Migrate to northern latitudes during winter months to breed.
Curlew Sandpiper	Shallow water areas of estuaries, lagoons, lakes dams and river systems. Mudflats, sandbanks and shoreline.	Invertebrates Small Fish	Generally roost on secure mudflats and sandbanks surrounded by water.	Migrate to northern latitudes during winter months to breed.
Sanderling	Shallow water areas of estuaries, lagoons, lakes dams and river systems. Mudflats, sandbanks and shoreline.	Invertebrates Small Fish	Generally roost on secure mudflats and sandbanks in surrounded by water.	Migrate to northern latitudes during winter months to breed.
Sacred Ibis	Shallow water areas of estuaries, lagoons, lakes dams and river systems. Mudflats, sandbanks, grasslands reedbeds and shoreline.	Invertebrates Small Fish Amphibians Reptiles Rubbish	Generally roost on secure mudflats and sandbanks surrounded by water. Will roost in trees and other foliage.	Construct platform nests in trees. Normally breed in mixed bird colonies. Close proximity to water.
Swift Tern	Forage in shallow, medium and deep water of estuaries, lagoons, lakes dams and river.	Invertebrates Small Fish	Generally roost on secure mudflats and sandbanks surrounded by water.	Scrap in ground on sandbanks, beaches or grassland areas.

	Mudflats, sandbanks and shoreline.			
Caspian Tern	Forage in shallow, medium and deep water of estuaries, lagoons, lakes dams and river. Mudflats, sandbanks and shoreline.	Invertebrates Small Fish	Generally roost on secure mudflats and sandbanks surrounded by water.	Scrap in ground on sandbanks, beaches or grassland areas.
Grey-head Gull	Forage in shallow, medium and deep water of estuaries, lagoons, lakes dams and river. Mudflats, sandbanks and shoreline.	Invertebrates Small Fish Amphibians Reptiles Rubbish	Generally roost on secure mudflats and sandbanks surrounded by water.	Scrap in ground on sandbanks, beaches or grassland areas.

Appendix G

Land Cover Classes Classification System

Land Cover Classes		**A Brief Description of Land Cover**
Indigenous and Invasive Forest and Woodland	Woodland	Tree Canopy cover between 30-60%
	Coastal Forest	Tree Canopy cover between 60-100%
	Mangrove Forest	Vegetation covers between 70-100%. Majority of vegetation cover consisting of mangrove tree species.
	Island Mangrove Vegetation	Vegetation covers between 40-60%. Majority of vegetation cover consisting of mangrove tree species.
Grasslands (Natural and Artificial)	Man-Managed Grass Area	Open artificial or natural grass covered area maintained by local municipality or other affiliated groups.
	Grassland Scrubland	Mixture of indigenous vegetation and grass cover.
Wetlands/Reedbeds	Reedbeds and Marsh	Vegetation covers between 70-100%. Majority of vegetation cover consisting of indigenous or invasive reed species.
	Reedbeds and Grassland	Vegetation covers between 30-40%. Mixture of grass, sedge and

		other vegetation species present.
Coastal Vegetation	Dune Vegetation	Dune adapted vegetation covers between 60-100%.
Water Bodies	Shallow Water	Water of a depth less than 1 meter
	Open Water	Water of a depth greater than 1 meter
Conservation Managed Area	**Development**	Areas of roads and buildings managed by KZN Ezembelo Wildlife.
Other Land Covers	Exposed Mudflats	Areas of exposed mud and sand within the vicinity of the river channel or estuary mouth.
	Sandbanks	Sand deposited by river and sea currents at mouth of estuary.
	Salt Marsh	Bear or partly vegetated ground highly saline in nature.
	Beach	Open area of sand used for recreational purposes.

Appendix H

CWAC Data Permission Request Form

Animal Demography Unit

Department of Zoology

University of Cape Town

Rondebosch 7701

South Africa

www.adu.org.za

Tel. +27 (0)21 6504698

Fax +27 (0)21 6503434

marius.wheeler@uct.ac.za

CWAC Data Request Sheet

Please provide the relevant information to allow me to process your data request effectively. You can send the form back to the CWAC project coordinator: marius.wheeler@uct.ac.za. Upon receiving the request I will be in touch regarding availability, permission, conditions of data use and costs if applicable.

Date: 01/06/2009

Name: Andrew Batho

Company / Affiliation: Private use (Masters Research Paper)

Postal address: 7 Barn Place Westville Durban 3630

Email address: andybatho@gmail.com

Contact telephone number: 0836019411

Please give us an indication of the data you require:

(For site data, give the correct site name(s) and if possible site code(s). Also give an indication of which counts you need; specific counts or do you require all counts?)

- I request all available data relating to the Umgeni Estuary

(For species data, give the name of the species you need data for, including the species code(s) if possible. If you require specific information, please let us know what exactly you need.)

- Request data on all bird species counted within the Umgeni Estuary and surrounding area.

Please give us a brief but adequate description of what the above CWAC data is intended to be used for and if, and what, deliverables will be produced:

Appendix I

Review of Avian Indictor Performance as Land Cover Change Indicator Species

As already stated, certain avian indicator species proved to be effective indictaor species forr monitoring land cover change within an esturine and mangrove ecosystem. The table below presents these findings:

Avian Indicator	Land Cover Class
Water Dikkop	Reed Beds, Marshes and Grassland
Little Stint	Exposed Mudflat
Grey-Headed Gull	Beach and Sand Bank
Swift Tern	Beach and Sand Bank
Pink-Backed Pelican	Open Water

Other avian indicator species showed potential as indictaor species for monitoring land cover change within an esturine and mangrove ecosystem. These are shown in the table below.

Avian Indicator	Land Cover Class
African Darter	Open Water

The following avian indicator species appeared to be ineffective as a montiroing tool for land cover change within an esturine and mangrove ecosystem.

Avian Indicator	Land Cover Class
Woolley-Necked Stork	Reed Beds, Marshes and Grassland and Grassland and Scrub
Purple Heron	Reed Beds, Marshes and Grassland and Grassland and Scrub
Black-Smith Plover	Exposed Mudflat

Caspian Tern	Beach and Sand Bank
Sanderling	Exposed Mudflat
Sacred Ibis	Exposed Mudflat

Appendix J

Criteria Utilised for Selecting Avian Indicators

The Little Stint is the smallest wading bird species was considered ideal as a mudflat indicator species because it is adapted to hunting for its prey on exposed mudflats, and is a regular visitor to the Mgeni Estuary. The Little Stint has small legs which prevent it wading into the deeper water channels and estuary itself, plus it has a small beak which cannot probe far beneath the surface of the mudflats. Little Stints rely entirely upon mudflats as a source of nutrients (Velásquez and Hockey, 1992). Other mudflat zone indicator species such as Curlews and Sandpipers, are recognisable because of their larger body size correlating with a larger beak and longer legs adapted to wading into deeper water as mentioned previously. The longer bill provides these wading species with the ability to probe deeper into mudflats and sandbanks to catch prey. Meanwhile, Black-Smith Plovers are exclusively a visual foraging bird species. Black-Smith Plovers have a small beak designed for shallow probing and securing prey on the surface of exposed mudflats (Velásquez and Hockey, 1992). Sacred Ibis are described as a generalist species because of their ability to forage in a variety of different habitats ranging from the exposed mudflats of an estuarine ecosystem to man-made waste disposal sites further inland. However, the researcher observed ibis congregating and foraging on exposed mudflats and sandbanks within the Mgeni Estuary and Beachwood Mangrove Swamp study area on a regular basis throughout the cause of the study. Therefore, based on the information provided by avian literature and ornithologists, and the researchers own observations, the Little Stint, Curlew Sandpiper, Sanderlings, Sacred Ibis and Black-Smith Plover were selected as an indicator species for mudflat habitats that are found along the main Mgeni Estuary waterways and channel.

The researcher selected African Darter, White-Breasted Cormorant and the Pink-Backed Pelican as medium to deep water habitat indicators based on the information provided by avian literature and advice provided by ornithologists. These sources indicated that cormorants, darters and pelicans forage exclusively in open, deep water habitats such as the channels of rivers, estuaries and lagoons (Velásquez and Hockey, 1992). Pelican species forage in open water of the estuary channels and inlets and generally consume prey that has been caught just below the water's surface. Cormorants and darters forage for a variety of different fish species by diving beneath the water's surface and hunting amongst submerged logs, water vegetation and other obstacles below the surface.

Herons, storks and egrets have adopted a wading foraging technique. Goliath Herons and Little Egrets are ideally adapted to their chosen foraging habitats and prey species with long legs to carry them above the water quickly and efficiently, a long snake-like flexible neck and a robust beak to grasp and restrain struggling prey (Allen, 2008). White Egret tends to forage in shallow water of an average depth of 100mm, while Goliath Heron can be found foraging in water of a depth of 325mm (Velásquez and Hockey, 1992).Goliath Herons and Little Egrets are often seen moving steadily through shallow and medium deep water along the estuarine shoreline, moving their feet around amongst the mud and vegetation of the estuary bottom to scare fish, amphibians and other prey out into the open. When the bird observes movement below the water surface, it will plunge its beak into to water to catch the prey item. Herons and egrets have perfected a second foraging technique that helps conserve value energy. Little Egrets will often standing motionless, practising a 'sit-and-wait' strategy to catch unsuspecting prey along the water's edge (Velásquez and Hockey, 1992). These foraging techniques unique to the heron, stork and egret species and the reliance on water habitats for foraging, provided the researcher with adequate empathises for the selection of the Goliath Heron and Little Egret as Medium and Shallow Water Zone Indicator Species.

Kingfisher species either hover in the air above open water or the shallows trying to locate a fish, before plunging at great speed into the water to catch their prey (Velásquez and Hockey, 1992). This foraging technique allows Pied Kingfishers to forage successfully over a wide range of different water habitats that range from shallow tidal pools to the open estuary channel. This adaptability provided adequate motivation for the selection of Pied Kingfisher as a Water Zone Indicator.

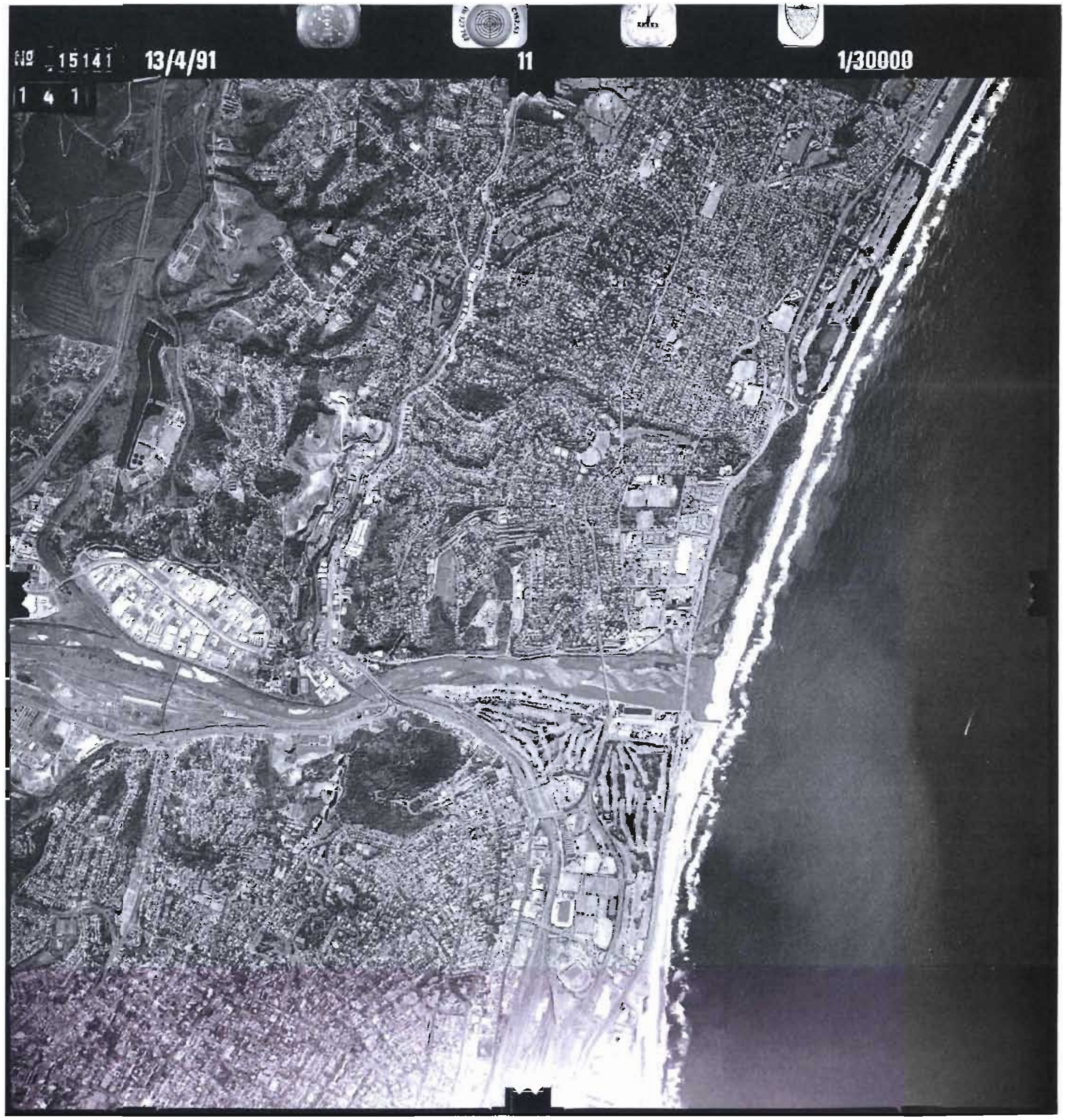
Based on observations and the advice provided by local ornithologists and birders, the researcher selected the following wetland bird species as Vegetated Area Indicators: Woolley-Necked Stork, Purple Heron and the Water Dikkop. These species were selected by the researcher because of their reliance on swampy, vegetated habitats for foraging, roosting and reproduction. Woolly-Necked Storks are usually seen foraging singly and in small groups moving through vegetated areas such as marshes, open grasslands and along the shorelines of pans, dams, rivers and estuaries (Allen, 2008). This species tends to prefer swampy, well wooded regions of Southern Africa, and the lush vegetation and swampy nature of the Mgeni Estuary and Beachwood Mangrove Swamp study area make it an ideal habitat for this stork species. Ornithologists indicated that the Purple Heron is a permanent resident within the Mgeni Estuary and the adjacent Beachwood Mangrove Swamps, but its solitary and secretive nature makes it difficult to observe. This species favours the security and shelter of dense reed beds and marshes adjacent to pans, lakes, rivers and estuaries. Water Dikkop rely on dense vegetation fringing rivers, lakes and estuaries for shelter, foraging and reproduction. This species lies up during the day in reed beds, marshes and other vegetation, becoming active at dusk (Allen, 2008). These requirements make these species ideal indicator species for vegetated areas within the study area, because any disturbance or alteration to these habitats would have a detrimental impact upon the local resident population of these species.

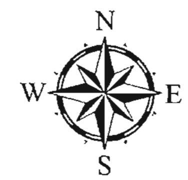
Grey-Head Gulls, Caspian and Swift Terns were identified as Dune and Shoreline Indicator Species based on the researchers own observations and discussions with ornithologists. Caspian and Swift Terns were regularly observed roosting on the beach adjacent to the Beachwood Mangrove Swamps and the sand banks at the mouth of the Mgeni Estuary. Further examination of avian literature and interviews with ornithologists indicated that these species tend to favour roosting on beaches, mudflats and sand banks close to waterbodies. Ornithologists also indicated that gulls and terns are nomadic and will forage over a wide area, instead of relying on one specific location for foraging. Basically these species are not reliant on the study area for foraging. For example, Grey-Head Gulls are scavengers and the close proximity to the large refuse dump in the Springfield area encourages large numbers of gulls to move away from the estuary and mangrove swamps during the day, returning at night to roost.

Appendix K

Aerial Photography of Study Area

1991, 1997, 2003 and 2008





Mgeni Estuary and
Beachwood Mangrove
Swamps
1991 Land Cover

Mgeni Estuary and
Beachwood Mangrove
Swamps
1997 Land Cover


31°0'30"E
31°1'0"E
31°1'30"E
31°2'0"E
31°2'30"E
31°3'0"E
29°47'30"S
29°48'0"S
29°48'30"S
29°49'0"S
Kenville
Greenwood Park
Broadway
Parkhill
Sea Cow Lake
Athlone
Beachwood
Briardene
Prospect Hall
INDIAN OCEAN
Beachwood Mangrove Swamps
Umgeni Park
Mgeni River Estuary
Blue Lagoon
Springfield Flats
Stamford
Durban Beach
Morningside
Springfield
Mgeni Estuary and Beachwood Mangrove Swamps 2003 Land Cover


31°1'0"E
31°1'30"E
31°2'0"E
31°2'30"E
31°3'0"E
29°47'30"S
29°48'0"S
29°48'30"S
INDIAN OCEAN
Beachwood Mangrove Swamps
Mgeni River Estuary
N
W
E
S
0 100 200 400 600 m
Mgeni Estuary and Beachwood Mangrove Swamps 2008 Land Cover