

BIRDS AND THE URBAN ECOLOGY OF POTCHEFSTROOM

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Abstract

Human activities cause drastic changes in the environment, such as the fragmentation of habitats, which is the greatest threat to the world's biodiversity and biogeography. By using birds to study habitat changes, it is possible that the type of habitat qualities that may still be possible near and in cities could be determined. It is possible that by improving the quality or conditions of habitats for birds, habitat qualities for other fauna would also improve. Birds are also considered to be good indicators as they are collectively sensitive to changes in their environments; however, they are also easy and relatively inexpensive to survey.

There is no single definition for an urban area, however, these are the places where environmental problems greatly affect the quality of life. Urbanisation is a continuous complex process and in order to understand the ecology of urban areas, the reasons and factors behind this process need to be understood. Cities themselves represent the extremes of human-modified environments and usually only contain a few remnants of the original habitat. On the other hand, many cities in South Africa are characterised by secondary woodland, as trees and other plants are planted in gardens and parks. This creates habitat that could be advantageous to birds. Biotopes have been used to map this aspect of cities, and it has generally been assumed that birds will distribute accordingly.

The hypothesis for this study was as follows: Due to the mobility of birds, coupled with their ability to use multiple biotopes (e.g. nesting and feeding), urban bird communities or bird demography will show patterns different from vegetation and structure based biotopes alone, and could therefore be considered as avitopes.

The primary aim of this study was to determine the distribution patterns of avian diversity in Potchefstroom. Secondary aims/objectives for this study included:

- Determining the bird species distribution in Potchefstroom using point counts
- Determining the distribution of feeding and nesting guilds in Potchefstroom
- Determining whether it is possible to identify urban avian indicators with this type of research
- To investigate, develop and define the concept of “active-habitat selectors” (AHS)
- To introduce, develop and define the concept of “avitopes”

The research area included the city of Potchefstroom, with its associated suburban areas, Ikageng, Promosa, Mohadin, the rural areas and the surrounding natural areas. Point counts were used to identify bird species at 56 different sites. The data was analysed using two different programmes, GS+ and Primer 5. The data was analysed according to species richness, species abundance and numbers of birds.

I found that species were most abundant in the agricultural areas, the eastern residential areas and the military areas. The socio-economic factors affecting the abundance and distribution of all the species, still needs to be further researched. When looking at the total avian biomass for this study, biomass was highest in the industrial area, which is probably the most highly urbanised site in the study area, due to the high numbers of doves and pigeons. The results for species richness indicated that the greatest species richness occurred in the less highly urbanised areas, and was lowest in the more highly urbanised (industrial) areas. The lower half of the western part of Ikageng also had a low species richness, even though this is not a highly urbanised area. However, it is possible that conditions in this area are highly unsuitable for bird species due to various reasons such nesting availability, resource availability, density of people etc.

When looking at the results for granivores, the majority of the species, and more so their numbers, were found primarily in the urbanised areas, with

some present in the agricultural areas. However, this could possibly be put down to the fact that the agricultural areas are primarily a foraging area. In the case of omnivores, the highest numbers were found in the military areas and included only a small part of the very top section of the residential areas. The military areas are not highly urbanised areas. However, it is possible the reason for their low occurrence in the more urbanised areas was due to the insufficient observation time, since omnivores were observed in many of the more urban areas whilst not sampling in those areas. Omnivores and granivores are superior competitors when compared to other species, as they are better able to exploit urban food resources.

In the case of the insectivores, the majority of them were located outside of the more urbanised areas; however, a focal point did occur in the very southern tip of the eastern residential areas. It is possible that they nest in this part of the residential areas but forage in the nearby agricultural areas.

Birds were therefore not restricted to a single area or biotope, as they are able to utilise various suitable areas for different purposes e.g. foraging, nesting etc. Because of their mobility and ability to choose a suitable habitat, I have introduced the concept of active-habitat-selectors (AHS) in this study. Various elements support this idea, such as birds being able to choose a suitable habitat through choice, rather than as an automatic response, and that birds are able to continuously select habitats to support their needs etc. A preliminary definition for AHS could be the following:

Active habitat selectors are those species of which the adult individuals within their lifetime are almost continuously able to select multiple, suitable habitats for different purposes, through choice, due to their mobility and comparative knowledge of different available habitats that are in range.

The concept of avitopes has also been introduced and various elements have been taken into account with its definition. Some of these elements include, birds are good indicators of environmental change, they are not restricted to

any single areas, etc. Various elements should be considered when defining avitopes. A preliminary definition could be:

Avitopes are geographically delineated areas, defined by diversity indices, and do not take into account non-naturally occurring, non-vagrant, and otherwise generalist bird species.

There are still arguable aspects of these definitions, which will require more development, refinement and research.

All the objectives for this study have been achieved and new issues identified, that will require further investigation.

Opsomming

Menslike aktiwiteite veroorsaak dramatiese veranderinge in die omgewing, soos die fragmentering van habitats, wat die grootste bedreiging vir die wêreld se diversiteit is. Deur van voëls gebruik te maak om habitatsveranderinge te bestudeer, is dit moontlik dat die tipe habitatkwaliteite wat steeds naby of binne stede moontlik is, te bestudeer. Dit is moontlik, deur die kwaliteitskondisies vir voëls te verbeter, dat habitatkwaliteite vir ander fauna ook sal verbeter. Voëls word ook as goeie indikatore beskou, aangesien hulle as groep sensitief is vir veranderinge in hul omgewing. Hulle is egter ook relatief goedkoop en maklik om te identifiseer en te monitor.

Daar is geen enkele definisie ten opsigte van 'n stedelike gebied nie, maar, hierdie is die plekke waar omgewingsprobleme duidelik die kwaliteit van lewe beïnvloed. Verstedeliking is 'n aanhoudende, komplekse proses, en, om die ekologie van stedelike gebiede te verstaan, moet die redes en faktore grondliggend aan hierdie proses verstaan word. Stede verteenwoordig die uiterstes van mens-gemaakte omgewings en bevat gewoonlik slegs 'n paar oorblyfsels van die oorspronklike habitat. Aan die ander kant, word 'n menigte Suid-Afrikaanse stede gekenmerk deur sekondêre boomveld, siende dat bome en ander plante in tuine en parke aangeplant word. Dit skep habitatte wat voordelig kan wees ten opsigte van voëls, en dit word algemeen aanvaar dat voëls dienoreenkomstig sal versprei.

Die hipotese vir hierdie studie is as volg: Weens die beweeglikheid van voëls, gepaardgaande met hul vermoë om veelvoudige biotop te gebruik (soos nesmaak en voedselverkryging), sal stedelike voëlgemeenskappe verspreidingspatrone toon wat nie streng met plantegroei en struktuur-gebaseerde biotop sal ooreenstem nie. Hierdie verspreidingspatroon noem ek 'n "avitoop".

Die primêre doelwit van hierdie studie was om te bepaal wat die verspreidingspatrone van voëldiversiteit in Potchefstroom is. Sekondêre doelwitte vir hierdie studie was die volgende:

- Om die verspreidingspatrone van voëlspesies in Potchefstroom te bepaal
- Om die voedings- en broeigildes van voëls in Potchefstroom te bepaal
- Om te bepaal of dit moontlik is om stedelike voël-indikatore vir hierdie tipe navorsing te bepaal
- Om die konsep van “Aktiewe Habitat Selekteerders” (AHS) te ondersoek en te definieer
- Om die konsep van “avitoop” bekend te stel, te ontwikkel en te definieer

Die navorsingsgebied sluit Potchefstroom, met sy geassosieerde voorstede van Promosa, Mohadin, Ikageng en die plattelandse dele in. Puntopnames is gebruik om voëlspesies op 56 verskillende, eweredig gespaseerde punte te identifiseer en te tel. Die data is geanaliseer deur van twee verskillende programme gebruik te maak, nl. GS+ en Primer 5. Die data is geanaliseer volgens spesie-rykheid en volopheid van voëls.

Ek het gevind dat spesies meer volop was in die landbou-gebiede, die oostelike residensiële gebiede en die militêre gebiede. Die sosio-ekonomiese faktore wat die oorfloed en verspreiding van al die spesies beïnvloed, moet egter verder ondersoek word. Wanneer gekyk word na die totale voël-biomassa vir hierdie ondersoek, was biomassa die hoogste in die industriële gebied, wat moontlik ook die mees bevolkste deel in die gebied was, weens die hoë getalle duiwe. Die resultate vir spesie-rykheid het aangedui dat die grootste mate van spesie-rykheid voorgekom het in die minder verstedelike gebiede, en was op sy laagste in die meer verstedelike (industriële) gebiede. Die onderste helfte van die westelike gedeelte van Ikageng het ook lae spesie-rykheid gehad, selfs al is hierdie nie 'n hoogs-verstedelike gebied nie. Dit is egter moontlik dat toestande in hierdie

gebiede, weens verskeie redes soos nesplek-beskikbaarheid, hulpbron-beskikbaarheid, mensdigtheid, ens, baie ongeskik is vir voël-spesies.

Wanneer gekyk word na die resultate vir graanvreters, wat die meeste van die spesies verteenwoordig het, is die meerderheid in stedelike gebiede gevind, met sommige teenwoordig in die landelike gebiede. Dit kan egter wees dat landelike gebiede as voedingsgebiede gebruik word. In die geval van omnivore is die meeste in die militêre gebiede gevind, en het slegs 'n klein gedeelte van die boonste deel van die residensiële gebiede ingesluit. Die militêre gebiede is nie hoogs-verstedelike gebiede nie. Dit is egter moontlik dat die rede vir die lae voorkoms in die meer verstedelike gebiede te danke is aan die ontoereikende waarnemingstyd, omdat dat omnivore wel op tye waargeneem wanneer daar nie opnames gedoen is nie. Omnivore en graanvreters is goeie kompeteerdere wanneer hulle vergelyk word met ander spesies, siende dat hulle stedelike voedselbronne beter kan benut.

In die geval van insektivore, is die meerderheid van hulle buite die stedelike gebiede gevind. 'n Fokuspunt het egter die suidelike punt van die oostelike gebiede voorgekom. Dit is moontlik dat hulle broei in hierdie deel van die stedelike gebiede, maar dat hulle in die aangrensende landelike gebiede voed.

Voëls is daarom nie beperk tot 'n enkele gebied of biotoop nie, siende dat hulle 'n verskeidenheid van verskillende gebiede vir verskillende doeleindes, soos voedselvergaar en nesmaak, kan gebruik. Weens hul beweeglikheid en vermoë om 'n paslike habitat te kies, het ek die konsep van "Aktiewe Habitat Selekteerders" (AHS) in hierdie studie voorgestel. Verskeie waarnemings ondersteun hierdie konsep; voëls verkies sekere habitats deur die uitoefening van keuse, eerder as 'n outomatiese reaksie, en dat voëls die vaardigheid het om voortdurend van habitat kan verander om aan hul behoeftes te voldoen. 'n Voorlopige definisie vir AHS lui as volg:

Aktiewe habitat selekteerders is daardie spesies waarvan die volwasse individue binne hul leeftyd gedurig 'n vrye keuse kan maak uit 'n

veelvoud van habitats, vir verskeie doeleindes, vanweë hul beweeglikheid en onderskeie kennis van die verskillende habitas wat binne bereik is.

Die avitopkonsep is ook voorgestel en verskeie elemente is in ag geneem ten opsigte van hierdie definisie. Twee van hierdie elemente sluit in; voëls is goeie indikatoren van omgewingsveranderinge, en hulle is nie beperk tot enkele gebiede nie. Verskeie elemente moet dus oorweeg word wanneer avitope gedefinieer word. 'n Voorlopige definisie kan as volg luid:

Avitope is geografies-belynde gebiede, gedefinieer deur diversiteitsindeks, wat nie-natuurlike, nie-swerwende en andersins algemeenvoorkomende voëlspesies in ag neem nie.

Daar is egter argumnteerbare aspekte in beide hierdie definisies, wat meer ontwikkeling, verfyning en navorsing sal verg.

Al die doelstellings vir hierdie studie is bereik, en nuwe aspekte is geïdentifiseer wat verdere ondersoek vereis.

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Chapter 1

Introduction

“The urban community is neither an undifferentiated mass nor a haphazard collection of buildings and people.” (Timms, 1971).

1.1 General introduction to urbanisation

Urbanisation is a continuous complex process, where rural lifestyles are changed into urban ones (Antrop, 2004). Cities have been centres of religion, record keeping, education, communication, political power and commerce since their earliest origin (Tolba, 2001). As cities have served as the cradles of civilization, they have greatly influenced both society and culture. The greater majority of humans have always lived in rural areas, but since the beginning of the Industrial Revolution, cities have grown rapidly in power and size (Tolba, 2001).

Urban areas are the places where environmental problems most affect the quality of life and they in turn create environmental problems in their own right due to the high density of activities that occur there (Europa, 2004).

There are no universal standards used to define urban areas. According to the United Nations (UN, 1999), an urban area is defined by the number of residents, the population density, the percentage of people not dependent on agriculture or the provision of such public utilities, and services such as electricity and education. Tolba (2001) in turn defines an urban area as a majority of the people that are not directly dependent on natural resource-based occupations. Various other terminology is also defined by Tolba (2001) and includes:

Rural area: In rural areas, residents are dependent on agriculture or other ways of harvesting natural resources for their livelihood.

Village: A village is a collection of rural households linked by culture, family ties, custom and association with the land.

City: A city is a differentiated community with a population and resource base large enough to allow residents to specialize in crafts, arts, professions or services rather than natural resource-based occupations.

Megacity: An urban area with more than 10 million residents is considered a supercity or megacity.

Core regions: Cities that have merged and formed agglomerations and that have expanded to beyond what is normally considered a city, are sometimes referred to as urbanized core regions by some geographers.

Urbanization: Is defined as an increasing concentration of the population in cities and a transformation of society and land use to a metropolitan pattern of organisation.

Shantytowns: These are settlements created when people move onto undeveloped lands and build their own houses.

Squatter towns: These are spontaneous or popular settlements where people occupy land without the owner's permission.

In order to understand the ecology of urban areas, the factors and reasons behind this global phenomenon need to be understood. The following information is provided in order to aid in this understanding.

Approximately 2% of the world's population lived in cities in 1850 but by 2000, 47% of the population was urban (Tolba, 2001). It is only south Asia and Africa that have remained predominantly rural, however, people in Asia and Africa are swarming to cities in increasing numbers. The world has thus experienced unprecedented urban growth in recent decades and it is thought that by 2030, 60% of the world population will be urban, with most of the urban growth occurring in less developed countries (UN, 1999). In other words, over the next 25 years, it is expected that 90% of the population growth will occur within less-developed countries and that the rural

populations will either remain constant, or in some cases, maybe even decline as a result of rural people migrating to the cities (Tolba, 2001).

Cities grow in two ways, either due to natural increase (i.e. the excess of births over deaths) or due to the immigration of people from other rural areas, cities or other countries being greater than the out-migration (UN, 1999). Natural increase is the result of better sanitation, improved food supplies and advanced medical care, which decreases death rates and in turn causes population growth in both cities and the surrounding rural areas (Tolba, 2001). In countries such as Latin America and East Asia, the major cause of population growth has been natural increase. On the other hand, in countries in West Asia and Africa, the greatest source of growth is the result of immigration. Immigration can occur due to **push** or **pull** factors.

Push factors include the following (Tolba, 2001): In some places, the rural areas are over-populated and cannot support more people. These "additional" people are then usually forced to migrate to the cities in order to find housing, jobs and food. In other places, people can be driven out of their homes due to political, economic, religious or racial forces. These refugees then, usually end up in already over-crowded cities. People can also be pushed into cities due to land tenure changes and patterns in agriculture. In cases where land ownership belongs to the wealthy elite, small farmers are often pushed off the land so as to provide grazing lands or monoculture cash crops. Absentee landlords and speculators also let good farmland that could feed and house rural families, sit idle.

Pull factors include the following (Tolba, 2001): Many people are in cities by choice as they are attracted by the excitement, vitality and opportunities to meet other people like themselves. Cities support specialisation in crafts, arts and professions that are not existent elsewhere. They also provide possibilities for upward social mobility, power not ordinarily available in the countryside, and prestige. Most importantly, cities provide jobs, entertainment, housing and freedom from village traditions. People are also

drawn to cities through modern communication e.g. television, as they appear to make city life more attainable and familiar.

Transportation has always played an essential role in the development of cities (Tolba, 2001). Most of the older cities have been reshaped and remodelled as a result of changing transportation systems. Before the Industrial Revolution, transport was by horse-drawn vehicles, sailboat or on foot, whereas streetcars and railroads provided mass transportation. Housing in turn tended to cluster around these transportation corridors. Many changes occurred in cities with the introduction of automobiles. Business offices remained downtown and shopping centres sprang up wherever major streets intersected transit lines. Those that were wealthy moved to rural estates and satellite cities. The development of freeways has profoundly reshaped where people live, work, shop and how they get from one place to another (Tolba, 2001). Freeways also provide the means to travel with greater freedom, convenience, privacy and with more speed than a mass transit system would. Although they provide so many advantages, they also cause many problems. Freeways have caused pollution, noise, have choked cities with traffic, increased energy consumption and caused urban sprawl. In an attempt to try and relieve this problem, some cities use modern mass transit systems to redesign where people work and live (Tolba, 2001).

Government policies usually favour urban over rural areas in such a way that people are both pushed or pulled to the cities. Even though only a small percentage of the population in developing countries live in cities, most of their budget is spent on improving urban areas. This in turn brings in rural people in search of a better life (Tolba, 2001).

Cities in both developing and developed countries face similar challenges. The problems are, however, most intense in rapidly growing cities in developing countries (Tolba, 2001). There is also a marked difference in the distribution of urban populations in different countries. In the developing countries, population growth rates in urban areas are increasing, whereas in developed countries, population growth is starting to level off (Anon, 1996b).

In African countries, urban growth since obtaining independence has largely taken place on the basis of the framework established during the colonial and pre-colonial times (O'Connor, 1983). Cities are often structured differently to those of European or developed countries as a result of history and tradition. In various parts of West Africa, tribe members that are not part of the dominant tribe, customarily live in separate parts of the town and have their own distinct administrative unit consisting of its own chief and elders (Timms, 1971).

In tropical African countries, the simplest form of differentiation of African urban traditions would be based on either the traditional and modern or the indigenous and alien (O'Connor, 1983). Within these countries, elements that are entirely indigenous (traditional) are still dominant in their societies and can still be observed in their political and economic life, regardless of a number of years of colonial rule. In south-western Nigeria, urban centres are indigenous in origin and are a traditional feature of the Yoruba culture. The subsequent intrusion of the colonials only brought about modification (O'Connor, 1983). There are, however, some urban centres that are entirely of colonial origin in Africa. These include urban centres in Kenya and Zambia, and only until recently, were Europeans responsible for the majority of major decisions affecting the growth and character of these centres (O'Connor, 1983).

According to O'Connor (1983), cities in tropical African countries can be divided into six various categories based on valid generalisations and are the following:

1. **The indigenous city** e.g. Yoruba of s-w Nigeria

In this case, urbanism is associated with divine kingship. The 19th century brought about drastic changes in the urban patterns of this region. It was previously questioned as to whether these settlements were truly urban due to a lack of sharp cultural distinction between the rural and urban population, the dependence of town dwellers on farming, and the cohesion of large kinship units. Today, however, a city such as Ibadan could

certainly not be denied as being an urban centre. There is clear evidence in various other regions, of the spontaneous emergence of urbanism in earlier centuries. However, no real representation of those urban traditions can be seen today.

2. **The Islamic city** e.g. Katsina (extreme north of Nigeria)

In the savannah belt or Sahel of West Africa and in some cases in eastern Africa, a different type of urban tradition is found. The forms of urbanization in these urban areas have resulted in these cities being known as Islamic cities. This type of urbanism was highly influenced by Islam and has much in common with the traditional cities of the Middle East. In most cases, the concept of urban life was "imported" and in some cases, cities were founded by invaders. Most of these cities were built by Africans, who were also dominant in the early stages of their growth. Islamic cities that are occupied by Hausa people in northern Nigeria show a great amount of cultural continuity with the rural areas surrounding these cities. Although much change has occurred during the last century, these changes have been incorporated into the traditional social system, rather than producing an entirely new system.

3. **The colonial city** e.g. Bouaké (Ivory Coast)

Colonial cities contrast sharply with the urban traditions of the indigenous cities and the Islamic cities. Most of the urban centres of tropical Africa are of colonial origin. Many cities or towns were created by Europeans for their own purposes of trade and administration. Many of those towns have prospered as ports, as they were developed at the main points of contact between the local population and colonial powers. New towns absorbed one or more traditional African settlements in some cases, but generally immigration ensured an African majority among the population. Changes have occurred due to political independence. However, these changes have not been as

drastic as expected, since the new national administrations within the capital cities wish to retain many of the inherited structures. It is through these cities that strong economic ties are maintained with Europe. Although today many decisions are made locally, they are still constrained by the inherited colonial framework.

Foreign influence varies from one city to another in its intensity, thus sometimes reflecting the policies of different colonial powers. With regard to education and language, the French influence seems to have been greater than that of the British in West Africa.

4. **The European city** e.g. Harare in Zimbabwe

These cities may be regarded as a special case of colonial cities, however, from the urban traditions point of view, they are quite distinct. These cities were built by Europeans who had little regard for pre-existing settlements. They served primarily as places for Europeans to live in and to a great extent, to provide urban services for permanent European settlers in the surrounding rural areas. These cities, in terms of origin, differ little from cities such as Cape Town (South Africa) or Melbourne (Australia). However, more manufacturing was permitted and encouraged in these African cities so as to meet the needs of the European settlers. Interaction with the local population did occur as they came under the new territorial administration and provided a cheap source of labour. Although Africans soon constituted a majority of the population within these cities, the residential areas put aside for them occupied only a small part of the total. These towns were designed as replicas of the towns in Europe and were established under highly authoritarian governments.

Potchefstroom falls into this category. Potchefstroom is the oldest city, in what used to be the Transvaal province. This city

was established by Voortrekkers (of Dutch decent), who were led by Andries Hendrik Potgieter.

5. **The dual city** e.g. Kano in Nigeria

Dual cities combine elements from two or more of the types of cities already mentioned and can be clearly distinguished on the ground. Kano is a city that incorporates an ancient Muslim city, which is similar to Katsina in its population structure and physical character, but beyond the city walls, a newly built area has more in common with the physical character and population structure of Kaduna (a city of colonial origin). Dual cities are distinguished by physically separate components. Each component has a certain degree of independence and self-respect and each develops in its own way.

6. **The hybrid city** e.g. Kumasi in Ghana

These cities combine both alien and indigenous elements in more or less equal proportions. They are, however, integrated to a greater extent rather than just being adjacent to one another as in the case of dual cities. More and more cities can be regarded as moving into this category, including cities that were originally indigenous, cities that were colonial and those of dual origin.

Even though cities offer more freedom to experiment, to be upwardly mobile and for residents to distance themselves from restrictive traditions, they can also be harsh and impersonal (Tolba, 2001).

The above exposition indicates that cities have developed along different lines, depending on various factors, such social history, ecology and natural resources. It therefore stands to reason that the urban ecological character of each would be different. In the context of the present study, I will concentrate on urban ecology of South African cities, with special reference to Potchefstroom.

1.2 Urbanisation in South Africa

In South Africa, the process of urbanisation has been rapid. This urban growth or development has been shaped by economic development, political policies of the past and the concomitant spatial economic development of the country

(Coetzee *et al*, 1994). Coastal towns in South Africa initially experienced urbanisation as their export harbours served as the main engine of growth. With the discovery of gold and diamonds, the Witwatersrand (PWV) area began to play a more important role as capital and entrepreneurs became attracted to the country. The country was thus integrated into the world economy and while the Witwatersrand continued to develop, an entire transport and communications network was established (Coetzee *et al*, 1994). The secondary sector also started to grow relative to the agricultural sector and the PWV emerged as the centre of the manufacturing industry, commercial services and modern technology. Urbanisation also increased as a result of the government supporting commercial farming and the modernization of agriculture, which in turn led to the establishment of a large number of towns and service centres. However, due to structural economic changes, these centres have experienced relative decline since the 1970s.

The homelands also form a distinctive category of spatial economic framework in South Africa. Due to the limited economic base and the pressures placed on these areas, an increase in urbanisation within the homelands has resulted (Coetzee *et al*, 1994). A large percentage of this increase has occurred relatively close to the metropolitan cities or areas.

Urban policies in South Africa before 1986 resulted in misplaced urbanisation, retarded city growth and imposed heavy costs and inefficiencies on the economy. However, these policies have changed drastically since 1986. Urbanisation and urban development saw a new era with the acceptance of an "orderly urbanization" policy and the establishment of the White Paper of 1986 (a comprehensive policy document on urbanisation), which was the first

of its kind. This meant that the role of urban planners changed and in recent years has become quite diversified. It has had to become socially and economically sensitive, instead of just concerning the physical (Coetzee *et al*, 1994). This also meant that urban planning would have to acquire new approaches, thus past approaches, where different areas were planned for in isolation, needed to be revised. These changes were not only true for social and economic sciences, but also for the environmental sciences. Thus with regard to urban policies, strategy guidelines also need to be established so as to ensure the protection of the environment in circumstances of rapid urbanisation. This also includes other issues such as alternative fuel resources, air pollution, soil protection (erosion), solid and toxic waste management, long term resource scenarios, optimisation of energy resources, effective marine resource management and the effect of uncontrolled settlement on water resources (Coetzee *et al*, 1994).

As can be deduced from above, a variety of factors are at play, that affect urban ecology. These could conceivably be both positive and negative, and will be discussed in the following sections.

1.3 Environmental and social issues resulting from urbanisation

Urbanisation often results in both environmental and social issues. Both the unplanned and uncontrollable growth of cities in the developing world cause tragic urban environmental problems (Tolba, 2001). The environmental problems resulting from urbanisation seem to be similar in both developing and developed countries (Anon, 1996b). However, some of the most severe urban problems are found in the megacities of the developing countries (Tolba, 2001). Environmental factors (or perhaps aspects) affected by urbanisation include (Anon, 1996b):

- **Plants and animals**

The primary effect of urbanization is loss of original habitat through alteration of local climate, pollution, physical destruction etc, and a concomitant new structure of fragmented secondary urban habitats.

- **Soils and landscapes**

Natural landscapes that have been converted to urban areas are practically irreversible. Some habitats that are at risk due to urbanization include:

(a) Agricultural lands – urban areas are consuming much of this land and new agricultural lands may not be so productive.

(b) Hillsides – hills could be considered as unstable (and with the development of cities spreading to hills), in the sense that they are subject to landslides and erosion due to the removal of native vegetation (Anon, 2001a).

(c) Coastal ecosystems – for example wetlands, tidal flats, marshes and swamps. These systems are often drained and filled for development.

- **Water resources**

Changes in hydrology, aquatic pollution and “exhaustion” of water supplies are the result of urban development (Anon, 2001a).

(a) Hydrology – built up environments do not absorb precipitation, thus increasing runoff. Due to this excess runoff and lack of adequate disposal places, the number and magnitude of floods increases. Vegetation removal leaves water exposed, resulting in colder winters and warmer summers.

(b) Water pollution – Urbanisation contributes to ground and surface water pollution. Wastes are often dumped into waterways as they dilute and disperse them. Aquatic pollution is caused by some of the following:

- (i) **Runoff:** Waterways are polluted by urban runoff as it contains pollutants from various sources.
- (ii) **Sewage:** This is a large source of nutrients, which may lead to the eutrophication of lakes. Many pathogens are also found in sewage, and are hazardous to human (and by

implication also environmental) health. Only pathogens are usually removed with treatment, leaving the nutrients to pollute the water.

- (iii) Industry: Industries such as refineries, pulp mills etc. contribute dioxins, oil, heavy metals etc. to the water. Fortunately, government regulations have resulted in a decrease in industrial water pollution in many areas of the world.
- (iv) Sediment: Construction results in considerable erosion. Biological activity is reduced due to sediments ending up in waterways, and the build up of sediments can also contribute towards conditions that may lead to floods. Aesthetically, sediment pollution is also not very pleasing.

- **Atmosphere and climate**

Urbanisation pollutes the atmosphere and can alter local climate, temperature, precipitation patterns and winds.

Plants and animals are thus directly and indirectly affected by urbanisation. The alteration of soils, landscapes, water resources, atmosphere and climate through urbanisation also affects the availability, distribution and abundance of species, including birds (e.g. the use of pesticides or insecticides can cause pollution and in turn can harm non-target species). The introduction of exotic species results in competition for resources, or in some cases can be responsible for dramatic changes in natural communities e.g. the introduction of the brown tree-snake into Guam, has decreased 10 endemic bird species to the point of extinction through nest predation (Begon *et al*, 1996).

Social factors affected by urbanisation, include (Tolba, 2001):

- **Sewer systems and water pollution**

In developing countries, few cities can afford to build modern waste treatment systems for their rapidly growing populations. According to the World Bank, ± 400 million people ($\pm 1/3$) of the population in developing countries do not have safe drinking water. In Third World

countries, many of the rivers and streams are little more than open sewers. Diseases such as typhoid, cholera, dysentery etc. are widespread and infant mortality is high in these countries.

- **Air pollution**

Air pollution in cities is created by dense traffic, use of wood or coal fires for cooking/heating and emissions by factories. This problem is made more severe due to lenient pollution laws, inadequate testing equipment, corrupt officials, etc. Many respiratory diseases are linked to air pollution, and in cities such as Shanghai, lung cancer mortality is reported to be four to seven times higher than rates in rural areas.

- **Traffic and congestion**

In a supercity, there is a great amount of noise, congestion and confusion of traffic. Traffic is almost always chaotic and people easily spend three or four hours per day commuting to work and back from outlying areas. Approximately 20% of all fuel is consumed by stationary vehicles, in supercities, due to traffic congestion, adding to air pollution.

- **Housing**

It is estimated that 20% of the world's population live in crowded, unsanitary slums in cities and in the shantytowns and squatter settlements surrounding the cities. This is considered to be a symptom of the failure of social systems. Slums are usually legal, but are not adequate multi-family rooming houses and are either custom built for renting to the poor or are converted from another use. Shacks in shantytowns are built of brush, plastic sheets, corrugated metal, discarded packing crates or whatever building materials can be scavenged. These unauthorised settlements usually lack electricity, roads, sewers and clean water supplies. Productive farmland and wildlife habitat are also consumed by urban sprawl.

In developed countries such as North America and Europe, the rapid growth of central cities has slowed or even in some cases reversed. The worst urban environmental problems found in developed, industrialised countries have in

recent years been substantially reduced e.g. water and air quality have improved greatly. Working conditions and housing is better and improved medical care and sanitation have decreased or even eliminated some of the worst diseases. In the USA, the greatest problems facing their cities tend to be associated with decay and blight. USAID (United States Agency for International Development) has recently started paying more attention to their own inner cities rather than those in the developing world. According to Tolba (2001), many people in the inner cities of the United States live in more degraded and desperate condition than residents in Third World country cities.

The issues mentioned here often only result in negative effects. When social issues have negative results, it is often to the disadvantage of the urban environment and thus in turn affects the urban biodiversity (including birds), found within the urban areas.

1.4 Environmental advantages of urbanisation

Even though urbanisation has primarily negative effects on the environment, there are some benefits or environmental advantages to urban areas (Anon, 1996b). These benefits include:

- **Increased energy efficiency** – when compared to single housing units, attached housing and apartments need less energy for cooling and heating. Mass transit also consumes much less energy per person than personal automobiles.
- **Land and habitat reservation** – urban areas that grow up instead of out, preserve the rural areas surrounding the city as they use up less land. Sadly, this is not the trend being followed in some countries e.g. North America. In these countries, low-density urban sprawl consumes the land adjacent to the cities. More room is available for green space as less land is required for roads etc. if development is compact.

- **Increased access to education, jobs, health care and social services** – increased education results in more people being informed about environmental issues and possible solutions. Being more informed has resulted in lower birth rates in urban areas, which in turn lightens the environmental pressures caused by a growing population.
- **Efficient waste management systems** – recycling programmes in urban areas are often worth the effort as there are large amounts of material available. Industries can all benefit economically from recycling.

Although urbanisation will continue to affect the environment, the negative results could possibly be dramatically reduced if these benefits mentioned are applied to our way of life in a sustainable fashion.

1.5 Sustainable urban development

Many of the earliest cities were built in a civilised and orderly fashion by the Greeks (Tolba, 2001). These planned cities resembled efficient ecosystems where inhabitants participated in exchanges of energy and matter with their environment. Numerous experiments have been carried out during the 20th century to try and build new towns that combine the best features of the modern city and the rural village (Tolba, 2001).

According to the UN's Brundtland Commission (1978), sustainable development is defined as "development which meets present needs without compromising the ability of future generations to achieve their needs and aspirations".

Environmental degradation increasingly threatens the contribution of sustainable cities, which are fundamental to social and economic development (UN-HABITAT, 2003). Urbanisation generates dynamic and diversified economies that, not only raise productivity, but also provide essential services, absorb population growth and create employment and

wealth. These in turn become the key engines that facilitate economic and social growth (UN-HABITAT, 2003).

It can be surmised from the above that growing cities reduce local agricultural resources and changes the character of rural towns and previously pristine countryside. Another school feels that growing cities are a healthy solution to decongest central cities and to build smaller, more liveable communities that have the benefits of both rural villages and technological cities (Tolba, 2001). However, people still tend to prefer the suburbs to the city itself, but abandoning civic infrastructures and existing buildings would result in a terrible waste, besides, if everyone moved to the rural areas, natural areas would be “obliterated” (Tolba, 2001).

Urban areas therefore should be designed so as to only have a minimal impact on the environment. Cities should implement the following in order to succeed in becoming sustainable (Anon, 1996b):

- **Conserve natural habitats:** Habitats such as wetlands, groves, marshes etc. not only have aesthetic value, but are also functional. These include filtering out pollutants, keeping air fresh, providing food control and habitat for wildlife.
- **Compact development:** Cities should grow upwards instead of outwards in order to meet the housing requirements of a growing population.
- **Cautious development plans:** When urban areas are being developed, natural features should be protected. Development in valleys should be avoided as they are vulnerable to erosion and the topsoil is very arable. Development should conform to the contours of the land, thus reducing erosion and landslides.
- **Encourage water conservation:** Water use is currently very high in urban areas. Water prices are generally low, thus providing no incentive for conservation. Increasing prices may encourage people to conserve.

- **Provide ample green space:** By growing trees in urban areas, air quality could be improved, soils stabilised, climate could be moderated and habitats could be provided for bird species. Plants provide food sources, habitat for wildlife and are pleasing to the eye.
- **Initiate recycling programmes:** Many different types of waste can be recycled for other uses.
- **Discourage the use of motor vehicles:** By using fewer motor vehicles, energy can be conserved, air pollution reduced and to a certain extent reduce water pollution.

By becoming sustainable, cities or urban areas would be able to better provide for the urban environment and its biodiversity. Many of the factors mentioned above can either directly or indirectly affect the avian communities in urban areas, and as mentioned in the literature, improving factors that negatively affect birds, could in turn improve or provide advantages for other forms of biodiversity in urban areas.

Based on information from cities around the world, UN-HABITAT (2003) has also suggested a number of guidelines that can be grouped under five main headings. These guidelines both identify and describe the ways in which cities were found to be effective in moving towards sustainable development:

- Cities improve environmental information and technical expertise
As a starting point, environmental information should be organised into a City Environmental Profile (CEP), which involves all those whose cooperation is needed in environmental planning and management. A CEP is a compilation and synthesis of existing knowledge and data, which focuses on environmental and developmental management factors. This will stimulate the interest and participation of stakeholders and at the same time identify them. Priorities for environmental issues should be set so that those issues that affect the quality of life, especially those of disadvantaged groups, can be addressed as quickly as possible. Many cities systematically clarify

and identify their environmental/developmental issues thus giving a better understanding of the city's environmental problems, as well as the relationship between environmental and developmental factors. If a CEP is successfully completed, it will provide a valuable starting point and common information base. It will also promote a wider mutual understanding among the institutions and key actors that are involved.

- Cities improve environmental strategies and decision-making

A better sense of ownership and commitment among stakeholders can be developed if a consensus can be reached on political, social, technical and economic interests. This in turn leads to a better implementation and follow up. It is helpful if strategies are articulated and publicised in both technical and non-technical presentations and reports. This facilitates continued participation of the relevant stakeholders in the on-going process of clarifying policy options and agreeing strategies. These reports and presentations typically cover the following aspects:

- A review of the environmental/developmental issue
- A summary of the options considered
- A summary of the results which compares alternative approaches in terms of economic, social and environmental benefits and costs
- Both detailed and summary mapping information
- The agreed long-term environmental objectives and targets
- The associated policy reforms and institutional strengthening agreed upon to support the implementation of the strategy
- Discussion of the indicators and statistics that could be used to track the progress of actions as well as their impacts.

- Cities improve effective implementation of environmental strategies

Although cities all over the world have difficulties with implementing strategies and plans, these difficulties are most severe in lower-income

and transitional countries. With a multi-stakeholder approach for implementation, it becomes possible to utilise a wide variety of techniques and implementation instruments such as strategic capital investments, laws and regulations, public information and education campaigns and fiscal and economic incentives. An integrated approach helps to reduce conflicts that occur when strategy-formulation and plan-implementation activities are dealt with separately. The successful maintenance of political and organisational support makes it easier to mobilise and effectively apply the necessary technical and financial resources. However, there are no foolproof ways to ensure the maintenance of political support for desirable environmental management actions.

- Cities institutionalise environmental planning and management
It is crucial to build long-term system-wide EPM (Environmental Planning and Management) capacities in order for the improved environmental planning and management process to be sustainable. In order to accomplish this, a wide range of efforts such as structural reforms and legislation, provision of essential equipment, skill-training etc. are involved. Systematic monitoring and evaluation is an integral part of strengthening EPM. Useful indicators can be provided by the databases established by the CEP and through the subsequent work on strategies and action plans. Information obtained from monitoring and evaluation activities have proven to be essential for policy guidance.
- Cities make more efficient use of resources for effecting change
Radical changes in institutional and political structures in countries such as South Africa have provided important opportunities to move forward in ways that were not previously possible.

In South Africa, IDPs (Integrated Development Plans) have been formulated in order to facilitate sustainable development. Thus, to achieve sustainable

development, environmental planning for local governments is currently embedded in these IDPs (DEAT, 2004). The IDP process was primarily an initiative of the Department of Provincial and Local Government (DPLG). IDPs have been included or integrated into various areas of management in order to achieve sustainability, which include (DEAT, 2004):

- Biodiversity management
- National waste management (NWMS)
- Environmental monitoring and reporting (EMR)
- Marine and coastal management (MCM)

The DPLG has also listed key performance indicators (however, these are only social and economic indicators), that need to be incorporated into the IDP process (DEAT, 2004). Fortunately, a National Environmental Indicators Programme has been completed in 2002. Furthermore, a framework document, based on strengthening sustainability within the IDP process, aims to provide a better understanding of the potential links between IDPs and sustainability within the context of South Africa (DEAT, 2004).

For the first time, South Africa also has a comprehensive set of environmental management plans (EMPs), for provinces and national departments (DEAT, 2004). According to DEAT (2004), these plans set out:

- Environmental policies and legal frameworks
- Environmental programmes and targets
- Environmental functions that impact on the environment
- Specific mechanisms to facilitate co-ordination with other areas of government and stakeholders.

Aside from the obvious effects environmental deterioration has on human well-being and health, it also impedes socio-economic development. Extra costs are imposed on business and industry as well as on public services and households by soil, water and air pollution (UN-HABITAT, 2003). The depletion of natural resources and their inefficient use deters new investment and increases input prices and operating costs throughout the economy.

Environmental degradation usually directly affects the poor, however, the lives and health of urban residents are also affected. Better ways of balancing the needs and pressures of urban growth need to be found in order for development achievements to be truly “sustainable” (UN-HABITAT, 2003).

By becoming sustainable, not only are the effects of urbanisation on the environment reduced, but future generations will have the opportunity to learn from previous errors and to experience the beauty of a near as possible ecologically stable environment.

1.6 Urbanisation and bird studies

The development of urbanisation has resulted in natural areas becoming fragmented, wetlands being polluted or drained, cultivated areas being replaced by waste disposal sites or slums and large amounts of vegetation being cleared. Dramatic increases in human urban populations have caused changes in the biological balance between avian and human communities (Reynaud *et al*, 2000). As a result of this, maintaining and restoring biological diversity in urban areas should start with studies based on the relationship between biota and land-use. Bird communities are thus often used in this context to determine habitat changes (Reynaud *et al*, 2000). There are primarily two difficulties regarding these studies, namely:

- Characterisation of anthropogenic gradients within urban and sub-urban areas and,
- Characterisation of bird species/guilds as biological indicators.

When using birds to study habitat changes, it is often difficult to study the connection between human decisions and the resulting effects on bird populations. It has been suggested that studying the link between the scales at which humans change urban landscapes and the scales at which birds respond to these changes could be a solution (Hostetler, 1999). It is important to have research that integrates both natural and social sciences in order to understand the functioning of urban ecosystems. Up to date, little

has been done to include human processes into ecological studies (Hostetler, 1999).

The effect of scale is also an important issue as this concept is familiar to both ecologists and landscape planners or architects. Landscape structure is affected at a wide variety of scales when ideas are made by a wide variety of people.

Various socio-economic factors can affect the distribution and abundance of birds (Hostetler, 1999). Urbanisation usually creates complex environmental gradients that could be used in investigating the relationships between the diversity and abundance of species and environmental heterogeneity (Crooks *et al*, 2004). With regard to most urban bird communities, it has been reported that species richness usually decreases with urbanisation, but total avian biomass increases. Previous studies of urban bird communities did not, however, cover a complete gradient of urbanisation (Crooks *et al*, 2004).

A major cause of reproductive failure in birds is the result of nest predation. Changes in nest predation rates may result in the loss of sensitive bird species from fragmented landscapes (Keyser, 2002). Arguments have arisen as to the degree of impact that cats have on bird populations. Predation by cats on birds is not often taken into account when studying bird communities. One such argument favouring cats, is that people tend to witness avian depredation by cats more often than any other natural occurrence, which has led to the assumption that cats decrease bird populations (Lepczyk *et al*, 2004). Opposing arguments do, however, also exist, as some ecologists perceive cats to be opportunistic predators.

It has been found that as urbanisation increases, so do the number of exotic species and omnivores and seed-eating birds. The number of native species and insect-eating birds, however, decreases (Stiles, 2002).

Using birds, it could be determined what habitat qualities may still be possible near cities. The findings from this type of research could be used to develop

guidelines for the construction of urban green space corridors (Mörtberg *et al*, 2000).

1.7 Birds as indicators

Although birds are a widely appreciated component of wildlife, the question as to why birds should be used in various studies can be asked. According to O'Halloran *et al* (2002), conditions in more natural areas (eg. forests) that benefit birds, are also likely to provide benefits for other biodiversity. Birds, or a specific species of birds, can be seen as (O'Halloran *et al*, 2002):

- An 'umbrella' species, whose habitat conservation can benefit other species.
- Economically important
- Intrinsically important (as an individual species).
- Ecologically important (e.g. as a seed disperser etc.).
- As a 'flagship' species with a high public profile.

The term "indicator" is derived from the Latin verb meaning to point out or disclose (DEAT, 2002). Indicators focus and condense information about complex issues for monitoring, reporting and management, but primarily for decision-making. Although indicators provide such valuable information, they also have their limitations. The availability and confidence of the data, as well as the interpretation of the indicator, will affect the acceptability of any indicator (DEAT, 2002). Even with this constraint, indicators are, however, useful for various reasons. These reasons include (DEAT, 2002):

- Increasing accountability
- Ensuring movement towards a common goal
- Providing feedback on changes in the system and performance of policy
- Improved implementation
- Improving the chances of successful adaptation

Birds are recognised as good indicators of environmental change and are thought to be good organisms with which to examine various ecological questions (Morrison, 2002). There are a few reasons as to why birds could make good indicators, and according to U.S. EPA (2002), they include the following:

- Most birds are easy to survey.
- The public often take notice of birds and become concerned when they die or disappear.
- Birds can also indicate the condition of a landscape.
- A relatively large pool of interested data collectors exists.

Birds can directly indicate the condition of a landscape in contrast to methods such as chemical monitoring. Birds are collectively sensitive both directly and indirectly to various environmental influences such as salinity, water quality, vegetation extent, vegetation structure and pattern, disturbance by persistent human visitation, traffic and the associated predatory animals, and water depth, duration and seasonal frequency (U.S. EPA, 2002). However, bird studies used to indicate the condition of a landscape usually do not directly show the specific cause-effect connections. Regardless of this though, birds are valuable as indicators exactly because they are integrators of the cumulative effects of multiple environmental influences in a landscape (U.S. EPA, 2002).

From the preceding and following discussions and considerations, we could consider birds to be "active-habitat-selectors" (AHS). This concept encompasses the idea that the presence of birds in an area, indicate a choice exercised by those birds, based on the suitability of that specific area. The reverse, i.e. that the absence of birds indicate "unsuitability", does not directly follow, as there might not be enough birds available to fill all the suitable areas, or for reasons such as migration, recent removal of birds by predation, hunting, poisoning or other possible stochastic reasons. For this reason, birds could also possibly be used to determine the ecological status of urban

environments. I will return to this concept at a later stage, for more development and discussion.

1.8 Ideal Free Distribution (IFD)

According to Křivan (2003), the IFD strategy is the evolutionary stable strategy, which describes animal distributions across habitat patches. According to the Ideal Free Distribution Theory (2004), the IFD is an optimal foraging model that was developed to predict the equilibrium distribution of various organisms among patchy habitats or resources. Tregenza *et al* (1998), define the IFD as the equilibrium that is created when patches of different intrinsic quality prove to be equally suitable. Gray (1994) also indicated that the IDF predicts that when situations have continuous input, the equilibrium ratio of animals between various sites will match the food input ratio. According to Stephens *et al* (2001), the traditional IDF theory assumes definite boundaries around discrete sites and predicts how many individuals should occupy each site.

There are two mechanisms that lead to the IDF, which include exploitative competition for resources and direct consumer competition e.g. interference (Křivan, 2003). This theory has often been used to investigate habitat selection when fitness payoffs are frequency dependent (Grand *et al*, 1999). According to Grand *et al* (1999), up to date, researchers have not taken into consideration the possibility that individuals may simultaneously differ in their susceptibility to predators and in their abilities to compete for resources. According to Leturque *et al* (2002), they have shown that when dispersal is costly, the IDF and balanced dispersal do not occur. This concept will be elaborated on, in Chapter 2, together with the relevant literature (section 2.2).

1.9 Summary

It is only in recent years that ecologists and conservation biologists have come to recognise the fact that cities are also ecological systems. There are

two important examples of urban ecological studies. Firstly are the Long-Term Ecological Research (LTER) sites, which are in Phoenix and Baltimore. These projects are funded by the US National Science Foundation, and use modern technology to study each aspect of urban ecology (Tolba, 2001). One of the first things discovered from this research is that cities are not homogenous like other ecosystems. Secondly, at the forefront of many urban ecological projects is the concern for environmental justice. In some cases, public awareness of a problem is one of the best outcomes of this research. The aim of nature conservation in urban areas is thus maintaining and encouraging biological diversity as a component of everyday human life and experiences (Werner, 1999). Some cities are enabled to identify indicators of urban sustainability through participatory planning together with citizen science (Tolba, 2001).

Cities are usually located near rivers, estuaries, large water bodies or along coastlines. A large proportion of urban areas are thus situated on the productive riparian systems, floodplains and wetlands, which traditionally support rich vertebrate communities. As cities continue to grow and develop previous natural areas, the public has become increasingly concerned about the decrease of wildlife, especially birds (Clark *et al*, 1999).

It is clear that as urban settlements encroach on natural areas/habitats, their impacts need to be mitigated and their potential for conservation need to be better understood and exploited (Lim *et al*, 2003). A heterogeneous urban landscape is often the result of human decisions, and in turn, may or may not be attractive to wildlife species (Hostetler *et al*, 2003). However, it has been found in a few European studies that low-density residential areas may have potential for land management practices which could enhance the value of these areas for birds (Melles *et al*, 2003).

It has been said that by the end of the decade, more than half of humanity will be living in urban areas (Stiles, 2002). For this reason, cities are going to be important for bird conservation in general. The motivation for urban ecological studies on birds is based on the idea that nature is important to enhance the

quality of human life, however, urban areas are built in the middle of species' habitat.

Bird watching has become a major recreational activity in the last decade and the use of bird feeders and baths, confirms the public's desire for wildlife observations in urban and suburban areas. If the requirements of various wildlife species can be addressed, the quality of human life values can be maintained while communities continue to grow (Clark *et al*, 1999). In turn, by understanding urban bird ecology, cities can help sustain birds and ecologists can develop solutions compatible with human uses (Stiles, 2002).

1.10 Considerations and conclusion

Man's influence is expressed nowhere so strongly as in urban landscapes (Snep *et al*, 2003). Man occupies a central position in the urban habitat, thus man has to be the primary focus of nature conservation strategies in urban areas (Werner, 1999).

Habitats often become simplified where urbanisation increases next to natural areas and parks. Bird communities in turn have fewer species that are dominated by abundant non-native species (Melles *et al*, 2003). It is expected that in a complex landscape, the presence and detection of individual birds will vary with land use and with the overall composition of the landscape (Melles *et al*, 2003).

When using birds as indicators, the aim of any study should be to establish which avian groups and attributes are most regionally suitable as indicators. It is also important to determine at which scales they are suitable due to their ability to sensitively distinguish between anthropogenic and natural background conditions (U.S. EPA, 2002).

Urban nature should receive attention as nature in cities and towns contributes significantly as to how citizens perceive the quality of their direct

living environment (Snep *et al*, 2003). Even though the effects of cities stretch far beyond their boundaries, it is essential that environmental protection is improved within urban areas themselves (Anon, 2002a). Over the past few decades, an increasing number of plant and animal species have discovered cities as a habitat that provides shelter, nesting places and food. Urban landscapes are primarily man-made and completely new dimensions are given to the ecological terms disturbance, mortality and habitat quality as a result of the continuous presence of man. Thus in order for plants and animals to survive in these areas, they need to adapt to man's influence. Fortunately, nature has the ability to adapt, even to the most extreme conditions. Common examples of urban species include swifts, rats and house sparrows. However, the number of species in cities has increased over the past few years (Snep *et al*, 2003).

Many of the considerations mentioned in this chapter are European, however, some of these considerations may differ in South Africa. Prime examples of these differences are discussed in Chapter 2 under section 2.3.

In connection to the items discussed in Chapter 1, a literature review follows in Chapter 2. An objective will then be derived at the end of Chapter 2, based on the elements discussed in both these chapters.

Chapter 2

Literature review

2.1 General

Using the literature obtained for this study, the following will be discussed in relation to birds: studies carried out in Europe, ecological models, factors affecting various species in urban areas, disturbances resulting from land-use, urban bird studies, predation and nest site selection, edge effects, ideal free distribution (IFD), nestedness and factors affecting birds in urban areas, studies carried out in South Africa, biotopes and finally, a conclusion. Based on the elements discussed in this chapter, a hypothesis and aim will be derived.

2.2 Evaluation of literature

2.2.1 Studies carried out in Europe

Based on studies carried out in Europe, cities represent the extremes of human-modified environments and contain only a few remnants of the original habitat. Increased human activity causes drastic changes in the environment such as the fragmentation of habitats and a decrease in vegetation cover. Fragmentation is the greatest threat to the world's biogeography and biodiversity. Diversity is functionally important as it increases the probability that the key species will be present in maintaining artificial systems in both normal and stressful conditions (Garagna *et al*, 2001). As the fragmentation of natural habitats has increased, the importance of landscape matrix in animal population changes, reserve planning and management practices have become quite evident. Various animals, including birds, can be used as biological agents for assessment in urban areas. When studying habitat fragmentation, it is also important to include the temporal variation of species along with the associated changes in species diversity. Habitat destruction

associated with urbanisation can also affect the population size and local abundances of migratory birds (Avian Ecology Lab, 2004). Fragmentation may, however, have positive impacts that relate to the increased heterogeneity of landscapes (Jokimäki, 2000). Cities that are built next to water bodies, result in large parks and reserves in urban areas that could support high species diversity, as these protected areas are habitat "fragments" of highly diverse ecosystems (Melles *et al*, 2003).

Under natural conditions, the number of species is primarily influenced by climate and seasonal changes in the type and amount of food available (Jokimäki *et al*, 1993). Species richness and abundance of bird species in European cities seem to be affected by the presence of feeding tables. Based on a winter study done in two different parts of Europe, the presence of feeding tables increased the species richness and abundance of birds in Finland, even though the average number of birds was higher in France (Jokimäki *et al*, 2002).

Based on research in Spain, France and Finland, it has been found that bird species richness decreases with latitude and urbanisation (Jokimäki, 2000). Urban bird communities have in turn become more diverse in Finland over the past few decades (Tianinen *et al*, 2000). This could be the result of intensive winter-feeding by humans in Finland.

Studies based on wintering bird communities in central and northern Europe, indicated that the average number of species were higher in France than in Finland (Jokimäki *et al*, 2002). This, however, has been attributed to a large number of the bird species being migratory in northern Finland. It was also found that the urbanisation level affected bird community composition more in Finland than in France. The total biomass of wintering species in Finland, were higher in single-house areas, whereas in France, it was higher in areas of apartment blocks (Jokimäki *et al*, 2002). The most abundant bird species were primarily omnivores and granivores, which are superior as competitors when compared to other species, as they are better able to exploit urban food

resources. Urban habitats are generally dominated by a few resident bird species with broad geographical ranges (Jokimäki *et al*, 2002).

With the rapid expansion of urban and suburban areas and the associated modification of habitats, the importance of understanding the relationship between bird life and urban habitats is quite evident (Jokimäki *et al*, 2000). Increased urbanisation has also resulted in an increasing level of detachment between the human population and the rest of nature, thus leading to development that is insensitive to natural processes (Avian Ecology Lab, 2004).

In most of the studies mentioned here, a common aspect was apparent. Most of the studies mention the influence human feeding had on bird communities throughout Europe. In countries such as Finland, intensive feeding occurs and in other countries, feeding tables are often found. These food resources that are made available to birds affect both the species richness and abundance of birds species in Europe.

2.2.2 Ecological models and research programmes

Various models are used to understand the ecology of species and their habitat. Two expert models include SmallSteps and LARCH (Landscape ecological Analyses and Rules for the Configuration of Habitats). LARCH is a model that is able to predict the long-term chances of survival of a particular indicator species in a particular landscape. It is used to assess the sustainability of ecological and spatial networks in rural areas (Timmermans & Snep, 2001). Another integrated research approach is the human ecosystem approach. In this human ecosystem model, many social processes and components that are connected to ecological fluxes, structures and processes, are included (Anon, 2001a).

There is little information on how changes impact the biodiversity (including birds) in various parts of the world, as a result of modified land types (Niemi *et al*, 2000). This required a global programme, one able to assess human-

impacted landscapes, so as to distinguish between global patterns and effects, and local ones. As a result of this requirement, GLOBENET was developed. This programme is a global research and assessment programme that makes use of a common methodology. According to Niemelä *et al* (2002), the primary objectives of this programme include making use of:

- The same group of organisms
- A single methodology
- The same human-influenced landscape

In recent years, a large body of theory has been developed for the spatial dynamics of populations (Hanski *et al*, 2003). Unfortunately, a large proportion of this theory assumes homogenous space, making it difficult to test theoretical predictions using empirical data. The reason for this is that populations typically occur in heterogeneous space (Hanski *et al*, 2003). There is however, a well-established approach to spatial ecology, which assumes that heterogeneous space is based on stochastic patch occupancy models (SPOM). Using these models, it is assumed that habitats occur in discrete patches that are surrounded by unsuitable matrices (Hanski *et al*, 2003).

Cities are highly dynamic landscapes with extreme forms of land-use, human influence and multi-functionality (Snep *et al*, 2003). Biotopes (see section 2.4), such as the industrial biotopes, are not automatically linked to nature, however, various involuntary nature values may be present in industrial estates (Snep *et al*, 2003). Species that have had their habitats highly fragmented usually form local populations that are often not viable on their own. As a result of links between different local populations, these species are present as they provide each other with mutual support (Timmermans & Snep, 2001). Patches can be recolonised from other nearby patches still inhabited by the meta-population should a species be about to die out (Timmermans & Snep, 2001). Birds have thus been considered to be good indicators of environmental changes (Eeva *et al*, 2002), for various reasons, as was discussed in Chapter 1, section 1.7 and in Chapter 2, section 2.2.8.

2.2.3 Factors affecting various species in urban areas

Species that are less affected by toxic substances flowing through cities, that are better able to communicate over the noise of traffic, that are able to breed successfully on human built structures, able to adapt to artificial light and those able to rebound after city council decisions to decimate their populations, are the species favoured by urban habitats (Ehrlich *et al*, 1988).

According to Hostetler (1999), factors that affect various species in urban areas include:

- **Scale:** Depending on ranges of scales relevant to a specific species, landscape changes at various scales has the potential to affect different organisms (Hostetler, 1999).
- **Socio-economic factors:** Factors such as planning and design decisions have impacts on animal diversity as they have huge impacts on the urban landscape (Hostetler, 1999).
- **Other factors:** Factors such as city laws, zoning, homeowner association regulations, development regulations, historical planning decisions etc. also affect various species and could be used to determine species distribution.

Within habitat fragments, the reduced habitat area can lower survival and reproduction of the species occurring in these fragments (Smith *et al*, 2002). When considering any urban study with regard to environmental issues, it is now obvious that various factors need to be considered for both a study and at a later stage, for successful management. Because these factors originate from various fields or situations, the importance of an integrated approach for research and management planning is quite evident.

2.2.4 Disturbances resulting from land-use

'Disturbance' is defined as a collective term for all the consequences that directly or indirectly have an impact on the chance of a certain animal species

being present and that cannot be ranged under other effects (Timmermans & Snep, 2001).

With regard to fragmented patches, little is understood about bird communities that have inhabited the various ranges of habitat types associated with each land-use within the urban environment (Azerrad *et al*, 2001). Each land-use usually contains patches of vegetation varying in origin and disturbance history.

The surrounding types of sites also influence these land-uses. Various factors have been associated with creating spatially diverse areas. These include soil compaction, intensive park management and abandonment of developed land, which are important in defining bird communities in urban green-spaces (Azerrad *et al*, 2001). Nature reserves and natural areas are becoming increasingly more fragmented due to the growing density of infrastructure and housing (Timmermans & Snep, 2003). In countries such as the Netherlands, it has been suggested that these areas be linked by means of wildlife overpasses. This is, however, a costly affair. Infrastructure often has a fragmenting affect on nature, and animal populations are fragmented by the barrier effect, loss and disturbance of habitat and mortality (Timmermans & Snep, 2003). Barriers such as roads often have negative effects on animal species or groups of species, which result in various consequences. These include stressing and ceasing to roam about, and drawing back and trying to move "around" the barrier. Although overpasses may seem a good solution, it must be remembered that different groups of species have their own specific requirements with regard to the design of the overpass. With regard to birds, their preferred habitats are varied (Timmermans & Snep, 2003). Should an overpass be constructed for birds, the overpass should be designed so as to consider those species that are less mobile.

2.2.5 Urban bird studies

The general biogeographical patterns that are found in natural bird communities may not occur in urban bird communities as urbanisation can lead to uniformity in these urban communities (Jokimäki *et al*, 2002). The distribution of birds in urban areas has been investigated according to three dominant theories (Melles *et al*, 2003). Firstly, stand-level habitat models were previously used to compare species assemblages in relation to the structure and composition of urban resources at the stand or local level. The habitat requirements of individuals under this perspective were examined at the local scale. However, the influence of habitats surrounding each stand was generally not considered (Melles *et al*, 2003). Secondly, the island biogeography theory and meta-population theory have been applied to habitat patch dynamics in fragmented urban areas. The reason for this being, that these two theories relate island isolation and habitat patch size to species richness, immigration and extinction rates (Melles *et al*, 2003). Lastly, spatial-structuring theories of ecological communities have been used to investigate the distribution of birds in urban areas. In this case, local-scale habitat features are seen in relation to the surrounding landscape features (Melles *et al*, 2003).

Urbanisation has resulted in the amount of impervious surface being increased (Melles *et al*, 2003). The artificial concrete and steel ecosystems of cities can support a rather large number of birds (Ehrlich *et al*, 1988). According to Ehrlich *et al* (1988), as mentioned before in section 2.2.2, urban habitats favour species that are:

- a) less affected by toxic substances flowing through cities
- b) able to breed successfully on human-built structures
- c) better able to adapt to artificial light
- d) able to communicate over the noise of traffic and automation.

Only a few studies have addressed the consistency of variability in bird communities across different spatial scales. More recent studies have revealed that critical threshold levels for habitat availability exist. It has been

suggested that due to the higher temporal variability of the bird populations in urban areas, population sinks and sources can be distinguished. These sources and sinks can be reliably distinguished only by demographic parameters, namely fecundity and mortality (Jokimäki, 2000). The source-sink model indicates that most territories in good-quality habitats are occupied annually, due to high reproductive success in relation to mortality. This in turn results in relatively low variability in breeding population densities.

According to Drickamer *et al* (2002), habitat selection is defined as the choosing of a place in which to live, however, this choice is often an “automatic” reaction to key aspects of the environment. According to Jokimäki *et al* (1998), birds recognize their environment by signals or cues in the characteristics of the vegetation or of the habitat in general. In the case of birds, because of these social cues, a “suitable” habitat cannot be defined by its structural features alone, as social features now also need to be considered (Drickamer *et al*, 2002). The risk of predation and competition may also be factors that affect habitat use and many bird species’ choices are affected by the success of previous breeding sites (Drickamer *et al*, 2002). Anthropogenic disturbances can thus multiply and influence the effects of other regulating factors. In order to create or maintain suitable habitats for birds, urban planners need knowledge of the habitat requirements of animal populations. In Europe, it has been found that urban areas tend to attract birds, especially in winter. Many urban birds are habitat specialists, and urban areas are often able to provide adequate food supplies for a variety of bird species, and most bird species are also able to exploit urban warmth (Wood, 1993).

Most urban studies in Europe have indicated that the number and diversity of bird species decrease with increasing urbanisation i.e. species richness declines abruptly. Based on studies done in Finland, it was discovered that human agricultural activities increase the diversity of the original land and creates opportunities for an increase in the number of bird species (Jokimäki *et al*, 1993). Variability in patterns of species and species groups differ on various scales and animal abundance also varies over time. Research has

also indicated that community stability decreases with decreasing area of the habitat patch. Although regional population levels may remain stable, local animal communities may show remarkable year-to-year variation (Jokimäki, 2000). Highly variable populations also have a greater chance of becoming extinct than less variable populations.

Urban ecologists have previously found that as urban areas grow, the number of birds may increase but the numbers of different species decrease. In many cases the non-native or exotic species thrive whereas only a few native species survive. Ecologists have also found an increase in seed-eating and omnivorous birds and a decrease in insect-eating birds in urban areas (Newswise, 2002).

It has also been found in studies carried out in African tropical cities, that insectivores and carnivores were adversely affected by increased urbanisation and that frugivores favoured low-density housing (Lim *et al*, 2003). This could be attributed to fruit-bearing ornamentals being planted within these areas. It has also been found that shrub, tree and primary cavity nesters decreased with increased urbanisation (Lim *et al*, 2003).

2.2.6 Predation and nest site selection

Factors such as food, the availability of suitable nest sites, interspecific competition and predation are important in determining avian habitat selection and community structure (Schroeder *et al*, 1982). Predation pressure in any landscape is dependant on the response of different predator species to landscape structure, as well as the relative effects of these predators on different bird species. According to studies in Finland, the risk of nest predation is much higher in highly urbanised areas. This is usually the result of a higher degree of disturbance through humans e.g. many people keep cats as pets, conditions for unnatural predators of a bird species are provided etc. The rates of nest predation also differ between managed and unmanaged parks with rates being higher in the managed parks (Jokimäki *et al*, 2000). Birds that are cavity-nesters can also be attracted to parks in urban

areas by means of nest boxes that can be placed in the parks (Jokimäki, 1999). In most cases, however, invasive bird species often tend to select nests in areas that are more urbanised and open, with higher disturbances (Soh *et al*, 2002). A means of more effective management of a bird pest species is to gain a better understanding of its behavioural ecology. In cases where specific biological attributes are favoured, those attributes can be reduced as a means of control, however, it is critical to remember that the preferences of native species should also be taken into account and not eliminated during the process of pest control.

The presence of free-ranging domestic cats as predators is often not considered when studying avian communities within urban areas (Lepczyk *et al*, 2004). Cats may negatively impact on breeding birds as they have free access to the outdoors. Various arguments or debates do, however, exist as to whether or not these felines have a noticeable effect on bird populations. Some arguments in favour of felines include (Lepczyk *et al*, 2004):

- Domestic cats have co-existed with man for centuries and would thus have resulted in the extinction of various bird species had they not been able to withstand this predation.
- Some argue that cats fill a niche that would have otherwise been filled by any other predator and thus they play the role of a natural predator.

In opposition to these statements, the following is argued (Lepczyk *et al*, 2004):

- Cats are subsidised predators and would thus be likely to have a larger total effect on birds, especially since humans provide cats with levels of maintenance that other predators do not receive.
- In terms of time and habitat location, cats are opportunistic predators.
- Many top-level predators are absent in human-dominated areas and cats may have a larger predatory effect as a result of the meso-predator release effect ie. second-level predators have increased due to the decrease or elimination of top-level predators. Second-level predators include skunks, raccoons, domestic cats etc.

- It could also be possible that cats compete directly with avian predators such as certain hawks, kestrels and harriers. In South Africa, shrike and coucal species could also be out-competed.
- Cats also tend to prey on birds during the breeding season when nestlings are plentiful.
- Finally, the breeding success and viability of a species could be negatively impacted even in the case of low cat depredation.

Landscape characteristics such as fragmentation, differences in predator communities and distance to habitat edge could all affect the rates of nest predation. It has been reported that grassland and forest birds have greater rates of nest predation in fragments surrounded by urban development and agricultural fields (Vander Haegen *et al*, 2002). It has also been found that predator communities that are associated with developed or farmed lands cause higher predation rates in adjacent fragments of native habitats. It has also been considered that vegetation structure plays a key role in influencing predation rates on nests (Liebezeit *et al*, 2002). Nest predation has a significant influence on the reproductive success of individual birds (Chase, 2002). In most species, the rates of nest predations are related to nest site characteristics. It has also been observed that in some species, habitat attributes correlated with nest site selection and in turn with successful nests (Chase, 2002). However, it has also been found in other studies that nest site selection was not related to nest success.

2.2.7 Edge effects

The remaining natural and semi-natural vegetation within urban areas are essential for maintaining biodiversity in cities (Mörtberg *et al*, 2000). Many bird species have large area requirements. Some species are associated with interior habitats i.e. they avoid the edges, some have small or scattered populations, some are habitat specialists and a few may be resident species with relatively low dispersal rates (Mörtberg *et al*, 2000). These characteristics often make species vulnerable to habitat degradation or

fragmentation and in some cases, both. It has been found that at the edges of urban areas, vegetation structure is highly developed as well as diversified (Reynaud *et al*, 2000). Because of this, the relations between human and bird communities are easiest to study at these urban edges.

Although birds are not animals that are isolated within urban fragments, for many other species, the effect isolation has on colonisation rates, is not well known (Weidong *et al*, 2002). According to some studies carried out in forest fragments surrounded by urban development, it has been found that predation rates were highest nearer to the edge of the fragments (Keyser, 2002). According to Keyer (2002), edges are transitional zones from one habitat type to another. Edges are characterised by both biotic and abiotic features. These features are distinct from the habitats occurring on either side of the edge (Keyser, 2002). Studies based on how edge effects have affected rates of nest predation have however been contradictory and may be the result of experimental design (Keyser, 2002). Three types of edge effects have been described (Keyser, 2002):

- Indirect changes in abundance or distribution of a specific species due to interspecific interactions.
- Changes in abiotic conditions.
- Direct changes in abundance or distributions of a specific species caused by altered abiotic conditions.

2.2.8 The ideal free distribution (IFD)

As mentioned in Chapter 1 (section 1.8), the IFD deals with the behaviourally and ecologically important problem concerning the spatial distribution of foraging animals (Stephens *et al*, 2001). The models normally assume that animals move freely and instantaneously between patches. It also assumes that animals have a perfect knowledge of the qualities of all the patches and that they settle in the patch that provides them with the highest resource intake rate (Křivan, 2003). There are two mechanisms that lead to IFD, which were also only mentioned in Chapter 1. These mechanisms include direct

competition among consumers (a.k.a. interference), of which territorial defence is an example and secondly, exploitative competition under which the suitability of occupied patches decline due to the exploitation of the resources (Křivan, 2003).

The IFD makes various important assumptions about foraging organisms (The Ideal Free Distribution Theory, 2004), which are, (a) that all individuals act in order to maximise foraging efficiency, (b) all individuals are of equal competitive ability, (c) all individuals have the ideal (perfect) knowledge about resource profitabilities, (d) individual resource intake decreases with increased competitor density and (e) interpatch travel has a negligible cost (i.e. it is free) and no individual is prevented from being able to enter any habitat patch. According to Stephens *et al* (2001), theoreticians have both extended and modified the IFD in various ways, these now include incorporating resource dynamics, incorporating assessment rules and perceptual constraints, and also allowing unequal competitors.

In a fragmented urban environment, the assumptions of the IFD regarding foraging animals would likely be valid only for birds, bats and some flying insects such as bees and wasps. The movement of the mainly terrestrially bound animals will be constrained by roads, traffic and sudden change of cover when moving between different types of patches.

The mobility of birds (the subject of this study), combined with the assumptions of IFD, does present a number of predictions that could be considered when investigating the results of this study, although it is not the intention to test or apply IFD models in the present study. The first prediction is that birds, due to the patchy distribution of food and water, will not show an even distribution across and urban landscape. Secondly, competition between species will also tend to result in uneven distribution. Thirdly, due to their mobility and the use of flight to cross unsuitable territories, birds can utilise different patches for foraging, nesting, resting and other activities, again resulting in distributions covering more than one particular patch. In the case of a fragmented urban area such as Potchefstroom, with the longest axis of

14 km, the distance between different patches, for most birds can be assumed to be relatively short, and the cost of travel relatively small. If all available bird niches are filled, then species composition and numbers will reflect the condition of each particular patch, and it can be assumed that species composition and numbers should be in equilibrium with surrounding and nearby patches.

2.2.9 Nestedness and factors affecting birds in urban areas

Nestedness is related to the actual species in a community, not just the number of species present. A community is "nested" if the species in low diversity sites are also found in progressively higher diversity sites. Various factors are relevant in promoting nestedness in animal communities. These factors/mechanisms include selective colonisation, selective extinction, nested habitats, speciation, historical effects and differential reproductive success (Fernández-Juricic, 2002). Another factor that promotes nestedness is human disturbance. Community structure, at the landscape scale, can be affected by an increase in local levels of human disturbance as the suitability and availability of the fragments for reproduction can be decreased. Human disturbance could also lead to areas dominated by widespread species with a high tolerance to people. Finally, human disturbance and area may be interacting in such a way that a buffer is formed (Fernández-Juricic, 2002).

Nestedness has been used in determining assemblage composition. In combination, the factors previously mentioned in paragraph 1, could also affect species composition, thus giving rise to interactive effects (Fernández-Juricic, 2002).

One of the prime examples of negative impacts that humans have on bird populations is environmental pollution. It has been observed that pollution has affected birds at the community level. There has been a great dearth of studies regarding the relationship between environmental pollution and the changes in birds at the community level. A proposed reason for this would be

the fact that the wide geographical scale of pollution would make it difficult to obtain comparable and accurately controlled data on the effects of pollution experienced by bird communities (Eeva *et al*, 2002).

Many studies have found that bird communities were influenced by the amount and structure of vegetation cover (be it native or exotic species), as well as the availability of food provided by humans (Lim *et al*, 2003). It appears to be generally accepted that species richness increases with increasing habitat areas until a “saturation” point is reached within “homogenous” habitats (Loo *et al*, 2002).

Factors affecting the success/failure of species in urban areas should be identified and used to develop principles to develop urban landscapes. There are, however, a few reasons that have been identified as hampering this goal (Turner, 2002). These include:

- Lack of data that spans a variety of land uses that occur in developed and nearby areas.
- Lack of data obtained from repeating surveys at the same sites on a long-term basis.
- A lack of data collected over multiple spatial scales that are relevant to urban ecological processes

2.3 Studies carried out in South Africa

Conservation issues in the urban environment in South Africa are rather bleak as the most important aspects are considered to be economic development, the quality of life and environmental health. This is the result of the ultimate goal in this country, which is human well-being (Anon, 2002a).

The Department of Environmental Affairs and Tourism (DEAT) launched the first National State of the Environment (SOE) report in South Africa in 1999 (DEAT, 2002). In South Africa, DEAT has initiated a programme to identify a

core set of environmental indicators for SOE reporting. The purpose of these environmental indicators (DEAT, 2002) is to:

- Provide information about the environment in South Africa.
- Promote more informed decision-making.
- Improve access to environmental information.
- Promote sharing of information between different organisations.
- Eliminate duplication with other reporting requirements.

It is then thought that the indicators identified will monitor the impacts of environmental change, trends in environmental conditions, the effectiveness of existing and proposed response mechanisms, and the pressures on the environment and causes of environmental change (DEAT, 2002).

The environmental indicators programme initiated by DEAT, consists of 4 phases. Phase 1 consists of scoping; the outcome of the phase is a scoping report. Phase 2 consists of the selection of issues and criteria, with the outcome being an identification of issues and criteria report. Phase 3 includes the selection of indicators, with the outcome being indicator selection specialist reports and phase 4, is the implementation phase, with the outcome being an implementation report.

In South Africa, most ornithological studies are based on birds in rural and natural areas. The studies done on urban habitats are few and there are various factors in South Africa associated with birds that differ from those in other countries (Bouwman, 2001). Some of these factors may include the following:

- Urbanisation results in more available water in many of the arid areas of South Africa due to reservoirs, gardens and sewerage works, which has also affected the expansion of bird ranges.
- In South Africa, rainfall appears to be a major factor that affects birds.
- Many more species are present in South African urban areas than in European cities, especially in summer.

- Urbanisation in most of South Africa creates a form of secondary woodland whereas in some cases in Europe, urbanisation results in a decrease in native forest. Farmsteads also serve as refuges and as a mode of dispersal for birds. Urbanisation thus results in the decrease and/or expansion of many bird ranges.
- Peri-urban areas are extensive and expanding at a fast rate, which also affects adjacent areas as a result of wood harvesting and trampling.
- Urban areas also appear to severely affect raptors.
- Some birds have also been able to adapt very well to urban conditions and in some cases have almost abandoned their natural breeding sites.

A bird study based on the influences of landscape pattern, divergent past political land management and human impact on functional groups of bird species richness, was carried out in KwaZulu-Natal. According to this study, high intensity human transformation and bird richness generally indicated a positive relationship (Fairbanks, 2004). According to Fairbanks (2004), a positive trend in richness is the result of developed landscapes attracting generalist taxa. It was found that species richness was high in high habitat diversity, which in turn coincides with a high proportion of highly altered or transformed land. The study also indicated that the majority of the species represented mostly native generalist species, rather than exotic species (Fairbanks, 2004). It was concluded that land-use patterns and bird diversity are related through complex feedbacks and depending on the intensity of the development, these patterns coincide with an increase in species richness among all bird groups that were studied (Fairbanks, 2004).

Also with regard to avian conservation in South Africa, is the conservation of raptors in the Northern Cape Province. The Northern Cape is the largest and most sparsely populated province in South Africa, and is a semi-arid region (Anderson, 2000). Sheep farming is one the primary economic activities in this area, and the properties owned here are generally very large. According

to Anderson (2000), a heterogeneous environment results in many habitats for a great variety of raptors. Sadly, however, conflicts that have occurred between small-stock farmers and raptors, have indirectly or directly resulted in the persecution of these birds each year. Although these are not urban areas as such, anthropogenic effects on raptors have been both positive and negative. Fortunately, the various threats on raptors are being addressed, and through various efforts, the status of various raptors has improved, eg. the Lappet-faced Vulture and Bateleur have become increasingly common (Anderson, 2000).

According to Anderson (2000), other conservancies that have been established in order to protect birds of prey include:

- The “Molopo Raptor Conservancy”: Here the Bateleur, White-backed Vulture, Wahlberg’s Eagle and others that breed in this area are conserved.
- The development of a “raptor tourist route” through the Kalahari is one of the more recent initiatives in South Africa. The primary objective of this route is to indicate the monetary value of raptors, thus making valuable revenue available to entrepreneurs and businesses through eco-tourists.
- The “Rooibergbewarea”: When finally established, this conservancy will protect the Booted Eagle and the Black Eagle, as well as other smaller species occurring in the Asbestos Mountains.
- Two other conservancies are still in the planning stages, but will be established in the Kalahari and Kimberley area.

Another study in South Africa is based on the Cape Vulture at Colleywobbles, in the Eastern Cape (former Transkei). This study is not based within a city, but does investigate the effect of agricultural land-use. In the former Transkei, Colleywobbles is the largest breeding colony of Cape Vultures (Vernon, 1998). In this study, it was determined that the decrease of these vultures in the Cape was associated with a food shortage resulting from a reduction in stock numbers and improved farm management. Fortunately, the numbers

did not decline in the Eastern Cape. The survival of the vulture population is however dependant on the behaviour of the residents of the former Transkei (Vernon, 1998).

A major avian study that is currently running in South Africa, is that of the Blue Swallow Working Group. This working group was established in 1986 as a group of the Endangered Wildlife Trust (Endangered Wildlife Trust, 2003). On the international Convention for the Conservation of Migratory Species of Wild Animals (CMS), the Blue Swallow is listed in both Appendix I and II.

A study also based on the effect of agricultural landscapes, was carried out on the Yellowthroated Sandgrouse, *Pterocles gutturalis*. In this study, it was found that these sandgrouse were year-round residents, that nested and foraged exclusively in regions cleared for agriculture, especially in one-year fallow lands (Tarboton *et al*, 1999). It was determined that the sandgrouse were year-round residents in the Northern Province. Although some months yielded low counts, this was the result of the unpredictable drinking habits of these birds. This study also determined that sandgrouse were restricted to areas that had been cleared for agriculture. This was especially in areas consisting of fallow lands, where an abundant source of seeds on which they feed, were provided by pioneer plant communities (Tarboton *et al*, 1999).

In the case of wetlands, Durban Bay is one of Africa's busiest commercial harbours, but has one of the worst cases of coastal wetland destruction (Allan, 2001). The waterbird populations have suffered massive damage as a result of the environmental destruction associated with the development of this bay as a port. According to Allan (2001), there has been at least a 70-80% decrease in overall numbers. Durban Bay currently supports both regional and global important roosting concentrations of swifts, terns and Gulls, according to recent counts. A study carried out in the bay, in order to stall further wetland and waterbird attrition, as well as to motivate wetland habitat restoration, was carried out with the underlying emphasis being to guide the port authority so as to accomplish these two goals (Allen, 2001).

South African cities have also had a rapid increase in the number of squatting and informal settlements on the urban fringe, thus placing enormous pressure on natural and semi-natural areas inside and around cities (Cilliers *et al*, 2001). The destruction of natural vegetation also occurs at an alarming rate. One contributing factor is the absence of energy and building materials. This means people are turning to the natural environment in order to obtain these necessities (Anon, 2002a).

Only a few urban bird studies have been carried out in the southern hemisphere. One such study in Australia, found that some of the native bird species are reliant on high quality remnant vegetation, while others show a greater tolerance towards more disturbed landscapes. Overall, the study found that bird communities in urban environments appear to be highly dependant on the vegetation type and structure (White *et al*, 2004).

2.4 Biotopes

In urban areas, the most important influences on the biotopes of these areas are human uses, various types of buildings and typical urban structures such as city zones. According to Röthig (2002), a **biotope** is defined as the habitat of an animal or plant community with a minimum size and a unique composition with clear demarcations to its surroundings. Werner (1999), defines a biotope as ecotopes in their spatial dimension or as areas in which specific communities of plants and animals live, and which can be marked by biotic and abiotic features.

The second definition of a biotope is considered a 'neutral' one. Since animals and plants live everywhere, this definition includes all the habitats of animals and plants, whether valuable or not for conservation, in urban as well as rural areas (Werner, 1999). A **biotope type** refers to a unit of a classification system, in which a landscape type is defined by its type of use, structure of the vegetation and site conditions. The definition of the word biotope always refers to a single area. However, the term biotope type

includes the totality of biotopes of the same kind (Röthig, 2002) i.e. all the biotopes that are the same, together are known as a biotope type.

Biotopes have various ecological functions, which could include aspects of the following (Werner, 1999 & Müller, 1997):

- 1) They are significant to experience and enjoy nature as a part of life quality
 - They provide a variety of experiences and knowledge
 - They provide leisure
 - They provide education
 - They provide gardening
- 2) Biotopes are significant to protect natural resources
 - They are significant for environmental protection and ecological balance in nature, habitat and species protection and for bio-indication (monitoring) of environmental changes as well as anthropogenic impacts
 - They are significant for ecological research into urban ecology
 - They are important corridors, refuges and dispersal centres for species.
- 3) Biotopes are significant for the shaping of town and landscape
 - They are important for natural and cultural history
 - They are important for human identification with the local area
 - They are important for structuring and vitalising the urban scenery

There are two types of biotope mapping that can be distinguished, namely comprehensive mapping, which investigates all land-use types, and selective mapping, which investigates only areas regarded as worthy of protection (Cilliers *et al*, 2004). Comprehensive mapping was used to map the biotopes of Potchefstroom (Fig. 3.2).

Nature conservation in urban areas focuses on the protection of their biotopes. This is used as a basis for direct contact between urban residents

and the natural elements of their surroundings. It can also be used to mitigate the extremes of urban climates and water regimes, and to preserve biodiversity (Müller, 1997).

Based on the vegetation, bird species are selective about those they inhabit (Seoane *et al*, 2004). According to Seoane *et al* (2004), vegetation holds a great predictive potential for bird distribution, however, statistical models indicating this distribution that make use of vegetation predictor variables, are often not able to explain perfectly observed distributions. Some possible reasons include poor quality of predictive variables or response variables, historical reasons, statistical reasons or due to unsaturated habitats (Seoane *et al*, 2004).

2.5 AVITOPES

According to the above discussion on biotopes, it is clear that urban biotopes as such relates to the combination of both biotic and abiotic components within a specified area, usually defined by vegetation types, delineated by abiotic components such as roads, rivers, hills, buildings etc. According to Cilliers *et al* (2004), not only were the abiotic components and vegetation species lists used to define the biotopes in Potchefstroom, the vegetation was also further subdivided into native and exotic species, presence of any red data species, whether category 1 weeds are present (which need to be eradicated) and whether any medicinal species are present. In order to determine the conservation value of each biotope type, it is important to take such aspects into consideration (Cilliers *et al*, 2004). (In effect, a biotope could be equated with patches, as described in the discussion on IFD, section 2.2.) In essence, this means, that an assumption is made that the combination of vegetation and structures would predict the presence, absence and density of animals that could be present in such a biotope. However, birds are multiple biotope users, they are little constrained by movement and they can be considered to be “active-habitat-selectors” (AHS, see section 1.7). These aspects allow birds to utilise more than one vegetation-based biotope at

different times of the day and season. It follows therefore that birds, depending on their requirements such as territory, home range, foraging, social interactions, breeding, seasonality, etc. will in most cases (possibly excepting those that require very small territories year round), show patterns of distribution or demography that could differ substantially from the mainly vegetation and structure based biotopes.

In this context I would like to introduce the concept of “avitope”. I will not attempt to define avitope in this section yet, but rather provide a more detailed discussion in Chapter 5, after the data has been discussed. In essence I predict that an avitope would look substantially different from a biotope, although probably still encompassing some elements of the biotopes. It is likely that a map showing avitopes would be less sensitive or restricted, when compared to a map indicating structure-based biotopes, or even resource-based patches.

2.5 Conclusion

Nature conservation has a particular task in urban areas. This task is to maintain and improve species and habitat diversity in a wide range, with special regard to common species and common urban wildlife (Werner, 1999). Because urban areas are made up of a great number of different habitats (biotopes), each with specific communities, a prerequisite for successful urban nature conservation strategies is knowledge of individual biotopes and their ecological characteristics. Also included is the location and distribution of the biotopes in the city and the composition of their plant and animal communities (Sukopp *et al*, 1985). As has been mentioned before, improving conditions for birds may improve conditions for fauna in general. If “avitopes” can be identified, achieving certain conservation strategies may be easier.

Urban ecological studies are valuable for various reasons, which include (Anon, 2002a):

- To provide the setting for human restorative experiences from the busy city life that can lead to a general improvement of the quality of life.
- An understanding of how ecosystems work, change and what limits their performance. This in turn can add to the general understanding of ecosystems.
- The establishment of pleasing and healthy environments for humans.

Urban ecological studies may provide insight on the mechanisms that regulate species richness since urban biotopes differ in many ways from natural biotopes (Jokimäki *et al*, 1996). Cities have higher temperatures than the surrounding rural areas and anthropogenic wastes and feeding tables may alter the distribution regimes and the survival of animals. In some cases, many urban and suburban areas are positioned near undeveloped native areas or forests. Birds may thus respond directly to local characteristics of the vegetation within urban habitats as a result. However, they may also respond to broader landscape features, which include the proximity of large developed areas (Melles *et al*, 2003).

Birds can be used as useful biological indicators as they can be monitored relatively inexpensively, they are ecologically versatile and they respond to secondary changes that result from primary causes (Reynaud *et al*, 2000). Birds also have the ability to react to changes in their habitat very rapidly due to their high mobility (suggesting AHS). Ecologists and landscape architects could work together in order to determine how different designs affect bird populations (Hostetler, 1999). Various urban landscape designs could then be constructed to determine whether or not specific species would be attracted.

The requirements for bird-life in urban habitats vary from species to species. Understanding the relationship between animal community dynamics and landscape structure has become a priority for biodiversity conservation. The design and management of urban green spaces may be crucial if bird biodiversity is to be conserved as much as possible. It is possible that determining "avitopes" may aid this goal of conserving bird biodiversity. It is

also important to realise that ecological studies of the urban environment not only have scientific value, but also social value. For example, green spaces are usually considered necessary for the well-being of urban residents (Azerrad *et al*, 2001). The study of urban ecology could also possibly be used as guidelines for the design of urban green space corridors (Mörtberg *et al*, 2000).

The greatest challenge facing urban ecologists in general, as well as urban avian ecologists is to describe the urban ecosystems and then to measure the appropriate factors that influence both the processes and patterns of interest. In this regard, very often a direct association between vegetation communities and animal communities are assumed. This may, however, not be the case as was discussed in both Chapter 1 and 2. I have therefore decided, based mainly on the consideration that birds are highly mobile, to first measure the avian demography of a city landscape and only afterwards to relate it to the underlying biotopes and associated land-use patterns. This will to a great extent remove the bias inherent in pre-selecting different biotopes or land-uses, followed by bird surveys, and then to assume that the two are related, and also assuming that the bird demography patterns will follow biotope patterns closely.

2.6 Hypothesis

Due to the mobility of birds, coupled with their ability to use multiple biotopes (eg. nesting and feeding), urban bird communities or bird demography will show patterns different from vegetation and structure based biotopes alone, and could therefore be considered as avitopes.

2.7 Aim/objective of the study

The primary aim of this research was to determine the patterns of avian diversity in Potchefstroom.

Secondary aims/objectives for this study include:

- Determine the bird species distribution in Potchefstroom using point counts
- Determine the distribution of feeding and nesting guilds in Potchefstroom
- Determine whether it is possible to identify urban avian indicators with this type of research
- To investigate, develop and define the concept of “active-habitat selectors” (AHS)
- To introduce, develop and define the concept of “avitopes”

The study design used to achieve this objective will be introduced in Chapter 3.

Chapter 3

Methodology

3.1 Study design

Based on the information, considerations and aims of the study presented in Chapter 2, the study was designed as follows:

INTRODUCTION AND LITERATURE REVIEW

- Obtained literature relevant to research/study
- Review based on literature obtained
- Introduction of the concepts of “active-habitat-selection” (AHS) and “avitope”
- Hypothesis and objective of study formulated



IDENTIFICATION OF STUDY AREA AND SELECTION OF SITES

- Selection of study area – Potchefstroom
- Obtained map of study area
- Evenly spaced sites identified (Fig. 3.1)
- Sites selected so as to include most of the major biotopes
- Sites located by means of a GPS (Global Positioning System)



DATA COLLECTION

- Data collected by means of point counts
- Number of species and abundance of each species recorded
- Weather conditions recorded
- Time of day recorded
- Biotope recorded
- Habitat description recorded



DATA ANALYSIS

- Data analysed using Primer 5 & GS+ programmes
- Data analysed according to (a) abundance of species and individuals in

each biotope (b) abundance of species and individuals according to guilds



DISCUSSION AND CONCLUSION

- Discussion of results
- Define the concepts of “active-habitat-selectors” and “avitope”
- Conclusions
- Further suggestions and comments

3.2 Study Area

The research area included the city of Potchefstroom, with its associated suburban areas, Ikageng, Promosa, Mohadin, the rural areas and the surrounding natural areas. Potchefstroom is situated in the eastern part of the North-West Province, South Africa. The city is located on the Mooi River and is $\pm 100\text{km}$ south-east of Johannesburg (Gauteng). Potchefstroom was founded in 1838, was the first Boer settlement in the Transvaal and up until 1860 it was the state capital (Encarta, 2002). The city was incorporated in the North-West Province in 1994 with the re-division of the South African provinces. The economy of the city is based on white-collared professions and educational, cultural and religious activities. In 1869, the Potchefstroom University for Christian Higher Education (PU for CHE), now called the North-West University (Potchefstroom Campus), was established by the Dutch Reformed Church and is one of the most well-regarded universities in South Africa (Encarta, 2002). Potchefstroom also serves as the area's principle centre of agricultural research and gold mining is also another important local industry. Its central GPS location is the town hall ($27^{\circ} 05'E$ and $26^{\circ}42'S$), with the surrounding natural areas being various types of grasslands. Various types of bird species can be found in these grasslands. The average summer temperature is $17^{\circ}\text{C} - 31^{\circ}\text{C}$ and the average winter temperature is $3^{\circ}\text{C} - 21^{\circ}\text{C}$, with the average rainfall being 360mm, which falls mostly during the summer

(Encarta, 2002). Potchefstroom has also been divided into thirteen major biotopes, which include:

- Central city buildings
- Residential areas
- Commercial areas
- Industrial areas
- Managed green space
- Man-made water bodies
- Traffic areas
- Agricultural areas
- Plantations
- Natural and semi-natural areas
- Disposal sites and ditches
- Waste grounds
- Special land-use types

These major biotopes are further subdivided into smaller areas, however, a description of these subdivisions, can be observed in Appendix 2.

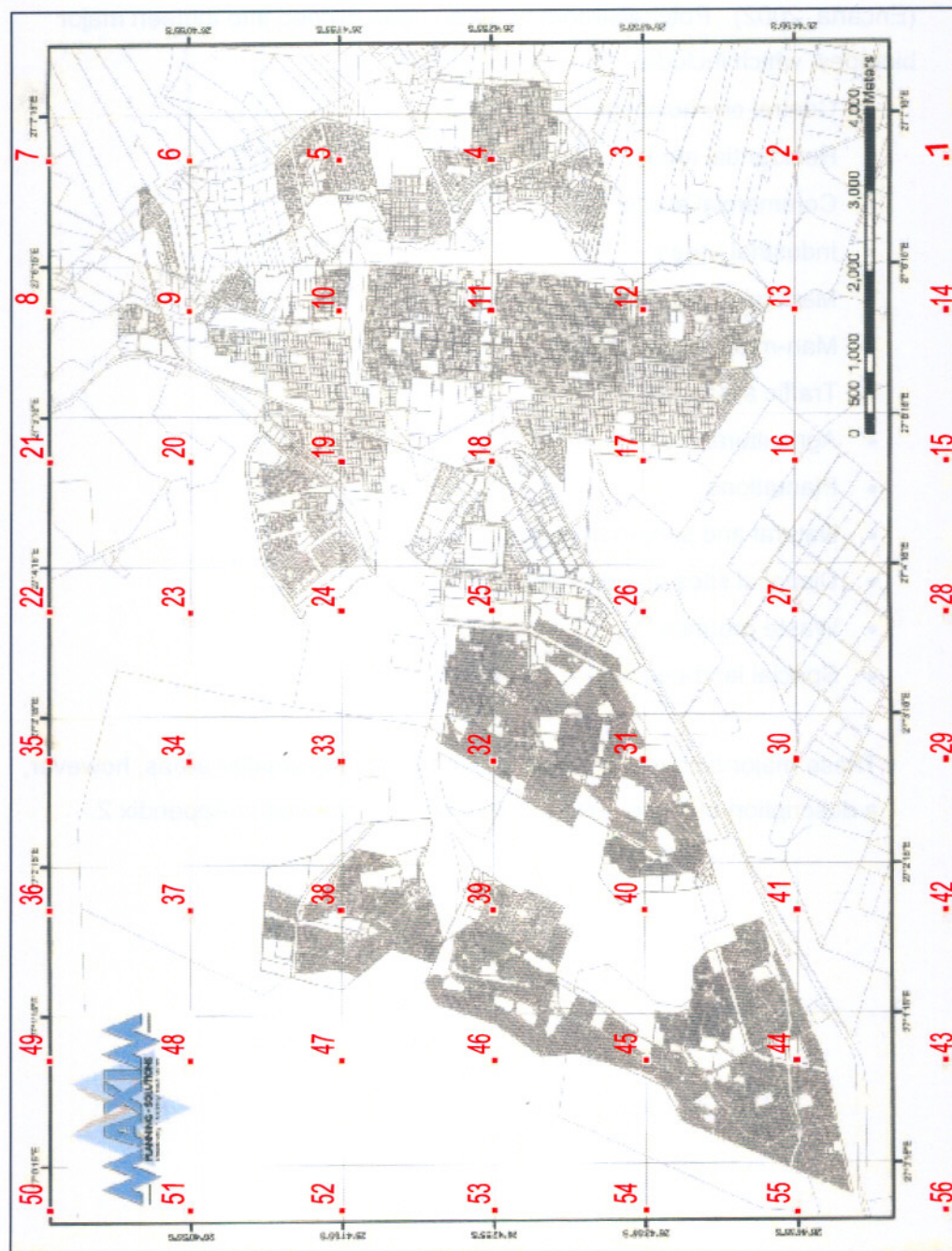


Figure 3.1: A map of the study area showing the locations of the sites



Figure 3.2: Scanned biotope map of Potchefstroom

This biotope map (Fig. 3.2), is only a scanned version of an existing paper copy, as the electronic version is unavailable. Due to this, the map cannot be labelled in order to indicate the various sites on the map itself. Figure 4.2.1 will be used for further references to the major biotopes. It is also important to note that not all of the areas included in this study are indicated on this biotope map. The different colours on this map refer to/indicate the thirteen major biotopes found throughout the study area (see Appendix 2).

3.3 Biotopes of Potchefstroom

Potchefstroom has been divided into thirteen major biotopes, which includes the city itself and the areas previously mentioned in 3.1. It is important to note

that some of these biotopes may not be suitable or relevant to be able to identify “avitopes” (see chapter 2, section 2.4). Although this study does not include all of the biotopes mentioned, the sampling sites included most of the major biotopes.



Figure 3.3: Site 12 was located in a residential area, representing one of the residential biotopes (see Appendix 2)



Figure 3.4: Site 16 was located in the agricultural areas, representing the agricultural biotope (see Appendix 2)



Figure 3.5: Site 25 was located in the industrial area, representing the industrial biotope (see Appendix 2)



Figure 3.6: Site 53 was located in the rocky grasslands and sparse woodlands (background), representing the natural and semi-natural biotope (see Appendix 2)



Figure 3.7: Site 29 was located next to a man-made water body, representing the man-made water body biotope (Canal in foreground in the left hand photo and on the right in the right hand photo, also see Appendix 2)



Figure 3.8: Site 11 was located in a park representing the managed green space biotope (see Appendix 2)

3.4 Materials and methods

The study was initially to be based on a gradient that spanned across the city as well as the suburban areas and all those areas mentioned in 3.1. A gradient is dependant on its definition, i.e. it is definition specific. A gradient that would apply to this type of study (i.e. one that would apply to birds), could not be identified or established through all of the areas included in this study, due to the manner in which Potchefstroom is structured. The mobility of birds, as well as the relatively small sizes of many of the identified biotopes, could not be used to make a distinct selection of a gradient as would be possible with botanical studies. The gradient used in the botanical studies was not deemed useable to investigate and define an avitope. As a solution to this problem, a map of Potchefstroom and its surrounding areas was used to select fifty-six sites that were uniformly spaced on a grid basis and which covered all the major biotopes of Potchefstroom (Fig. 3.1). The sites that were identified covered $\pm 4\%$ of Potchefstroom and its surrounding areas, with the distance between each site being 2km. The sites within these biotopes were located by means of a GPS (Global Positioning System). A 4X4 vehicle was used to travel to certain sites that were in the agricultural and natural and semi-natural areas as many of the sites were inaccessible by car. Data was collected during the mornings, with four repetitions at each site. Data was collected from January to March, April to June, July to September and October to December. The data for individual days was also collected according to the months mentioned above i.e. the data for day 1 was collected from January to March, for day 2 from April to June, for day 3 from July to September and for day 4 from October to December. A radius of 150m-200m was used at each site/point with a time limit of 20min. Birds were identified and counted by means of point counts, i.e. either by sighting or by means of bird calls (observability was the same for all sites). Binoculars were used for identifying the various bird species and if required, for counting the number of birds present. Data was recorded onto a data sheet that was specifically drawn up for this study. This sheet recorded the date of the observation, the season, the time of day, the GPS location, the climate/weather conditions, the

biotope and also consisted of a habitat description (see Appendix 3). A habitat description of each site was completed. Bird activity was found to be highest between sunrise and, depending on season, until 09:00 or 10:00 in the morning.

3.5 Analysis

Data was analysed using the Primer 5 and the GS+ programme. The Map Viewer programme was also used to obtain the outlines of the various areas on the map of Potchefstroom. The Primer 5 programme (Plymouth Routines in Multivariate Ecological Research), consists of various methods used to analyse the species or samples' abundances (or biomass) that result from the biological monitoring of environmental impacts. The programme can also be used in more fundamental studies in community ecology together with the associated physio-chemical data. This programme makes very few, if any, assumptions about the form of the data and concentrates on approaches that are both straightforward to explain and understand.

GS+ is a geostatistics programme consisting of a set of statistical procedures that could be used to model and analyse the spatial relationships that occur in nature. Geostatistics are generally used in geo-sciences but have recently been adopted in ecology (Geostatistical analysis of population distribution, 2004). Some advantages of this programme include the change in emphasis from estimation of averages to the mapping of spatially-distributed populations and that autocorrelations and sampling become less restrictive. There are five basic steps used in this programme in order to obtain maps. These include the collection of data from known locations, entering the data into the GS+ data worksheet, doing semi-variance analysis, produce an interpolation file by using kriging or conditional simulation and finally, drawing a 3D or 2D map (Gamma Design Software). The programme makes use of two types of kriging, namely block kriging and point (or ordinary) kriging. There are various advantages to kriging, which include the handling of spatial autocorrelation, it estimates both block averages and local population densities, it is not

sensitive to preferential sampling in specific areas and finally, it is able to replace stratified sampling if the size of aggregations is larger than the inter-sample distance (Elements of geostatistics, 2004). Block kriging was used for the analysis of results in this study.

The Map Viewer 5 programme is an analytical and graphical tool that allows the user to produce thematic maps easily. This programme provides several types of maps with which to present data.

Data was analysed according to the mean abundance of species and mean number of birds per biotope, the number of biotopes each species occurred in and according to the habitat descriptions. Using the results from the analysis, distribution maps were drawn up for Potchefstroom and the surrounding areas. From these distribution maps, I will try to identify "avitopes" for Potchefstroom.

Analysis of the sites within these biotopes, including their species, will continue in Chapter 4.

Chapter 4

Results

4.1 Introduction

As mentioned in Chapter 3, the Primer 5 programme and GS+ programme were used to obtain the results found in this chapter. The Map Viewer programme was also used in order to generate the outlines of the various areas found throughout this study (Fig. 4.2.1). Before the results are to be described in this chapter, the following will first be discussed, namely: the outlines of all these areas indicating their positions on the GS+ maps, the vegetation types or measure of urbanization of the various areas and the species found at these areas.

4.2 The outlines of the various study areas

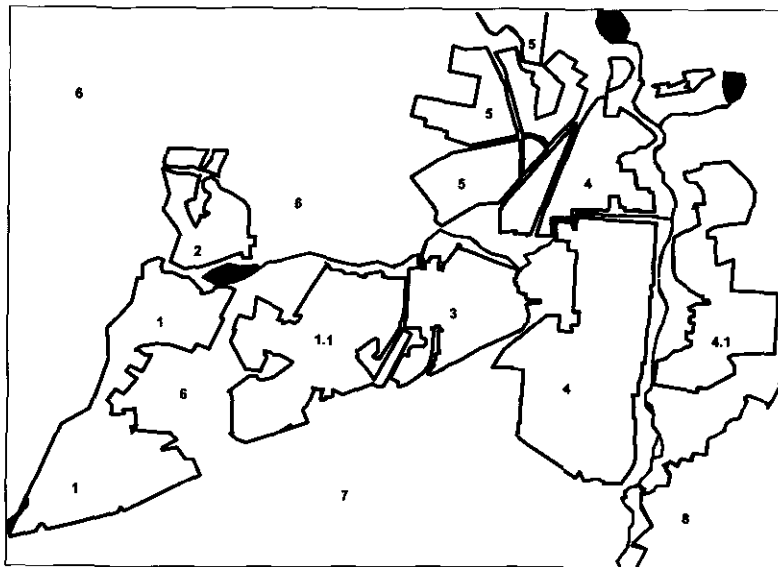


Figure 4.2.1: Map indicating the outlines of the various study areas

Table 4.2.1: The outlines of the various study areas used in this study (see Fig. 4.2.1)

Number	Study Area
Number 1	The western part of Ikageng
Number 1.1	The eastern part of Ikageng
Number 2	Mohadin and Promosa
Number 3	The industrial area
Number 4	The residential areas
Number 4.1	The eastern residential areas
Number 5	The military areas
Number 6	The natural and semi-natural areas
Number 7	The agricultural areas
Number 8	Prozesky (wetland)

It is important to note that the numbering on the map of the outlines are not an indication or reference to any of the major biotopes, but will be used in the later discussion. Table 4.2.1 can also be used for this purpose.

4.3 Vegetation types and measure of urbanization of the various study areas

The vegetation types and measure of urbanization for each area will be described in the following table:

Table 4.3.1: Vegetation description and measure of urbanization description of the study areas

Study Area	Description
1 Western Ikageng 1.1 Eastern Ikageng	1. Residential areas: Small single housing with reduced basic services 1.1 Residential areas: Small single housing with basic gardens
2. Mohadin and Promosa	Residential areas: Large single housing with large or small gardens. (Both these two areas are near a large water source)
3. Industrial area	Industrial area: Predominantly sealed surfaces, lesser sealed and managed surfaces and lesser sealed and unmanaged surfaces
4. Residential areas 4.1 Eastern residential areas	Residential areas: Large single housing with large or small gardens
5. Military areas	Special land-use types
6. Natural and semi-natural areas	Natural and semi-natural areas: Grasslands – rocky and sparse woodlands – dominated by trees
7. Agricultural areas	Agricultural areas: Crop fields (The classification only mentions crops, however, some agricultural areas did consist of cattle farms)
8. Prozesky	Natural and semi-natural areas: Wetland

4.4 The species found in each area

The names of the species observed in the study are according to the SASOL Birds of Southern Africa guidebook and the Robert's numbers are according to Roberts' Birds of Southern Africa (Maclean, 1993). The species found at each site were divided into their feeding and nesting guilds, which, are

indicated according to the following tables (Tables 4.4.1 – 4.4.2). Tables 4.4.3 – 4.4.10 presents the bird species recorded for each of the urban outlines.

Table 4.4.1: The feeding guilds for species indicated by number

<u>Feeding guild</u>	<u>Number</u>
Granivores	i
Insectivores	ii
Frugivores	iii
Omnivores	iv
Carnivores	v
Scavengers	vi
Herbivores	vii

Table 4.4.2: The nesting guilds for species indicated by number

<u>Nesting guild</u>	<u>Number</u>
Tree nesters	1
Structure nesters	2
Tree or structure nesters	3
Reed or grass nesters	4
Ground nesters	5
Shrub nesters	6
Shrub or tree nesters	7
Grass or ground nesters	8
Shrub or grass nesters	9
Grass nesters	10
Extra-limital	Ex

Table 4.4.3: The species found throughout Ikageng (Outlines 1 and 1.1. Also see Table 4.2.1)

Rob n°.	Common Name	Scientific Name	F. Guild	N. Guild
824	Southern Red Bishop	<i>Euplectes orix</i>	i	4
567	African Red-eyed Bulbul	<i>Pycnonotus nigricans</i>	ii	7

878	Yellow Canary	<i>Serinus flaviiventris</i>	i	7
354	Cape Turtle Dove	<i>Streptopelia capicola</i>	i	1
355	Laughing Dove	<i>Streptopelia senegalensis</i>	i	1
71	Cattle Egret	<i>Bubulcus ibis</i>	ii	1
451	African Hoopoe	<i>Upupa Africana</i>	ii	5
758	Indian Myna	<i>Acridotheres tristis</i>	iv	1
348	Feral Pigeon	<i>Columba livia</i>	i	2
349	Rock Pigeon	<i>Columba guinea</i>	i	3
255	Crowned Plover	<i>Vanellus coronatus</i>	ii	5
803	Cape Sparrow	<i>Passer melanurus</i>	i	3
801	House Sparrow	<i>Passer domesticus</i>	i	3
804	Southern Grey-headed Sparrow	<i>Passer diffusus</i>	i	3
799	White-browed Sparrow-weaver	<i>Plocepasser mahali</i>	i	1
764	Cape Glossy Starling	<i>Lamprolornis nitens</i>	iv	3
518	European Swallow	<i>Hirundo rustica</i>	ii	Ex
526	Greater Striped Swallow	<i>Hirundo cucullata</i>	ii	2
417	Little Swift	<i>Apus affinis</i>	ii	2
577	Olive Thrush	<i>Turdus olivaceus</i>	ii	7
814	Southern Masked Weaver	<i>Ploceus velatus</i>	i	1
Total species : 21				

* F. Guild: Feeding Guild *N. Guild: Nesting Guild

Table 4.4.4: The species found throughout Mohadin and Promosa (Outline 2
Also see Table 4.2.1)

Rob n°.	Common Name	Scientific Name	F. Guild	N. Guild
746	Bokmakierie	<i>Telophorus zeylonus</i>	ii	6
355	Laughing Dove	<i>Streptopelia senegalensis</i>	i	1
758	Indian Myna	<i>Acridotheres tristis</i>	iv	1
349	Rock Pigeon	<i>Columba guinea</i>	i	3
803	Cape Sparrow	<i>Passer melanurus</i>	i	3
801	House Sparrow	<i>Passer domesticus</i>	i	3
799	White-browed Sparrow-weaver	<i>Plocepasser mahali</i>	i	1
764	Cape Glossy Starling	<i>Lamprolornis nitens</i>	iv	3
577	Olive Thrush	<i>Turdus olivaceus</i>	ii	7
814	Southern Masked Weaver	<i>Ploceus velatus</i>	i	1
Total species: 10				

*F. Guild: Feeding Guild *N. Guild: Nesting Guild

Table 4.4.5: The species found throughout the industrial area (Outline 3 Also
see Table 4.2.1)

Rob n°.	Common Name	Scientific Name	F. Guild	N. Guild
354	Cape Turtle Dove	<i>Streptopelia capicola</i>	i	1
355	Laughing Dove	<i>Streptopelia senegalensis</i>	i	1
71	Cattle Egret	<i>Bubulcus ibis</i>	ii	1
758	Indian Myna	<i>Acridotheres tristis</i>	iv	1
348	Feral Pigeon	<i>Columba livia</i>	i	2
349	Rock Pigeon	<i>Columba guinea</i>	i	3
803	Cape Sparrow	<i>Passer melanurus</i>	i	3
801	House Sparrow	<i>Passer domesticus</i>	i	3
526	Greater Striped Swallow	<i>Hirundo cucullata</i>	ii	2
417	Little Swift	<i>Apus affinis</i>	ii	2

Total species: 10

*F. Guild: Feeding Guild *N. Guild: Nesting Guild

Table 4.4.6: The species found throughout the residential areas (Outlines 4, 4.1 Also see Table 4.2.1)

Rob n°.	Common Name	Scientific Name	F. Guild	N. Guild
824	Southern Red Bishop	<i>Euplectes orix</i>	i	4
567	African Red-eyed Bulbul	<i>Pycnonotus nigricans</i>	ii	7
391	Burchell's Coucal	<i>Centropus burchelli</i>	ii	5
377	Red-chested Cuckoo	<i>Cuculus solitarius</i>	ii	1
354	Cape Turtle Dove	<i>Streptopelia capicola</i>	i	1
355	Laughing Dove	<i>Streptopelia senegalensis</i>	i	1
71	Cattle Egret	<i>Bubulcus ibis</i>	ii	1
796	Cape White Eye	<i>Zosterops virens</i>	ii	7
203	Helmeted Guinea Fowl	<i>Numida meleagris</i>	i	5
451	African Hoopoe	<i>Upupa africana</i>	ii	5
94	Hadedda Ibis	<i>Bostrychia hagedash</i>	ii	1
857	Bronze Mannikin	<i>Lonchura cucullata</i>	i	1
425	White-backed Mousebird	<i>Colius colius</i>	iii	1
758	Indian Myna	<i>Acridotheres tristis</i>	iv	1
348	Feral Pigeon	<i>Columba livia</i>	i	2
349	Rock Pigeon	<i>Columba guinea</i>	i	3
255	Crowned Plover	<i>Vanellus coronatus</i>	ii	5
601	Cape Robin	<i>Cossypha caffra</i>	ii	6
803	Cape Sparrow	<i>Passer melanurus</i>	i	3
801	House Sparrow	<i>Passer domesticus</i>	i	3
764	Cape Glossy Starling	<i>Lamprotornis nitens</i>	iv	3
518	European Swallow	<i>Hirundo rustica</i>	ii	Ex
526	Greater Striped Swallow	<i>Hirundo cucullata</i>	ii	2
528	South African Cliff Swallow	<i>Hirundo spilodera</i>	ii	2
417	Little Swift	<i>Apus affinis</i>	ii	2
580	Groundscraper Thrush	<i>Turdus litsitsirupa</i>	ii	1
577	Olive Thrush	<i>Turdus olivaceus</i>	ii	7
713	Cape Wagtail	<i>Motacilla capensis</i>	ii	8
846	Common Waxbill	<i>Estrilda astrild</i>	i	5
814	Southern Masked Weaver	<i>Ploceus velatus</i>	i	1
860	Pin-tailed Whydah	<i>Vidua macroura</i>	i	1
Total species: 31				

*F. Guild: Feeding Guild *N. Guild: Nesting Guild

Table 4.4.7: The species found throughout the military areas (Outline 5 Also see Table 4.2.1)

Rob n°.	Common Name	Scientific Name	F. Guild	N. Guild
473	Crested Barbet	<i>Trachyphonus vaillantii</i>	ii	1
824	Southern Red Bishop	<i>Euplectes orix</i>	i	4
567	African Red-eyed Bulbul	<i>Pycnonotus nigricans</i>	ii	7
354	Cape Turtle Dove	<i>Streptopelia capicola</i>	i	1
355	Laughing Dove	<i>Streptopelia senegalensis</i>	i	1
71	Cattle Egret	<i>Bubulcus ibis</i>	ii	1
796	Cape White Eye	<i>Zosterops virens</i>	ii	7
698	Fiscal Flycatcher	<i>Sigelus silens</i>	ii	6

203	Helmeted Guinea Fowl	<i>Numida meleagris</i>	i	5
452	Redbilled Wood-hoopoe	<i>Phoeniculus purpureus</i>	ii	1
94	Hadedda Ibis	<i>Bostrychia hagedash</i>	ii	1
530	Common House-martin	<i>Delichon urbica</i>	ii	2
424	Speckled Mousebird	<i>Colius striatus</i>	iii	1
758	Indian Myna	<i>Acridotheres tristis</i>	iv	1
349	Rock Pigeon	<i>Columba guinea</i>	i	3
258	Blacksmith Plover	<i>Vanellus armatus</i>	ii	5
255	Crowned Plover	<i>Vanellus coronatus</i>	ii	5
803	Cape Sparrow	<i>Passer melanurus</i>	i	3
801	House Sparrow	<i>Passer domesticus</i>	i	3
764	Cape Glossy Starling	<i>Lamprotornis nitens</i>	iv	3
760	Wattled Starling	<i>Creatophora cinerea</i>	iv	7
518	European Swallow	<i>Hirundo rustica</i>	ii	Ex
526	Greater Striped Swallow	<i>Hirundo cucullata</i>	ii	2
528	South African Cliff Swallow	<i>Hirundo spilodera</i>	ii	2
417	Little Swift	<i>Apus affinis</i>	ii	2
577	Olive Thrush	<i>Turdus olivaceus</i>	ii	7
713	Cape Wagtail	<i>Motacilla capensis</i>	ii	8
814	Southern Masked Weaver	<i>Ploceus velatus</i>	i	1
862	Eastern Paradise Whydah	<i>Vidua paradisaea</i>	i	1
860	Pin-tailed Whydah	<i>Vidua macroura</i>	i	1
Total species: 30				

*F. Guild: Feeding Guild *N. Guild: Nesting Guild

Table 4.4.8: The species found throughout the natural and semi-natural areas
(Outline 6 Also see Table 4.2.1)

Rob n°.	Common Name	Scientific Name	F. Guild	N. Guild
703	Pirit Batis	<i>Batis pirit</i>	ii	7
824	Southern Red Bishop	<i>Euplectes orix</i>	i	4
567	African Red-eyed Bulbul	<i>Pycnonotus nigricans</i>	ii	7
746	Bokmakierie	<i>Telophorus zeylonus</i>	ii	6
878	Yellow Canary	<i>Serinus flaviventris</i>	i	7
548	Pied Crow	<i>Corvus albus</i>	vi	1
377	Red-chested Cuckoo	<i>Cuculus solitarius</i>	ii	1
354	Cape Turtle Dove	<i>Streptopelia capicola</i>	i	1
355	Laughing Dove	<i>Streptopelia senegalensis</i>	i	1
104	Yellow-billed Ducks	<i>Anas undulata</i>	vii	4
71	Cattle Egret	<i>Bubulcus ibis</i>	ii	1
796	Cape White Eye	<i>Zosterops virens</i>	ii	7
698	Fiscal Flycatcher	<i>Sigelus silens</i>	ii	6
203	Helmeted Guinea Fowl	<i>Numida meleagris</i>	i	5
62	Grey Heron	<i>Ardea cinerea</i>	v	1
451	African Hoopoe	<i>Upupa africana</i>	ii	5
94	Hadedda Ibis	<i>Bostrychia hagedash</i>	ii	1
239b	Northern Black Korhaan	<i>Eupodotis afraoides</i>	ii	5
	Eastern Long-billed Lark	<i>Certhilauda semitorquata</i>	ii	5
426	Red-faced Mousebird	<i>Urocolius indicus</i>	iii	1
425	White-backed Mousebird	<i>Colius colius</i>	iii	1
758	Indian Myna	<i>Acridotheres tristis</i>	iv	1
348	Feral Pigeon	<i>Columba livia</i>	i	2
349	Rock Pigeon	<i>Columba guinea</i>	i	3
716	Grassveld Pipit	<i>Anthus cinnamomeus</i>	ii	10
258	Blacksmith Plover	<i>Vanellus armatus</i>	ii	5

255	Crowned Plover	<i>Vanellus coronatus</i>	ii	5
685	Black-chested Prinia	<i>Prinia flavicans</i>	ii	6
732	Fiscal Shrike	<i>Lanius collaris</i>	v	1
803	Cape Sparrow	<i>Passer melanurus</i>	i	3
801	House Sparrow	<i>Passer domesticus</i>	i	3
799	White-browed Sparrow-weaver	<i>Plocepasser mahali</i>	i	1
764	Cape Glossy Starling	<i>Lamprotornis nitens</i>	iv	3
518	European Swallow	<i>Hirundo rustica</i>	ii	Ex
526	Greater Striped Swallow	<i>Hirundo cucullata</i>	ii	2
528	South African Cliff Swallow	<i>Hirundo spilodera</i>	ii	2
417	Little Swift	<i>Apus affinis</i>	ii	2
577	Olive Thrush	<i>Turdus olivaceus</i>	ii	7
621	Chestnut-vented Tit-babbler	<i>Parisoma subcaeruleum</i>	ii	6
713	Cape Wagtail	<i>Motacilla capensis</i>	ii	8
844	Blue Waxbill	<i>Uraeginthus angolensis</i>	i	1
814	Southern Masked Weaver	<i>Ploceus velatus</i>	i	1
832	Long-tailed Widow	<i>Euplectes progne</i>	i	10
862	Eastern Paradise Whydah	<i>Vidua paradisaea</i>	i	1
860	Pin-tailed Whydah	<i>Vidua macroura</i>	i	1
	Unidentified brown raptor			
	Unidentified grey raptor			
Total species: 47				

*F. Guild: Feeding Guild *N. Guild: Nesting Guild

Table 4.4.9: The species found throughout the agricultural areas (Outline 7
Also see Table 4.2.1)

Rob n°.	Common Name	Scientific Name	F. Guild	N. Guild
473	Crested Barbet	<i>Trachyphonus vaillantii</i>	ii	1
746	Bokmakierie	<i>Telophorus zeylonus</i>	ii	6
824	Southern Red Bishop	<i>Euplectes orix</i>	i	4
677	Levaillants Cisticola	<i>Cisticola tinniens</i>	ii	10
391	Burchell's Coucal	<i>Centropus burchelli</i>	ii	5
354	Cape Turtle Dove	<i>Streptopelia capicola</i>	i	1
355	Laughing Dove	<i>Streptopelia senegalensis</i>	i	1
352	Red-eyed Dove	<i>Streptopelia semitorquata</i>	i	1
356	Namaqua Dove	<i>Oena capensis</i>	i	6
104	Yellow-billed Ducks	<i>Anas undulata</i>	vii	4
71	Cattle Egret	<i>Bubulcus ibis</i>	ii	1
796	Cape White Eye	<i>Zosterops virens</i>	ii	7
834	Melba Finch	<i>Pytilia melba</i>	i	6
698	Fiscal Flycatcher	<i>Sigelus silens</i>	ii	6
199	Swainson's Francolin	<i>Pternistes swainsonii</i>	ii	5
203	Helmeted Guinea Fowl	<i>Numida meleagris</i>	i	5
223	Purple Gallinule	<i>Porphyrio madagascariensis</i>	iv	4
81	Hamerkop	<i>Scopus umbretta</i>	v	1
62	Grey Heron	<i>Ardea cinerea</i>	v	1
451	African Hoopoe	<i>Upupa africana</i>	ii	5
94	Hadedda Ibis	<i>Bostrychia hagedash</i>	ii	1
226	Common Moorhen	<i>Gallinula chloropus</i>	iv	4
424	Speckled Mousebird	<i>Colius striatus</i>	iii	1
758	Indian Myna	<i>Acridotheres tristis</i>	iv	1
348	Feral Pigeon	<i>Columba livia</i>	i	2
349	Rock Pigeon	<i>Columba guinea</i>	i	3
258	Blacksmith Plover	<i>Vanellus armatus</i>	ii	5

255	Crowned Plover	<i>Vanellus coronatus</i>	ii	5
685	Black-chested Prinia	<i>Prinia flavicans</i>	ii	6
821	Red-billed Quelea	<i>Quelea quelea</i>	I	1
732	Fiscal Shrike	<i>Lanius collaris</i>	V	1
803	Cape Sparrow	<i>Passer melanurus</i>	I	3
801	House Sparrow	<i>Passer domesticus</i>	I	3
799	White-browed Sparrow-weaver	<i>Plocepasser mahali</i>	I	1
518	European Swallow	<i>Hirundo rustica</i>	ii	Ex
526	Greater Striped Swallow	<i>Hirundo cucullata</i>	ii	2
528	South African Cliff Swallow	<i>Hirundo spilodera</i>	ii	2
107	Hottentot Teal	<i>Anas hottentota</i>	iv	4
713	Cape Wagtail	<i>Motacilla capensis</i>	ii	8
814	Southern Masked Weaver	<i>Ploceus velatus</i>	I	1
	Unidentified Geese			
	Unidentified grey raptor			
Total species: 42				

*F. Guild: Feeding Guild *N. Guild: Nesting Guild

Table 4.4.10: The species found throughout Prozesky (Outline 8 Also see Table 4.2.1)

Rob n°.	Common Name	Scientific Name	F. Guild	N. Guild
473	Crested Barbet	<i>Trachyphonus vaillantii</i>	ii	1
826	Golden Bishop	<i>Euplectes afer</i>	I	4
824	Southern red Bishop	<i>Euplectes orix</i>	I	4
354	Cape Turtle Dove	<i>Streptopelia capicola</i>	I	1
355	Laughing Dove	<i>Streptopelia senegalensis</i>	i	1
104	Yellow-billed Ducks	<i>Anas undulata</i>	vii	4
71	Cattle Egret	<i>Bubulcus ibis</i>	ii	1
698	Fiscal Flycatcher	<i>Sigelus silens</i>	ii	6
203	Helmeted Guinea Fowl	<i>Numida meleagris</i>	I	5
94	Hadedda Ibis	<i>Bostrychia hagedash</i>	ii	1
223	Purple Gallinule	<i>Porphyrio madagascariensis</i>	iv	4
226	Common Moorhen	<i>Gallinula chloropus</i>	iv	4
758	Indian Myna	<i>Acridotheres tristis</i>	iv	1
348	Feral Pigeon	<i>Columba livia</i>	I	2
258	Blacksmith Plover	<i>Vanellus armatus</i>	ii	5
255	Crowned Plover	<i>Vanellus coronatus</i>	ii	5
821	Red-billed Quelea	<i>Quelea quelea</i>	i	1
732	Fiscal Shrike	<i>Lanius collaris</i>	v	1
803	Cape Sparrow	<i>Passer melanurus</i>	I	3
799	White-browed Sparrow-weaver	<i>Plocepasser mahali</i>	i	1
764	Cape Glossy Starling	<i>Lamprotornis nitens</i>	iv	3
526	Greater Striped Swallow	<i>Hirundo cucullata</i>	ii	2
417	Little Swift	<i>Apus affinis</i>	ii	2
107	Hottentot Teal	<i>Anas hottentota</i>	iv	4
108	Red-billed Teal	<i>Anas erythrorhyncha</i>	vii	4
713	Cape Wagtail	<i>Motacilla capensis</i>	ii	8
814	Southern Masked Weaver	<i>Ploceus velatus</i>	i	1
860	Pin-tailed Whydah	<i>Vidua macroura</i>	I	1
	Unidentified Warbler			
Total species: 29				

*F. Guild: Feeding Guild *N. Guild: Nesting Guild

4.5 Discussion of results

There are many ways available to analyse the data than what I have, but due to time and space constraints, only a limited number (47) of distribution maps have been selected and presented in this chapter. When examining the figures for the discussion, it is important to take note of when the **total number of species** are being discussed, and when the **total number of birds** are being discussed so as to avoid confusion. When referring to the total number of birds or species, I am referring to all the birds or species that have been observed, and not the mean number of birds or species. The figures each consist of an x – axis, which is indicated as east longitude and a y – axis, which is indicated as south longitude. These (axes) were obtained by entering GPS co-ordinates into the programme. The top left corner (27°00'15"E & 26°39'55"S) and top right corner (27°7'15"E & 26°39'55"S) along with the bottom left corner (27°00'15"E & 26°45'55"S) and bottom right corner (27°7'15"E & 26°45'55"S), together, form the limits of the study area.

The distribution maps will be discussed according to certain criteria, which include:

- Obvious distribution
- Interruptions
- Presence of corridors
- Areas and patterns with low numbers or values (indices)

Each figure also has a corresponding variogram, that although is not included with each figure, indicates spatial distributions. The following are examples of the three different types of variograms, which will be referred to by number. Variograms with shape number 3 indicates the best fit (Geostatistical analysis of population distribution, 2004).

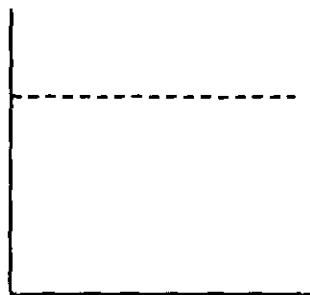


Figure 4.5.1: A variogram (number 1) indicating no spatial correlation

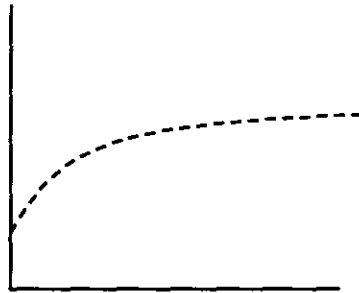


Figure 4.5.2: A variogram (number 2) indicating spatial correlation in combination with pure random variation

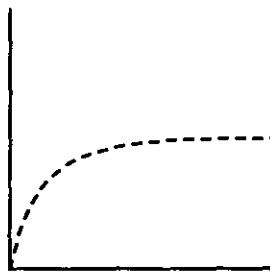


Figure 4.5.3: A variogram (number 3) indicating high spatial correlation with no random effects

After the results have been discussed, I will endeavour to determine whether or not main patterns of avian demography have been established and then to derive "avitopes" on the map of the study area at the end of Chapter 5.

(*Note: Please take note that when discussing the maps that follow, the line spacing has been altered to single line spacing due to space constraints.)

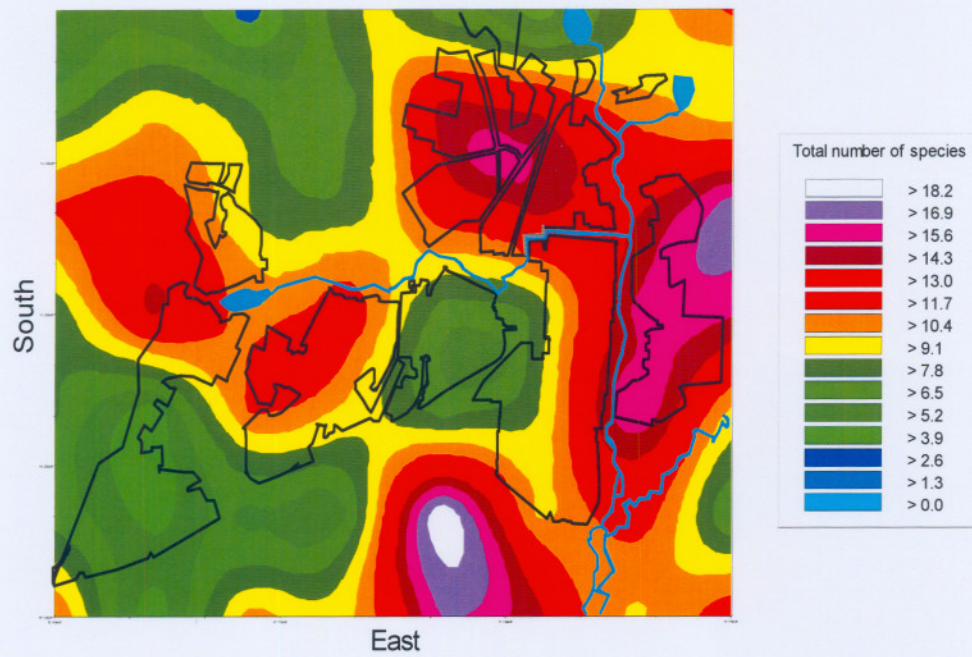


Figure 4.1: The total number of species interpolated over Potchefstroom

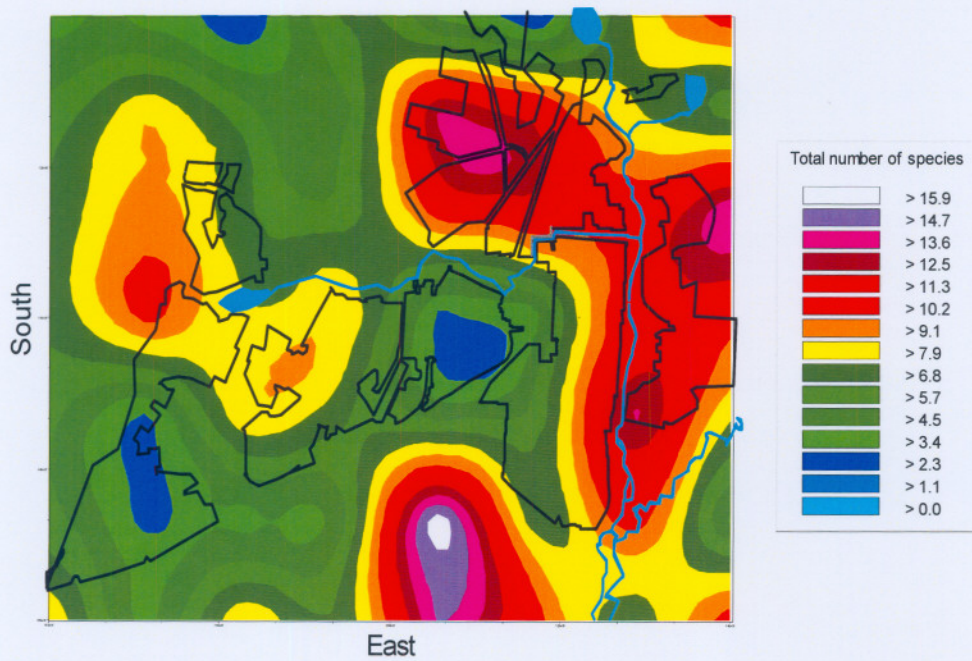


Figure 4.1.1: The total number of species, excluding doves and pigeons, interpolated over Potchefstroom

Figure 4.1: In this figure, the lowest number of species occurred in the western part of Ikageng, some of the natural and semi-natural areas and in the western part of the military areas. The second lowest number of species was found in the industrial area, the north-eastern part of Mohadin and Promosa, and in most of the natural and semi-natural areas. The second highest number of species occurred in the south-western part of Mohadin and Promosa, some of the natural and semi-natural areas just outside of Mohadin and Promosa, the eastern part of Ikageng, Prozesky and on the rest of the military areas. The highest number of species was found primarily in the residential and agricultural areas. This figure has a number 3 variogram (see Chapter 4, section 4.5).

Figure 4.1.1: Since most dove and pigeon species are commonly and abundantly found in urban areas, they were excluded from this data set in order to determine the contribution of the other bird species. With those species removed, the total number of species generally decreased over the entire grid. The lowest number of species was again found in Ikageng and in some of the natural and semi-natural areas. However, the species' totals were lower for these areas than when doves and pigeons were included. The area most affected, however, was the industrial area, which previously averaged a species total between 6.9 - 8.8 species. This area now only averaged between 2.3 -4.5 species. Most of the natural and semi-natural areas, as well as the north-eastern parts of Mohadin and Promosa, still had the second lowest number of species and the second highest number of species was still found to be in the south-western parts of Mohadin and Promosa, the eastern part of Ikageng, Prozesky and the military areas, however, compared to Fig. 4.1, the number of species on the military base increased. The residential areas continued to have the highest number of species. This figure has a number 3 variogram (see Chapter 4, section 4.5).

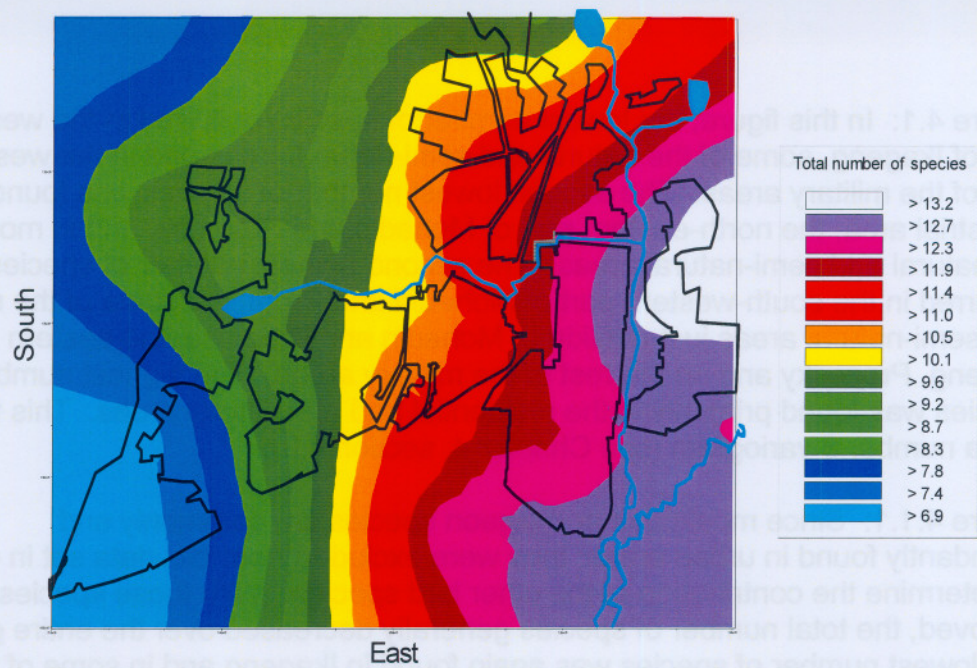


Figure 4.2: The total number of bird species found at each alternative site, interpolated over Potchefstroom

Figure 4.2: In this figure, data was analysed using only the data from each alternative site. This was done in order to try and determine whether or not less sampling sites could be used for this type of study. This figure has shown some similarities in some of the various areas found in Fig. 4.1. Some of these similarities include the highest number of species occurring in the residential and agricultural areas, as well as the lowest number of species in the western part of Ikageng. This figure also indicated various differences when compared to Fig. 4.1. In this case, the low number of species in the industrial area was not indicated in this figure as they were in Fig. 4.1. This figure has in fact indicated a much higher number of species for this area, and the same is indicated for Prozesky, which also has a higher number of species in this figure than in Fig. 4.1. This figure has also indicated a difference in the occurrence of the second highest number of species, which was found in the eastern part of Ikageng in Fig. 4.1. In this figure, the eastern half of this part of Ikageng has the second highest number of species, whereas in Fig. 4.1, the western half of this part of Ikageng had the second highest number of species. Mohadin and Promosa are also shown to have had the second lowest number of species in this figure, however, in Fig. 4.1, the western half of these two areas had the second highest number of species. This figure has a number 2 variogram (see Chapter 4, section 4.5).

This graph, although indicating some similarities, does not indicate sufficient similarities when compared to Fig. 4.1. For this specific study, the use of less sampling points do not prove to be sufficient in order to determine distribution patterns across the entire area used for this study.

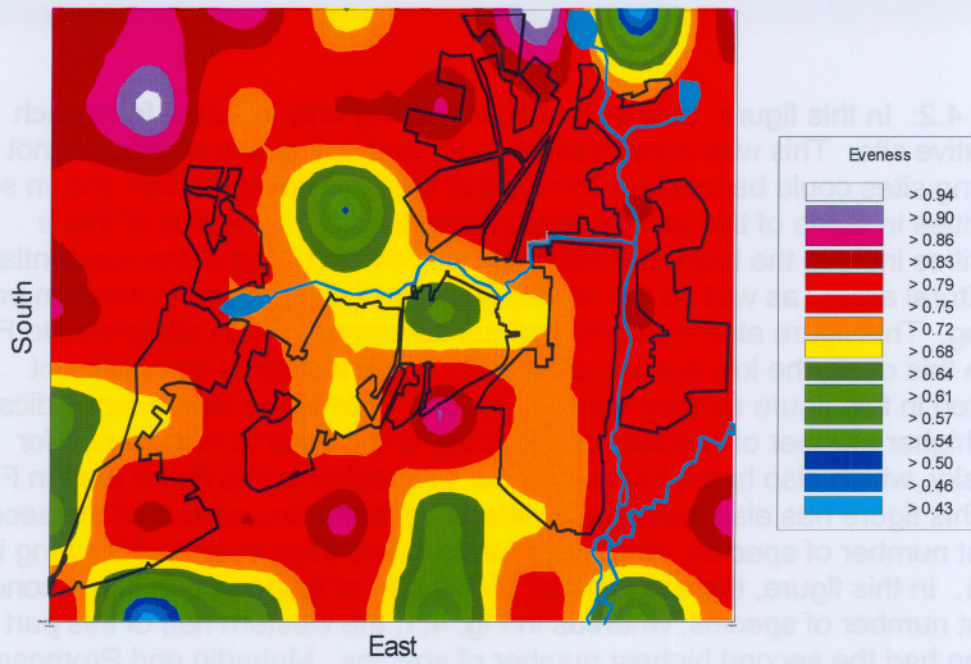


Figure 4.3: The evenness index indicating the bird species interpolated over Potchefstroom

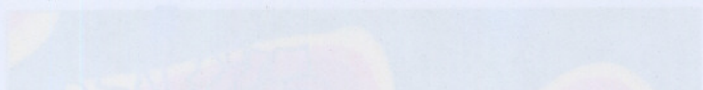


Figure 4.3: This figure indicates the evenness of the various areas (i.e. the relative abundance of the different species that make up the richness for each area). The lowest and second lowest evenness was found in the agricultural areas below the western part of Ikageng and those below the industrial area, most of the industrial area, most of Prozesky, the western half of the residential areas nearest to the industrial area, the majority of the eastern part of Ikageng, the central section of the western part of Ikageng and in the natural and semi-natural areas west of the western part of Ikageng and those between Mohadin and Promosa and the military areas. The second highest evenness was found in the majority of the remaining natural and semi-natural areas and those between the two parts of Ikageng, almost all of the military areas, the entire eastern part of the residential areas, the eastern half of the residential areas nearest to the industrial area, the upper half of Prozesky, in some of the agricultural areas and throughout Mohadin and Promosa. The greatest evenness was located in the north-western part of the natural and semi-natural areas, the northern-most part of the military areas, in two small parts of the agricultural areas and in a small part near Prozesky. This figure has a number 3 variogram (see Chapter 4, section 4.5).

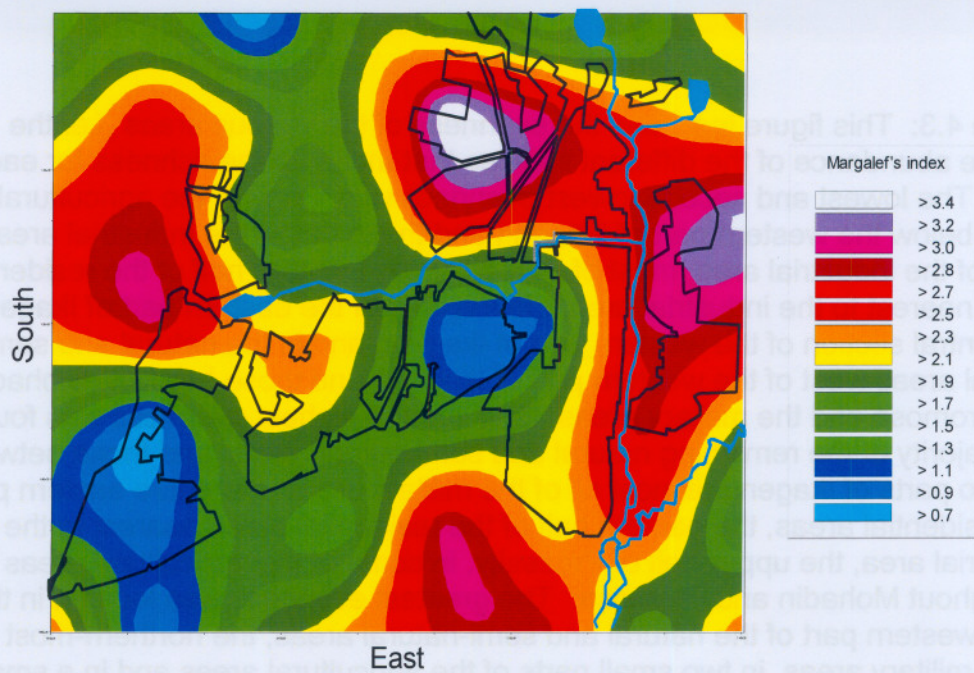


Figure 4.4: The Margaleff index indicating bird species richness, interpolated over Potchefstroom

Figure 4.4: This figure indicates the diversity of the various sites by making use of species richness. The lowest diversity was found in most of the industrial area, the agricultural areas below the western part of Ikageng, the central and lower half of the western part of Ikageng and in a small northern part of the natural and semi-natural areas. The second lowest diversity was located in most of Prozesky, the western half of the residential areas nearest to the industrial area, the rest of the industrial area, the eastern and lower half of the eastern part of Ikageng, a small part of the eastern half of Mohadin and Promosa, the agricultural areas below Ikageng and those just below the industrial area, the northern part of the military areas, small areas in the western part of Ikageng and in the natural and semi-natural areas between the two parts of Ikageng, between the military areas and Mohadin and Promosa, those west of Ikageng and some of those to the north. The second highest diversity occurred in the rest of the agricultural areas below the industrial area, the eastern half of the residential areas nearest to the industrial area, the eastern half of the military areas, the lower half of the eastern residential areas, the areas surrounding the western part of the military areas, the central and western half of Mohadin and Promosa, the western half of the eastern part of Ikageng, the rest of Prozesky, the top section of the western part of Ikageng, the areas to the north of the eastern residential areas and in the natural and semi-natural areas to the north and west of Mohadin and Promosa. The upper half of the eastern residential areas, the areas east of this part, the central and western part of the military areas, a small part in the natural and semi-natural areas west of the top section of the western part of Ikageng and in a small part of the agricultural areas below the industrial area had the highest diversity present. This figure has a number 3 variogram (see Chapter 4, section 4.5).

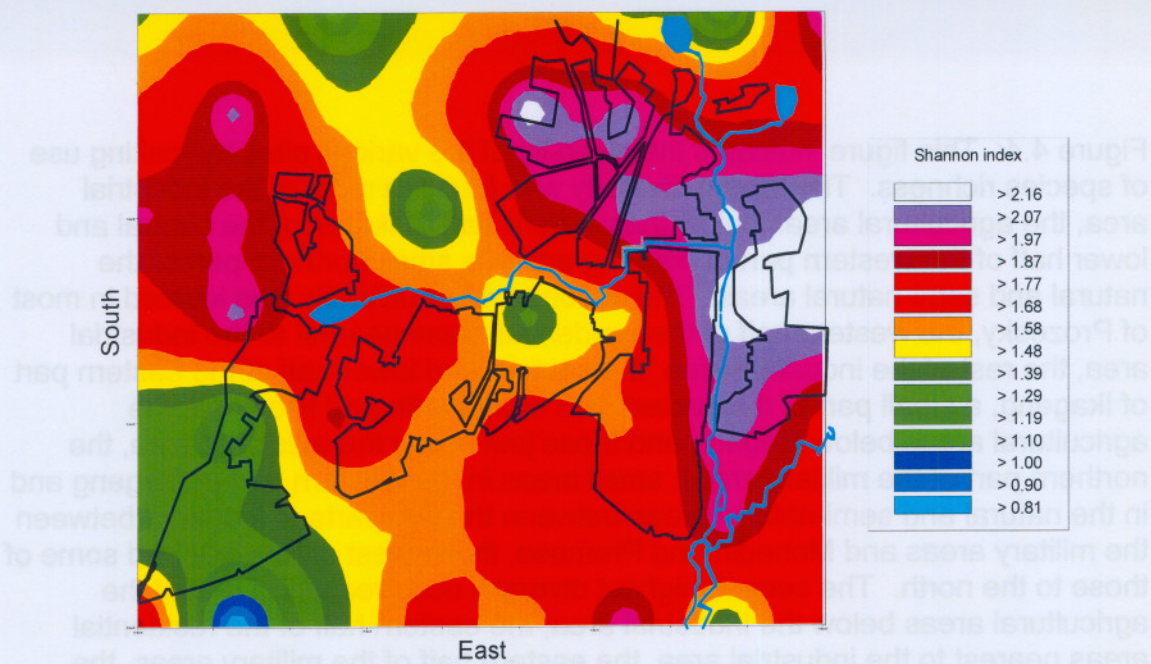


Figure 4.5: The Shannon index, indicating species diversity, interpolated over Potchefstroom

Figure 4.5: This figure also indicates the diversity of the various areas and is similar to Fig. 4.4. In this figure, the Shannon index indicates that the lowest area of diversity for bird species occurred in the lower half of the western part of Ikageng, in small parts of the natural and semi-natural areas north of the eastern part of Ikageng and in a small section of the industrial area. The second lowest areas of diversity for bird species turned out to be the rest of the industrial area and the natural and semi-natural areas to the west of the military areas. Prozesky, Mohadin and Promosa, most of the western part of the residential areas and the agricultural areas were found to have had the second highest diversity of bird species occurrence. The Shannon index also indicated that the eastern part of the residential areas, the military areas and the natural and semi-natural areas to the west of Mohadin and Promosa, had the greatest diversity of bird species. This figure has a number 3 variogram (see Chapter 4, section 4.5).

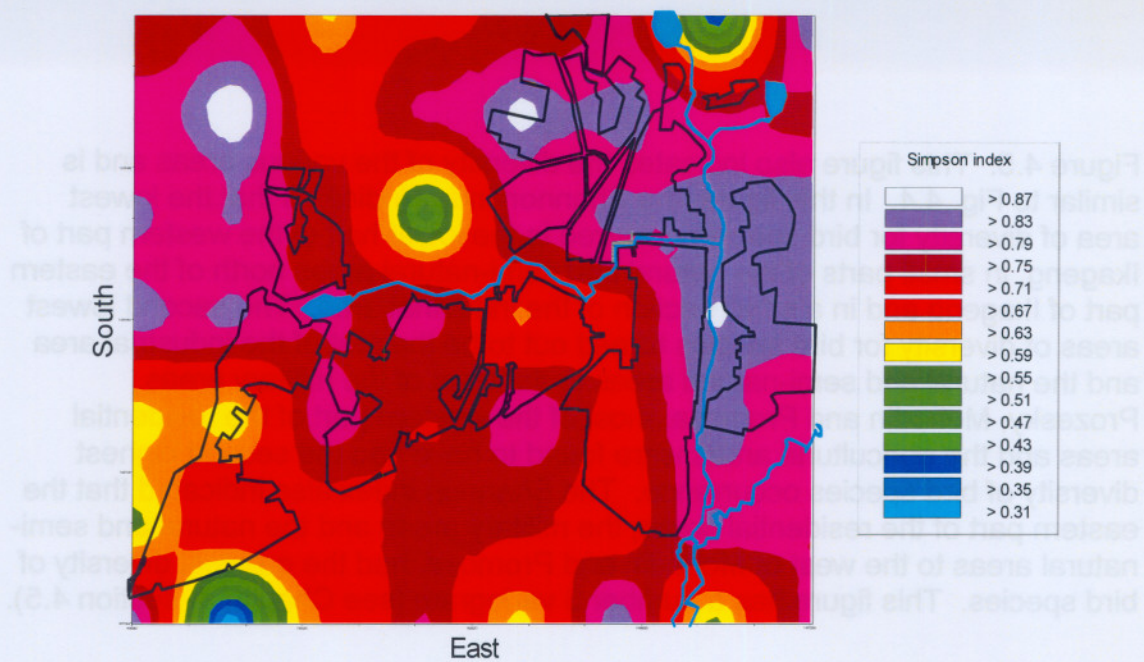


Figure 4.6: The Simpson index, indicating diversity, interpolated over Potchefstroom

Figure 4.6: This figure also indicates the diversity of the various areas by also making use of species richness, thus this figure and Fig. 4.4 both indicate diversity using species richness. This figure, however, does not correlate with the other findings that were observed in this study in terms of distribution. This figure's patterns do not correspond with patterns found in any of the other indices. Fig. 4.4 gives a better indication of what was observed in this study and this figure will thus not be described. This figure has a number 3 variogram (see Chapter 4, section 4.5).

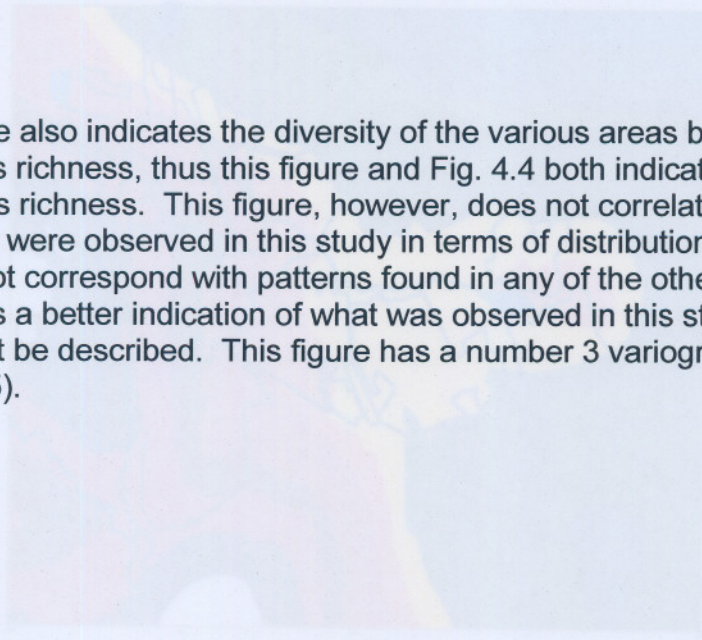
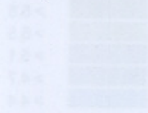


Figure 4.7: The maximum number of bird species interpolated over Potchefstroom

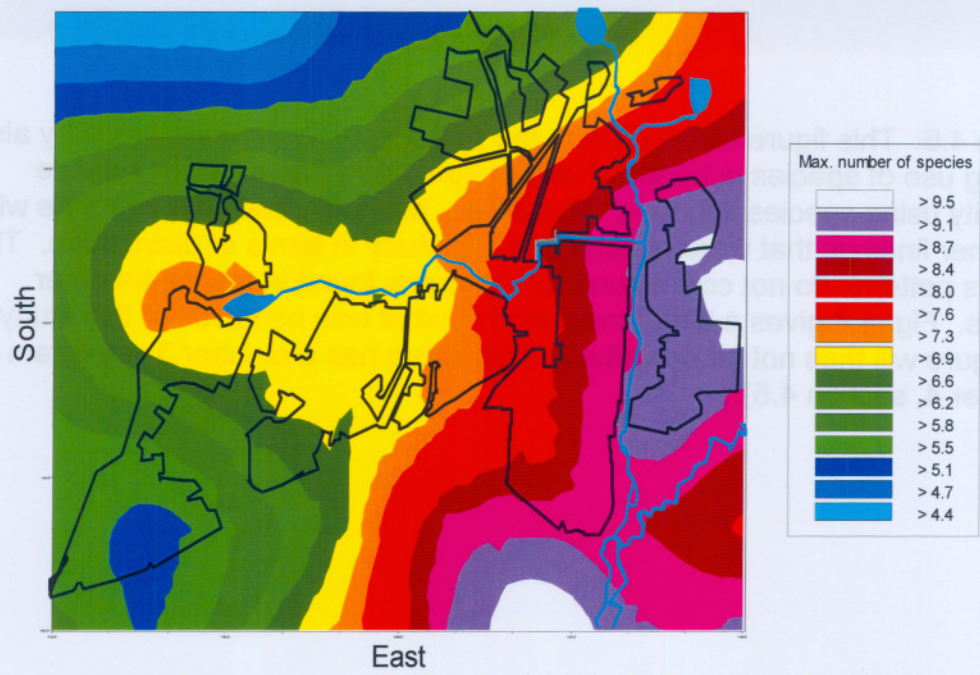


Figure 4.7: The maximum number of bird species interpolated over Potchefstroom

Figure 4.7: This figure made use of only the maximum number of species found over any one of the four days. The lowest maximum number of species was found in the lower section of the western part of Ikageng and the natural and semi-natural areas, excluding those directly north of Mohadin and Promosa and those west of Ikageng. The second lowest maximum number of species occurred in the northern parts of Promosa and Mohadin, the industrial area and the military area (excluding the eastern sides of both these areas). The second highest maximum number of species was found on the western side of the residential areas nearest to the industrial area, the eastern side of the industrial area, the southern parts of the military areas and in the agricultural areas below Ikageng. The highest maximum number of species were found in the eastern residential areas, the agricultural areas below the industrial area and the residential areas closest to it, and in Prozesky, where the maximum number of species found on one day was between 9 -10 species. This figure has a number 2 variogram (see Chapter 4, section 4.5).



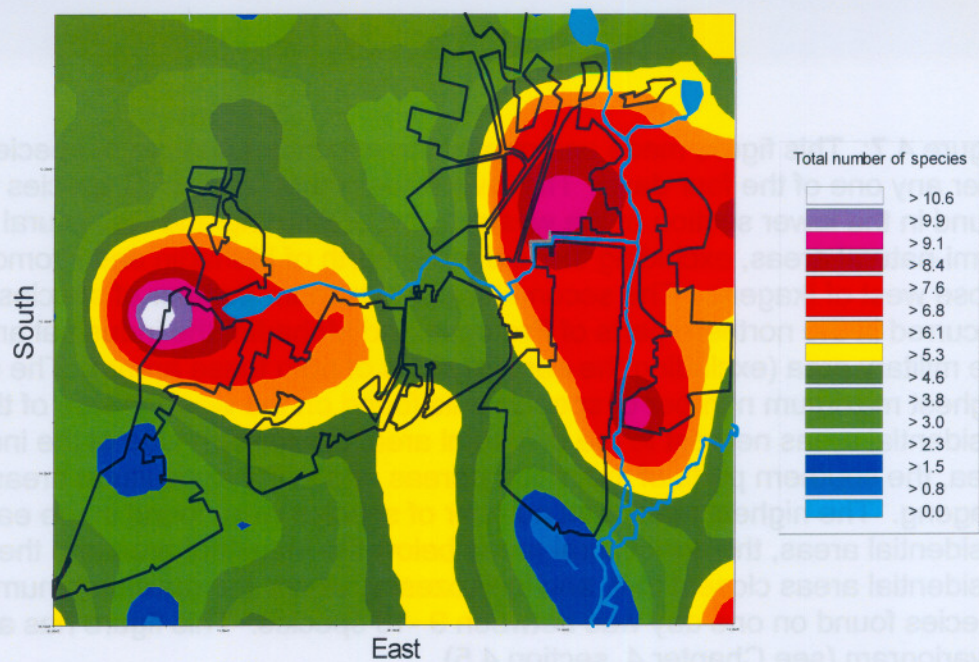


Figure 4.8: The total number of species, observed on sampling day 1, interpolated over Potchefstroom

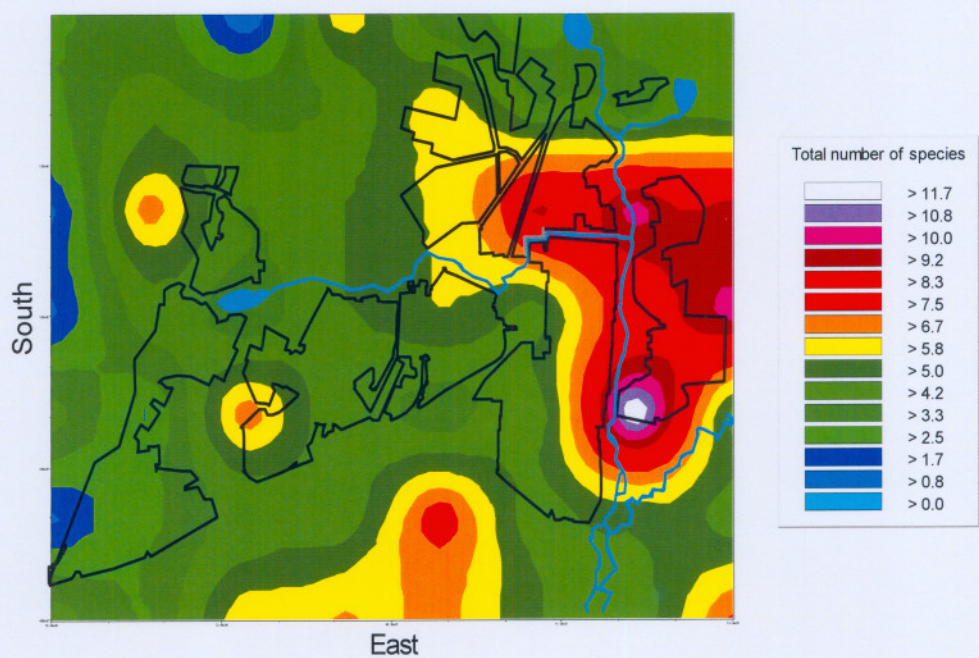


Figure 4.8.1: The total number of species, observed on sampling day 2, interpolated over Potchefstroom

Figure 4.8: Fig. 4.8 – Fig. 4.8.3 indicate the total number of species found in this study per day. This figure indicates the total number of species found on sampling day 1. The lowest total number of species was found throughout the lower half of the western part of Ikageng, in the agricultural areas below the residential areas nearest to the industrial area, in a small part of Prozesky, the northern tip of the military areas and in some parts of the natural and semi-natural areas. The second lowest total number of species was located in the rest of the agricultural areas, Prozesky, the industrial area, the lower parts of the eastern part of Ikageng, some of the military areas, the eastern parts of the residential areas nearest to the industrial area and in the natural and semi-natural areas. The second highest total number of species were located in the rest of the eastern part of Ikageng, in Mohadin and Promosa, in a small part of the natural and semi-natural areas just outside the eastern part of Mohadin and Promosa, the eastern residential areas, the western part of the residential areas nearest to the industrial area and in the majority of the military areas. The natural and semi-natural areas just to the west of Mohadin and Promosa had the highest total number of species. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.8.1: This figure indicates the total number of species found on sampling day 2. This figure is relatively similar to Fig. 4.8, however, the peaks for the highest total number of species shifted in this figure. The lowest total number of species were found in the central and most of the lower half of the western part of Ikageng, the natural and semi-natural areas outside this part of Ikageng, the natural and semi-natural areas far west of Mohadin and Promosa, a small part far north of this area and a small part in the north of the military areas. The second lowest total number of species were found throughout Mohadin and Promosa, the top part and eastern lower half of the western part of Ikageng, the industrial area, almost all of the eastern part of Ikageng, the western half of the residential areas nearest to the industrial area, most of the north and western half of the military areas, the upper parts of the agricultural areas, Prozesky and the majority of the rest of the natural and semi-natural areas. The second highest total number of species were located in the natural and semi-natural areas just west of Mohadin and Promosa and those between the two parts of Ikageng, the lower agricultural areas below the eastern part of Ikageng and the industrial area, the south-eastern corner of Prozesky, the rest of the military areas, the eastern half of the residential areas nearest to the industrial area and the majority of the eastern residential areas. The southern tip of the eastern residential areas had the highest total number of species present. This figure has a number 2 variogram (see Chapter 4, section 4.5).

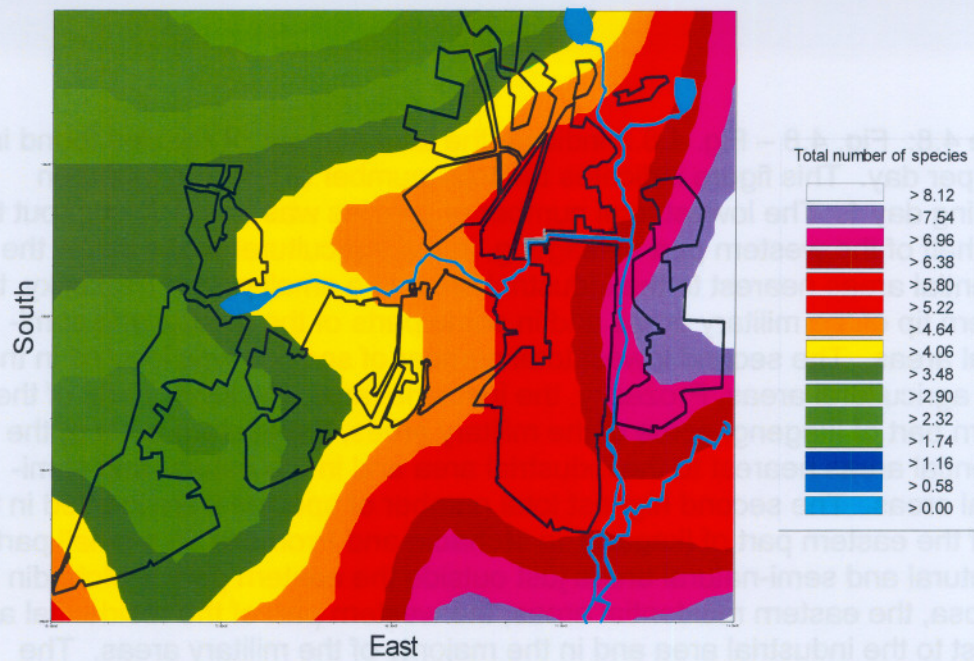


Figure 4.8.2: The total number of species, observed on sampling day 3, interpolated over Potchefstroom

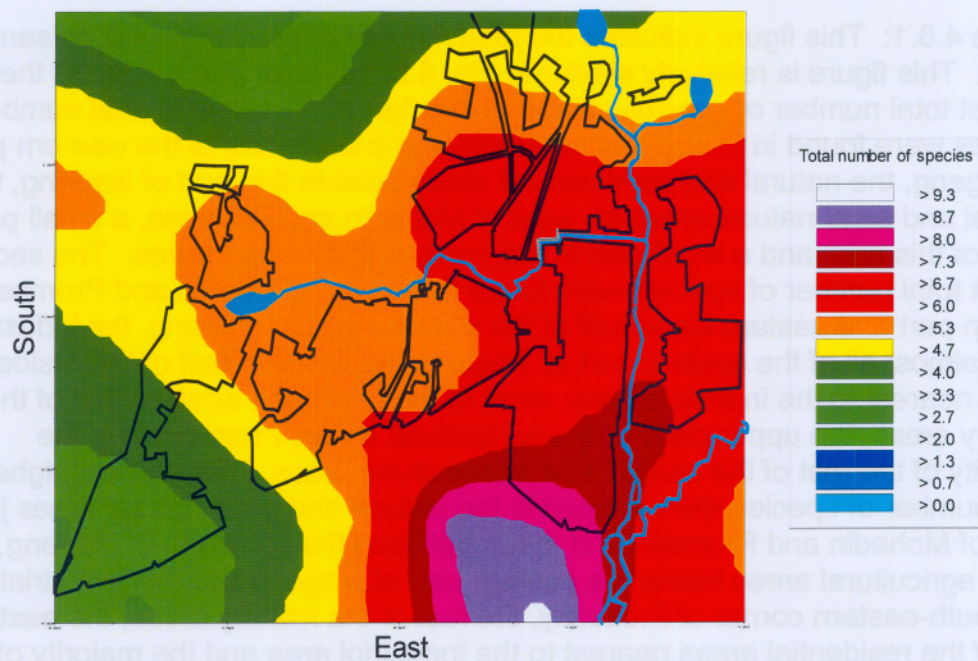


Figure 4.8.3: The total number of species, observed on sampling day 4, interpolated over Potchefstroom

Figure 4.8.2: This figure indicates the total number of species found on sampling day 3. This figure differs rather drastically from Fig. 4.8 and Fig. 4.8.1. The lowest total number of species were located in the entire northern part of the natural and semi-natural areas including those west of Ikageng, the central part and most of the upper and lower half of the western part of Ikageng, small sections of the eastern part of Ikageng and the natural and semi-natural areas between the two parts of Ikageng. The areas with the lowest total species in Fig. 4.8 and Fig. 4.8.1 were much smaller than in this figure. The second lowest total number of species was found throughout Mohadin and Promosa, most of the industrial area, most of the eastern part of Ikageng and most of the north and western part of the military areas, which was practically the same for Fig. 4.8.1. The topmost and lower half of the western part of Ikageng, the eastern part of the agricultural areas and the rest of the natural and semi-natural areas also had the second lowest total number of species. The second highest total number of species was located in the eastern half of the military areas (which was the same for Fig. 4.8.1), the entire residential areas nearest to the industrial area, Prozesky, the eastern part of the agricultural areas and the eastern part of the agricultural and the eastern part of the industrial area. The highest total number of species for day 3, were found in the whole of the eastern residential areas and the areas just east of it. In Fig. 4.8, these areas only had the second highest total number of species and in Fig. 4.8.1, only the southern tip of the eastern residential areas had the highest total number of species. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.8.3: This figure indicates the total number of species found on sampling day 4. This figure is more similar to Fig. 4.8.2 than the first two figures. The lowest total number of species was again found in most of the northern part of the natural and semi-natural areas (which is similar to Fig. 4.8.2), the whole lower half of the western part of Ikageng, the agricultural areas below this part of Ikageng and the natural and semi-natural areas west of this part of Ikageng. The second lowest total number of species was again located in Mohadin and Promosa, the eastern part of Ikageng and most of the industrial area, which were similar to Fig. 4.8.2. The northern part of the military areas, the rest of the natural and semi-natural areas and the agricultural areas below the eastern part of Ikageng also had the second lowest total number of species, which was also similar to Fig. 4.8.2, however, the areas covered differ in size from Fig. 4.8.2. The second highest total number of species were also found in the lower half of the military areas, the residential areas nearest to the industrial area, the eastern part of the industrial area and Prozesky, which was the same for Fig. 4.8.2, however, the eastern residential areas also had the second highest total number of species in this figure, but had the highest total number of species in Fig. 4.8.2. The agricultural areas below the residential areas nearest to the industrial area, had the highest total number of species, but in Fig. 4.8.2, this area only had the second highest total number of species. This figure has a number 2 variogram (see Chapter 4, section 4.5).

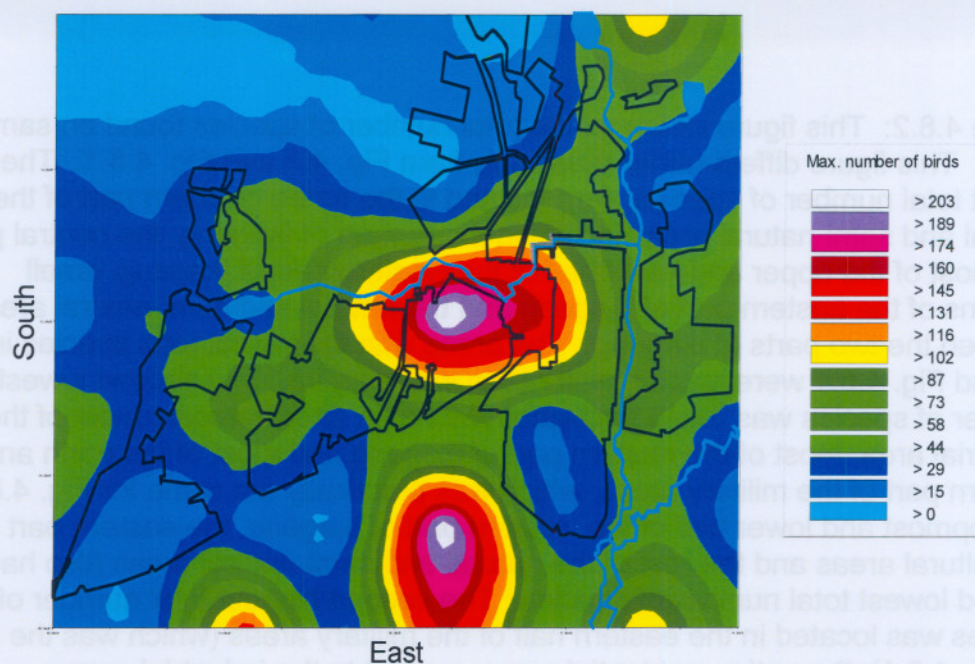


Figure 4.9: The maximum number of birds interpolated over Potchefstroom

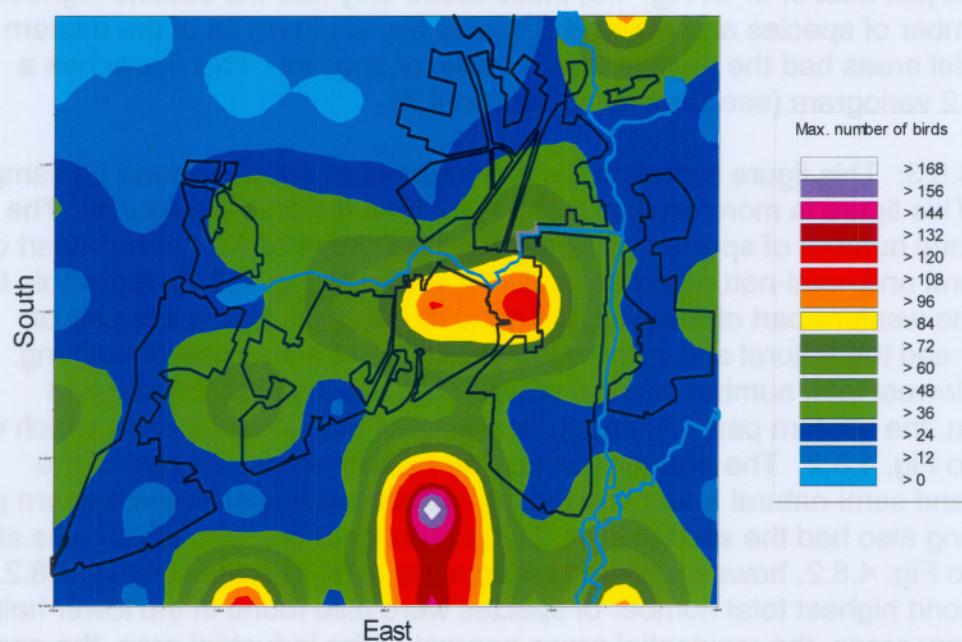


Figure 4.9.1: The maximum number of birds, excluding doves and pigeons, interpolated over Potchefstroom

Figure 4.9: This figure was the result of the maximum number of birds found over any one of the four days. The lowest maximum number of birds was found primarily in the western part of Ikageng, the natural and semi-natural areas, the western half of Mohadin and Promosa and the southern end of the residential areas nearest to the industrial area. The second highest maximum number of birds occurred in the eastern half of Mohadin and Promosa, both the residential areas (excluding the southern end of those nearest to the industrial area and the northern end of the eastern residential areas), in the southern part of the military areas, the eastern part of Ikageng, Prozesky, the areas to the east of the military areas and in the lower agricultural areas below Ikageng. The highest maximum number of birds occurred in the industrial area and agricultural areas below the industrial area. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.9.1: In this figure, dove and pigeon numbers were excluded in order to examine the contribution of other birds on the data, as was done in Fig. 4.1.1. The lowest maximum number of birds, were once again found in the western part of Ikageng, the majority of Mohadin and Promosa and in the natural and semi-natural areas, the northern parts of the military areas, the eastern part of the residential areas, the lower half of the residential areas nearest to the industrial area, the southern half of the eastern part of Ikageng and in the agricultural areas just below this part of Ikageng. The industrial area had the highest maximum number of birds in Fig. 4.9, however, a large decrease in these numbers occurred within this area when dove and pigeon numbers were excluded. The industrial area now had the second highest maximum number of birds, along with the southern parts of the military areas, Prozesky, the agricultural areas below both parts of Ikageng, the natural and semi-natural north of the eastern half of Ikageng and between both parts of Ikageng, and the areas east of the military areas also had the second highest maximum number of birds. The maximum number of birds decreased in most of the residential areas, however, the maximum bird numbers remained relatively the same for the eastern part of Ikageng. Even with the dove and pigeon numbers excluded, the highest maximum number of birds was again found in the agricultural areas, as in Fig. 4.9. This figure has a number 2 variogram (see Chapter 4, section 4.5).

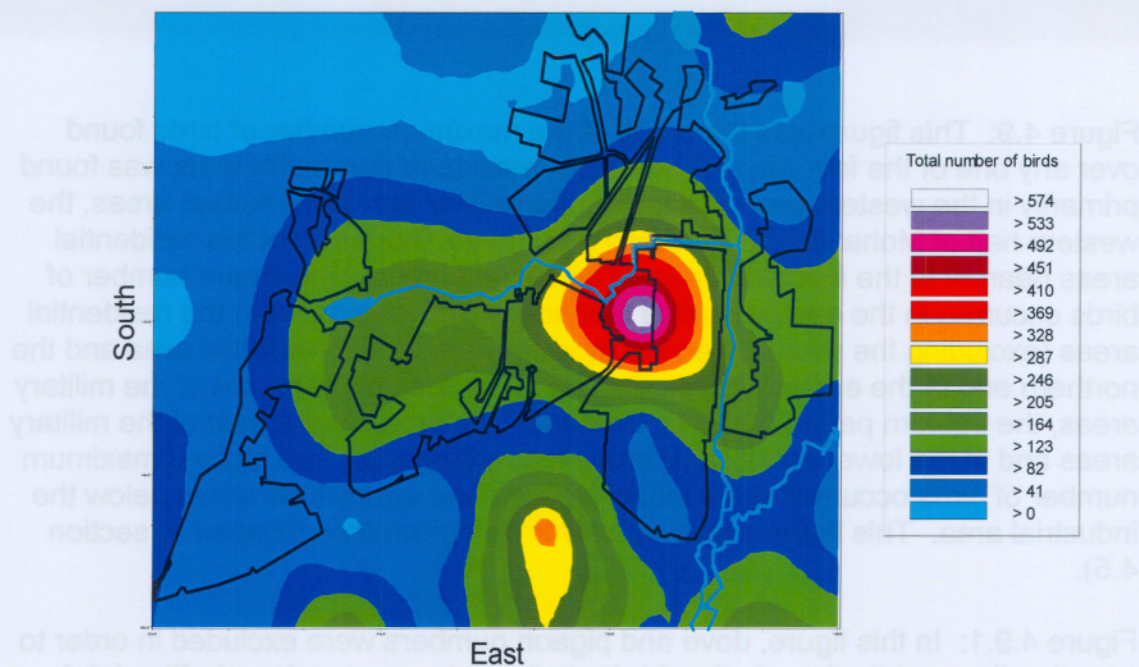


Figure 4.10: The total number of birds interpolated over Potchefstroom

Figure 4.10: This figure indicates the total number of birds found throughout the study. The lowest total number of birds was found throughout the western part of Ikageng, the majority of the natural and semi-natural areas, Mohadin and Promosa, the majority of the military areas, a small part of Prozesky, the lower tip of the residential areas nearest to the industrial area and in the agricultural areas below the eastern part of Ikageng. The second lowest total number of birds was found in the eastern residential areas, the eastern part of Ikageng, some of the residential areas nearest to the industrial area, Prozesky, the lower parts of the military areas, some of the natural and semi-natural areas surrounding the eastern part of Ikageng and in the agricultural areas below the industrial area. The second highest total number of birds was located in the lower agricultural areas also below the industrial area, the western half of the industrial area and in the upper parts of the residential areas closest to it. The eastern part of the industrial area had the highest total number of birds. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.11: The total number of birds, observed on sampling day 1, interpolated over Potchefstroom



Figure 4.12: The total number of birds, for sampling day 2, interpolated over Potchefstroom

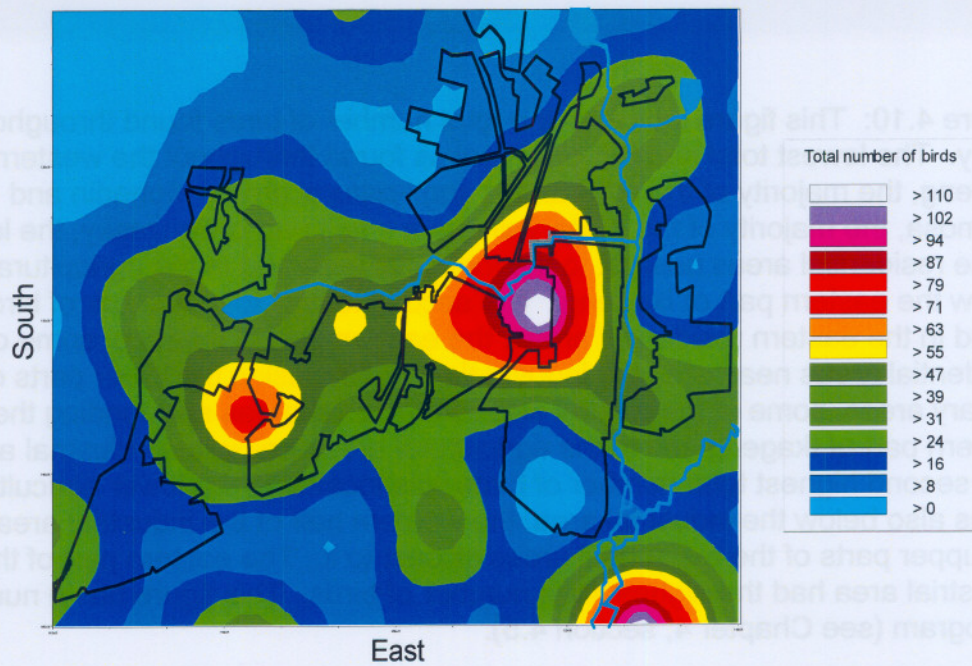


Figure 4.11: The total number of birds, observed on sampling day 1, interpolated over Potchefstroom

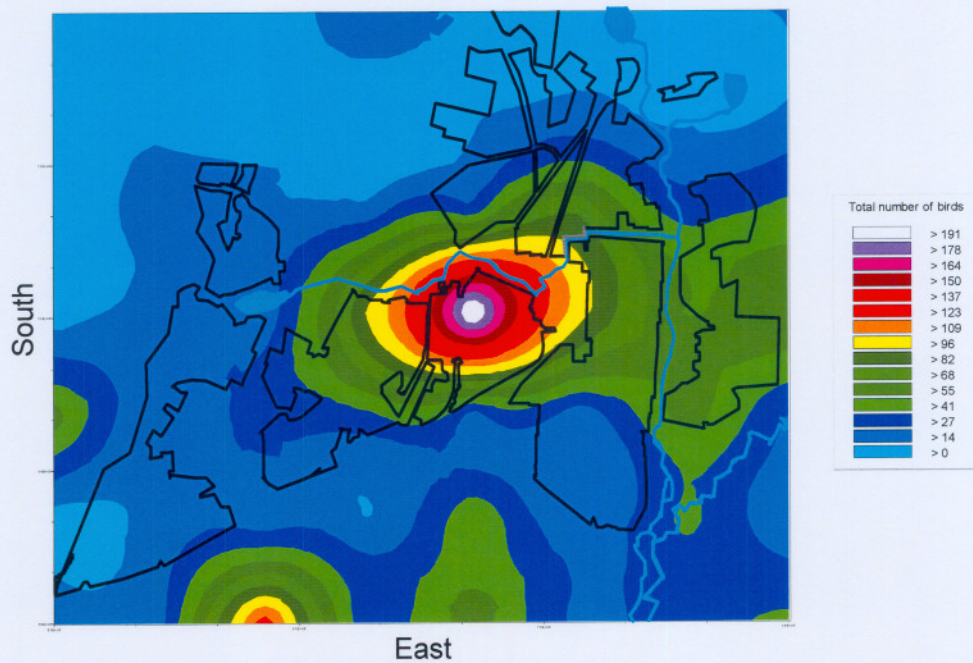


Figure 4.11.1: The total number of birds, for sampling day 2, interpolated over Potchefstroom.

Figure 4.11: The data for Fig. 4.11 – Fig. 4.11.2 includes all data collected over the four days of sampling. This figure indicates the data collected on day 1. The lowest total number of birds were located in most of the natural and semi-natural areas, most of the agricultural areas, the lower tip of the residential areas nearest to the industrial area, the upper half of the eastern residential areas, the northern parts of the military areas, practically all of Mohadin and Promosa and the lower half of the western part of Ikageng. The second lowest total number of birds were found in the lower parts of the military areas, the rest of the eastern residential areas, the eastern half of the residential areas nearest to the industrial area, almost all of the eastern part of Ikageng, most of the upper half of the western part of Ikageng, the upper agricultural areas and in some parts of Prozesky. The western half of the residential areas nearest to the industrial area, the eastern half of the industrial area, a small section in the eastern part of Ikageng, and the natural and semi-natural areas between the two parts of Ikageng, all had the second highest total number of birds. The highest total number of birds, were found in the eastern part of the industrial area and in the lower parts of Prozesky. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.11.1: This figure indicates the data collected on day 2. The lowest total number of birds were found again in most of the natural and semi-natural areas, Mohadin and Promosa, the lower tip of the residential areas nearest to the industrial area, the majority of the military areas and most of the agricultural areas, which is very similar to Fig. 4.11, however, this figure shows that the entire western part of Ikageng and more of the military areas have the lowest total number of birds, which differs from Fig. 4.11 and Prozesky now also has the lowest total but in Fig. 4.11 had the highest. The second lowest total number of birds was located in the eastern residential areas, the upper half of the residential areas nearest to the industrial area, some parts of the agricultural areas, the western half of the eastern part of Ikageng and in a greater part of the lower half of the military areas. The areas mentioned here are similar to those in Fig. 4.11, however, the spread for these areas was much broader in Fig. 4.11. The second highest total number of birds was found in a small part of the agricultural areas between the two parts of Ikageng (which differs totally from Fig. 4.11), the eastern part of the industrial area and the eastern corner of the eastern part of Ikageng. In Fig. 4.11, the industrial area and this part of Ikageng also had the second highest number of birds, however, they do not occur in the same places in these areas in this figure. The highest total number of birds was again located in the industrial area but more centrally in this figure than in Fig. 4.11. This figure has a number 2 variogram (see Chapter 4, section 4.5).

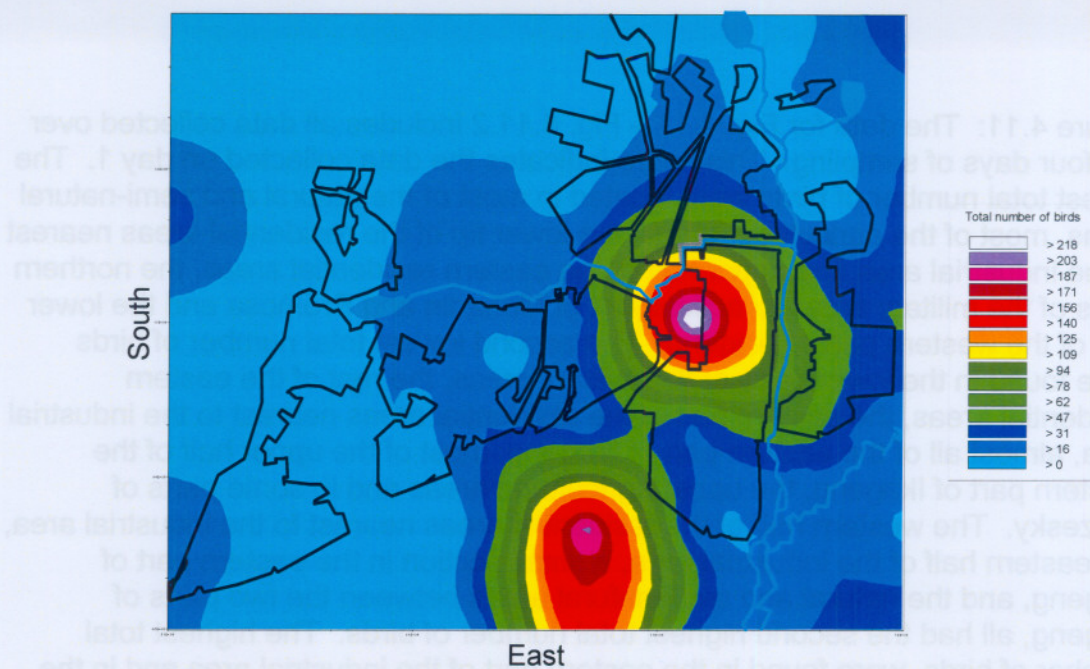


Figure 4.11.2: The total number of birds, for sampling day 3, interpolated over Potchefstroom

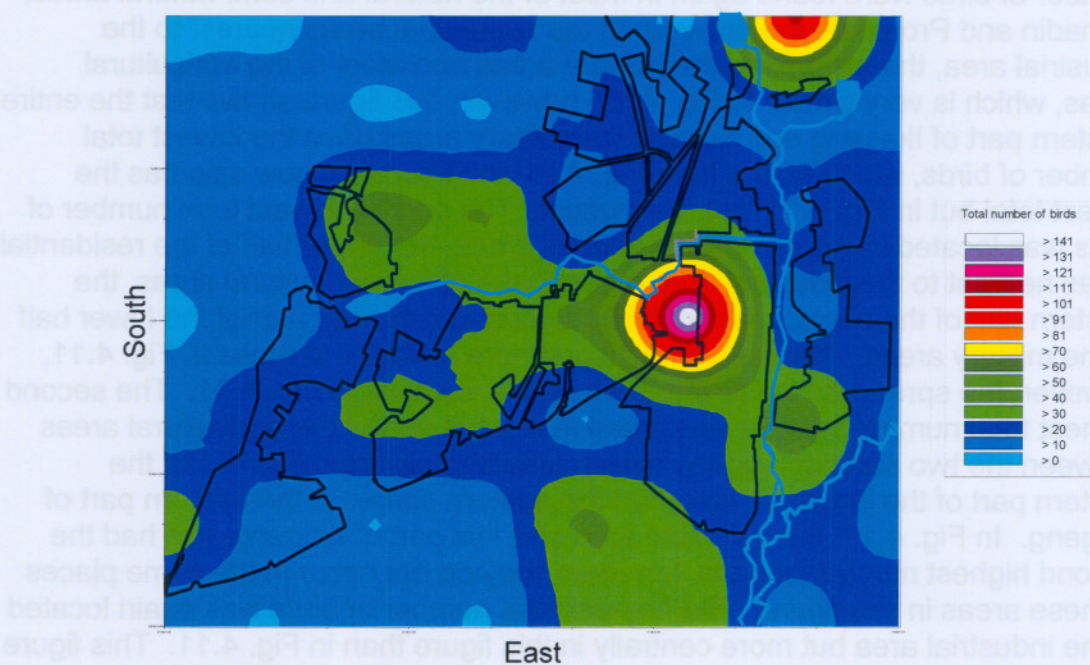


Figure 4.11.3: The total number of birds, for sampling day 4, interpolated over Potchefstroom

Figure 4.11.2: This figure indicates the data collected on day 3. This figure differs a great deal from Fig. 4.11 and Fig. 4.11.1 with regard to the location of the highest total number of birds. This figure does, however, show a greater similarity to Fig. 4.11.1 than to Fig. 4.11. The lowest total number of birds was located throughout Mohadin and Promosa, the western part of Ikageng, the military areas, the natural and semi-natural areas, Prozesky and most of the agricultural areas, all of which is very similar to Fig. 4.11.1 but not to Fig. 4.11. This figure also indicates that the eastern part of Ikageng had the lowest total number of birds whereas in the previous two figures, this area had the second highest total number of birds or more. The second lowest total number of birds, were found in the eastern residential areas, most of the residential areas nearest to the industrial area and in some of the agricultural areas. This is similar to both the previous two figures, however, the size of the spread again differs between these three figures in the areas mentioned. The second highest total number of birds was found in the eastern part of the industrial area and in a small part of the residential areas nearest to it. In Fig. 4.11 and Fig. 4.11.1, this part of the industrial area had the highest total number of birds. This figure shows that the highest total number of birds, which was primarily Redbilled Quelea, *Quelea quelea*, was now located in the agricultural areas below the industrial area, but in Fig. 4.11.1, only a small part in the agricultural areas had the second highest total number of birds and in Fig. 4.11 the second lowest. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.11.3: This figure indicates the data collected on day 4. The lowest number of birds was located in most of the western half of the study area and in most of the northern and southern parts of the study area. This is similar to Fig. 4.11.1 and Fig. 4.11.2. The second lowest number of birds was found in the eastern half of Mohadin and Promosa, the central section of the eastern part of Ikageng, the majority of the industrial area, the lower parts of the eastern residential areas, as well as the central parts of the residential areas closest to the industrial area and in a small part of the agricultural areas. These locations are similar to those found in Fig. 4.11.1. The second highest number of birds was located north-east of the military areas and the highest number of birds occurred at a focal point surrounded by the industrial area, the military areas and the residential areas. This focal point was found throughout all the figures represented here. This figure has a number 2 variogram (see Chapter 4, section 4.5).

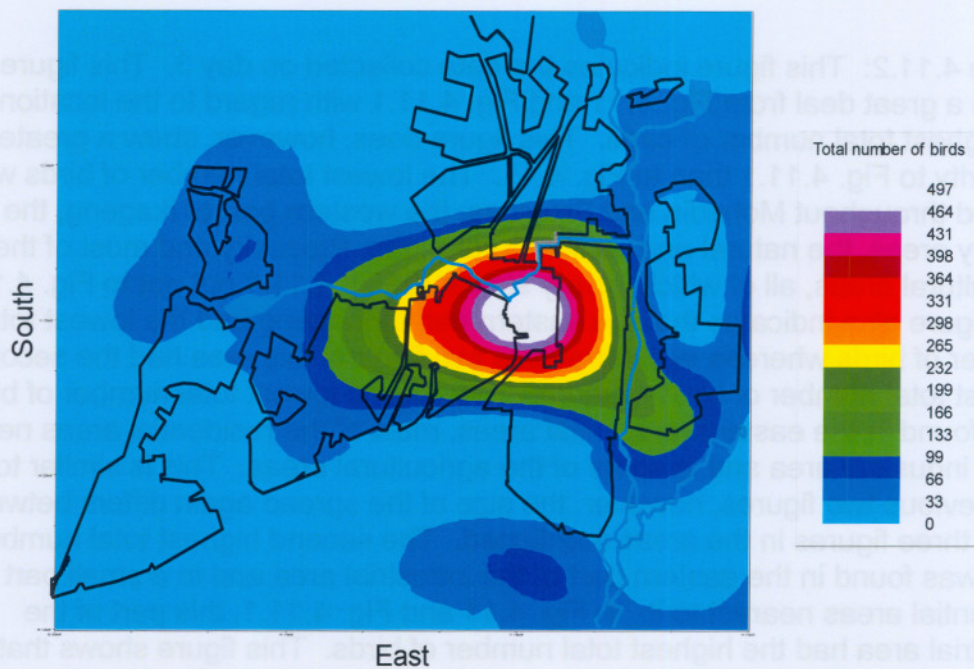


Figure 4.12: The total number of doves and pigeons interpolated over Potchefstroom

Figure 4.12: In this figure, only the data for doves and pigeons was used in order to determine their contribution. The total numbers for doves and pigeons was lowest in Mohadin and Promosa, the entire western part of Ikageng, small areas in the eastern part of Ikageng, the military areas, almost all the natural and semi-natural areas, the upper parts of Prozesky and the agricultural areas. The second highest total numbers for these birds was found in the eastern residential areas, most of the residential areas nearest to the industrial area, the majority of the eastern part of Ikageng, the natural and semi-natural areas surrounding these mentioned areas, Prozesky and in the agricultural areas nearest to the residential areas and the industrial area. The second highest total number of doves and pigeons were located in the residential areas nearest to the industrial area, a small section in the eastern part of Ikageng and the outer parts of the industrial area. The highest total number for these birds was found throughout the central parts of the industrial area. This figure has a number 3 variogram (see Chapter 4, section 4.5).



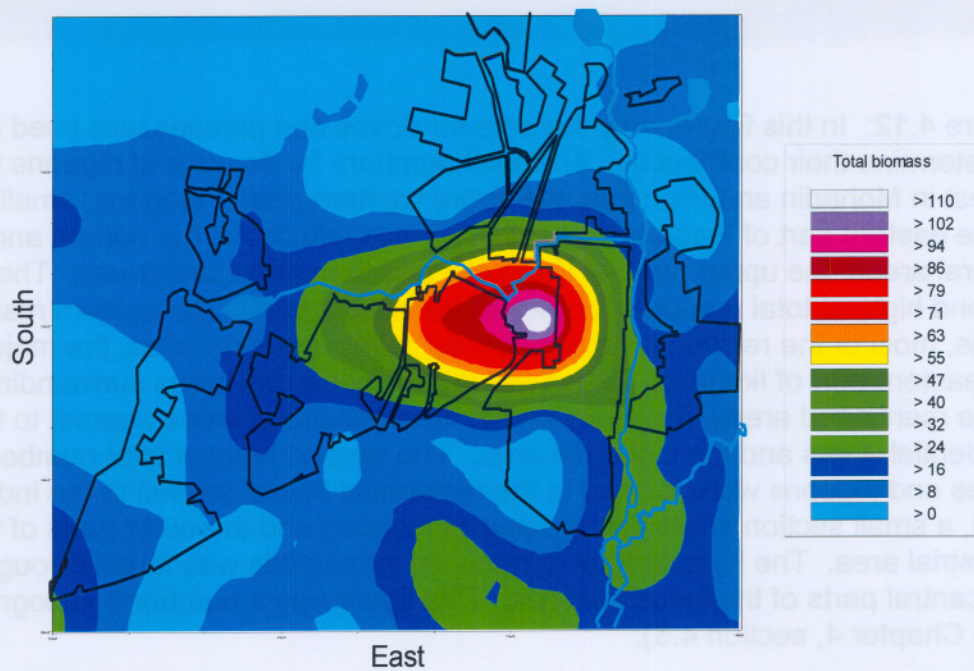


Figure 4.13: The total biomass of all birds interpolated over Potchefstroom

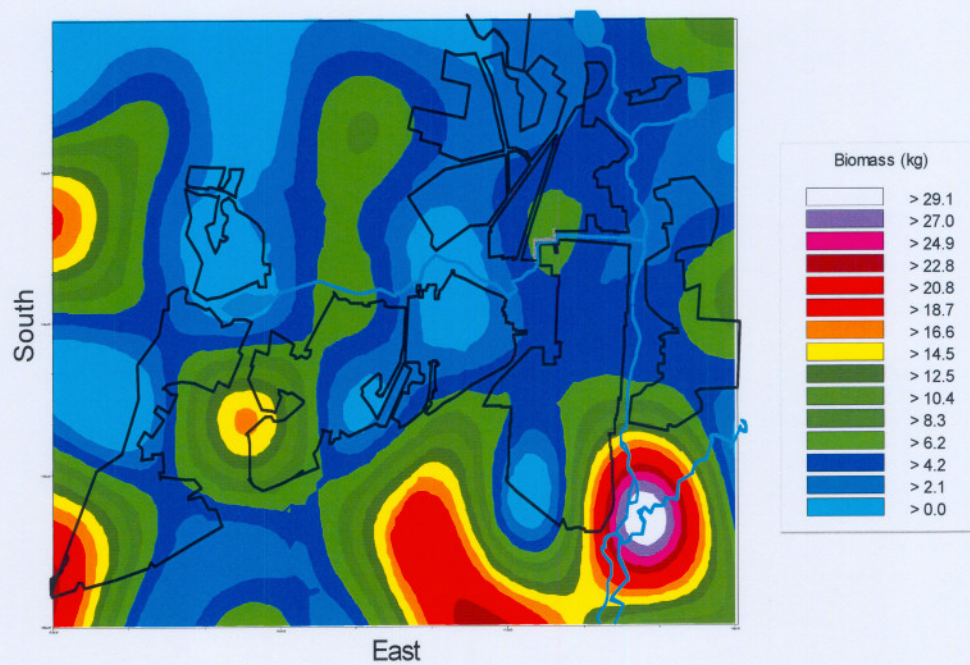


Figure 4.13.1: The total biomass of all birds excluding doves and pigeons, interpolated over Potchefstroom

Figure 4.13: This figure takes into account the biomass collected over all four days. The locations/sites with the lowest total biomass occurred throughout the western part of Ikageng, Mohadin and Promosa, almost all of the eastern part of Ikageng, the natural and semi-natural areas, the eastern side of the residential areas, almost the entire military area and the agricultural areas below both parts of Ikageng. The locations with the second highest total biomass occurred within a small part of the agricultural areas, the top section of the eastern part of Ikageng and Prozesky. The locations with the highest total biomass were found within the industrial area, the northern part of the residential areas nearest to the industrial area and the most southern part of the military areas. This figure has a number 3 variogram (see Chapter 4, section 4.5).

Figure 4.13.1: The total biomass doves and pigeons were also excluded from this data set in order to determine the contribution of other birds on the total biomass. This figure differs drastically from Fig. 4.13. In this figure, the locations/sites with the lowest total biomass occurred in the industrial area (whereas in Fig. 4.13, the industrial area had the highest concentration of biomass), Mohadin and Promosa, the military areas, most of the residential areas and both the parts of the natural and semi-natural areas directly north and west of the western part of Ikageng. The second lowest total biomass was found in the natural and semi-natural areas between the military areas and Mohadin and Promosa, the eastern part of the residential areas, the far north-eastern natural and semi-natural areas as well as the natural and semi-natural areas between the two parts of Ikageng. This includes the sections of the western parts of Ikageng and the eastern parts of Ikageng. The second highest total biomass occurred in the far western part of the natural and semi-natural areas, the south-western tip of the western part of Ikageng and its surrounding natural and semi-natural areas, and the agricultural areas below the eastern part of Ikageng and the industrial area. This figure also indicated that the highest total biomass occurred at Prozesky. This figure has a number 3 variogram (see Chapter 4, section 4.5).

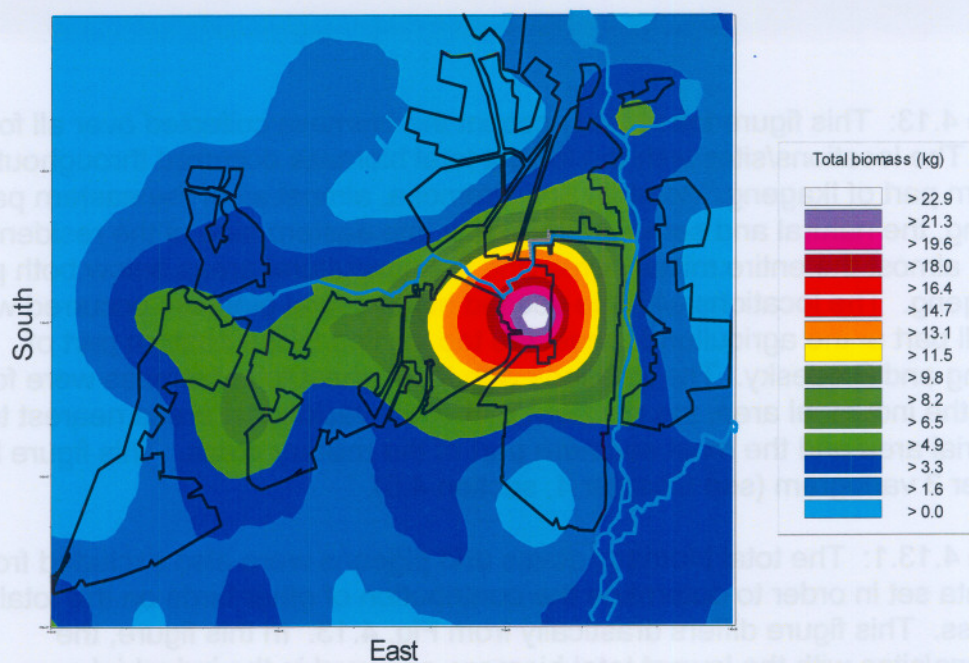


Figure 4.14: The total biomass for all birds, for sampling day 1, interpolated over Potchefstroom

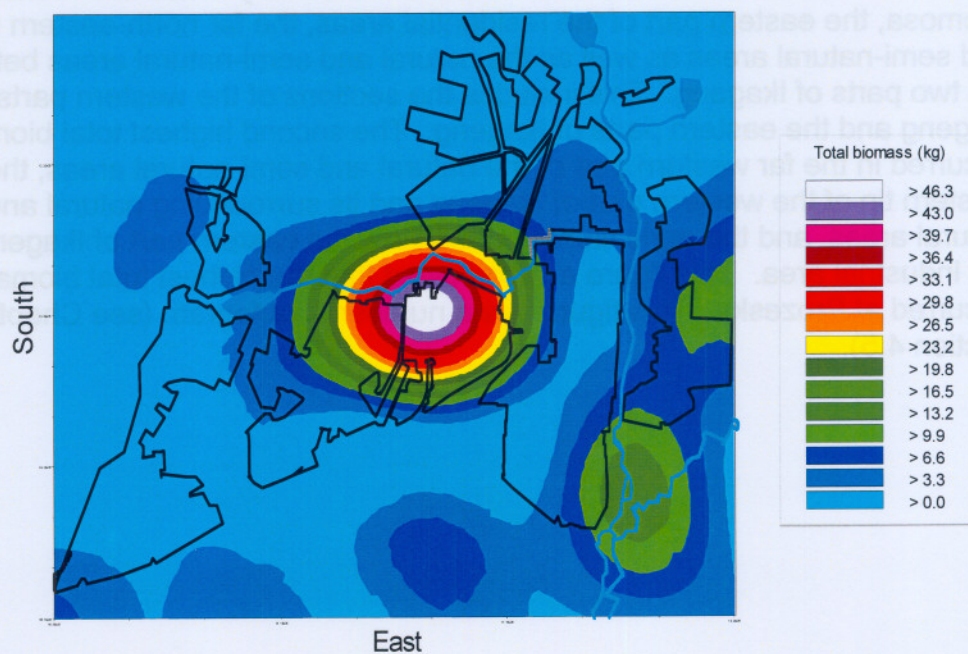
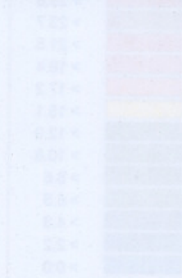


Figure 4.14.1: The total biomass for all birds, for sampling day 2, interpolated over Potchefstroom

Figure 4.14: Fig. 4.14 – Fig. 4.14.3 are based on the data collected over all four days, however, the data was divided into each individual sampling day. This figure depicts the data collected on day 1. Total biomass was lowest in the natural and semi-natural areas, the agricultural areas, Mohadin and Promosa, almost the whole of the western part of Ikageng, the eastern part of the residential areas, most of the military areas, Prozesky and the southern part of the eastern part of Ikageng. The second highest total biomass was located in the upper section of the western part of Ikageng, most of the eastern part of Ikageng, the natural and semi-natural areas between these two parts of Ikageng and the southern part of the military areas. The highest total biomass was found in the industrial area, which also spreads into part of the residential area closest to the industrial area. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.14.1: This figure depicts the data collected on day 2. The lowest total biomass for day 2 was found throughout the natural and semi-natural areas, the western part of Ikageng, Mohadin and Promosa, the agricultural areas, almost all of the military areas excluding the southern end, predominantly all of the residential areas nearest to the industrial area and the southern part of the eastern part of Ikageng. This is similar to Fig. 4.14. The second highest total biomass occurred within Prozesky, the lower part of the eastern residential area, the southern part of the military areas and the upper part of the eastern part of Ikageng. This figure also indicated that the highest total biomass was found again in the industrial area, which was the same for Fig. 4.14, however, the peak for this biomass shifted more centrally into the industrial area. This figure has a number 2 variogram (see Chapter 4, section 4.5).



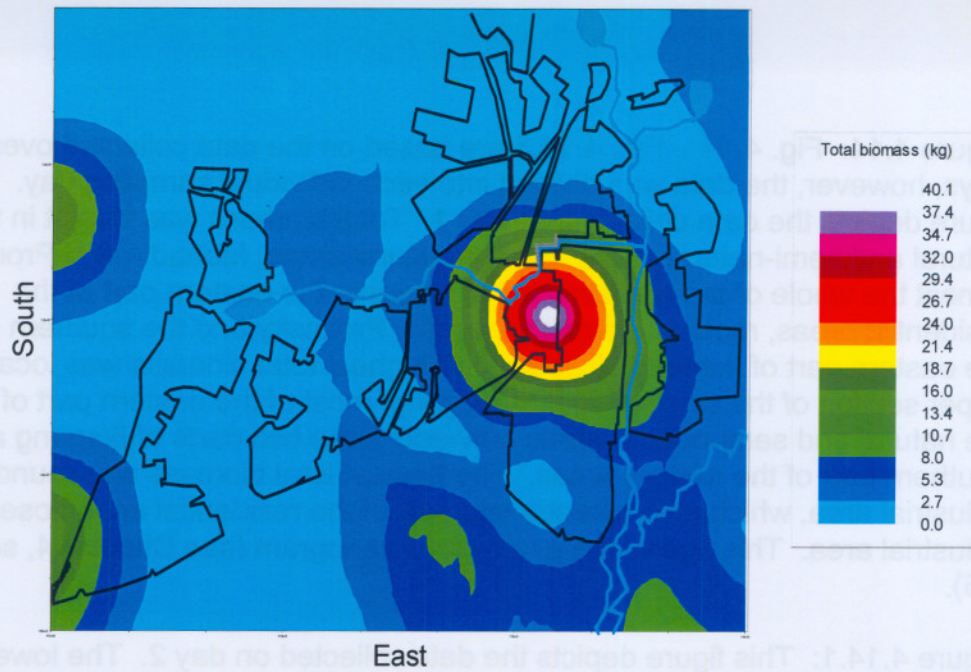


Figure 4.14.2: The total biomass of all birds, for sampling day 3, interpolated over Potchefstroom

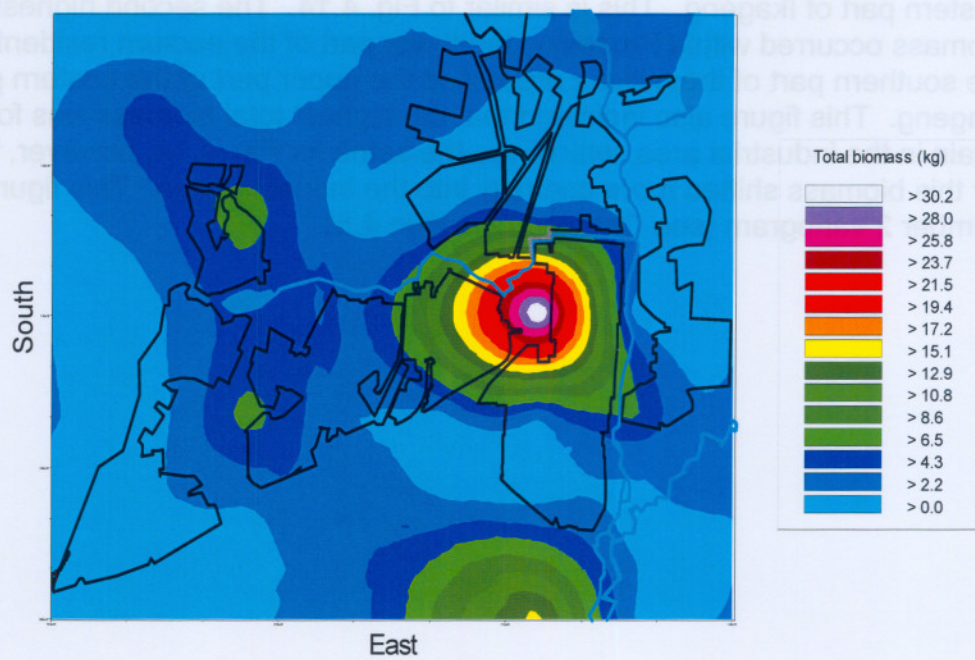
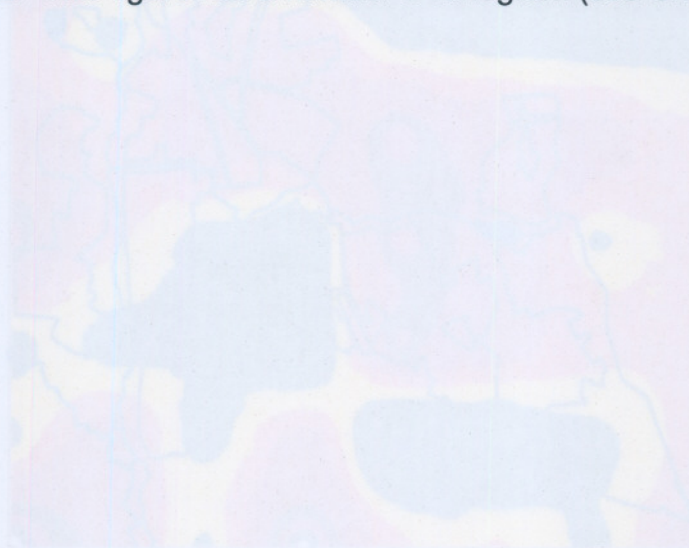
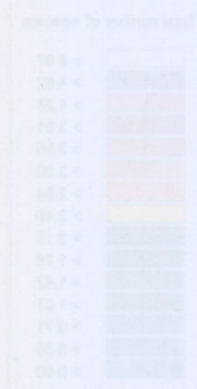


Figure 4.14.3: The total biomass of all birds, for sampling day 4, interpolated over Potchefstroom

Figure 4.14.2: This figure indicates all the data collected for day 3. In this figure, it was shown that the lowest total biomass occurred over Mohadin and Promosa, most of Ikageng (excluding the southern tip of the western part of Ikageng), almost all of the military areas, the eastern residential areas, most of the agricultural areas and the natural and semi-natural areas below and between the western part of Ikageng and the eastern part of Ikageng. The second highest total biomass occurred in the southern tip of the western part of Ikageng, in a small part of the agricultural areas below the industrial area, Prozesky and in the natural and semi-natural area west of Mohadin and Promosa. The highest total biomass was again found in the industrial area, which is similar to both Fig. 4.14 and Fig. 4.14.1, but the peak shifted again more into the residential area closest to the industrial area, which is more similar to Fig. 4.14. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.14.3: This figure indicates all the data collected for day 4. The lowest total biomass was found throughout Ikageng, the natural and semi-natural areas, most of the agricultural areas, as well as Prozesky, the eastern part of the residential areas and almost the entire military area. Total biomass was second highest in Mohadin and Promosa, the western section of the eastern part of Ikageng, the lower southern part of the agricultural areas and the southern tip of the eastern residential areas. The industrial area and the residential area closest to it indicated the highest total biomass, which is again similar to Fig. 4.14, Fig. 4.14.1 and Fig. 14.2. This figure has a number 3 variogram (see Chapter 4, section 4.5).



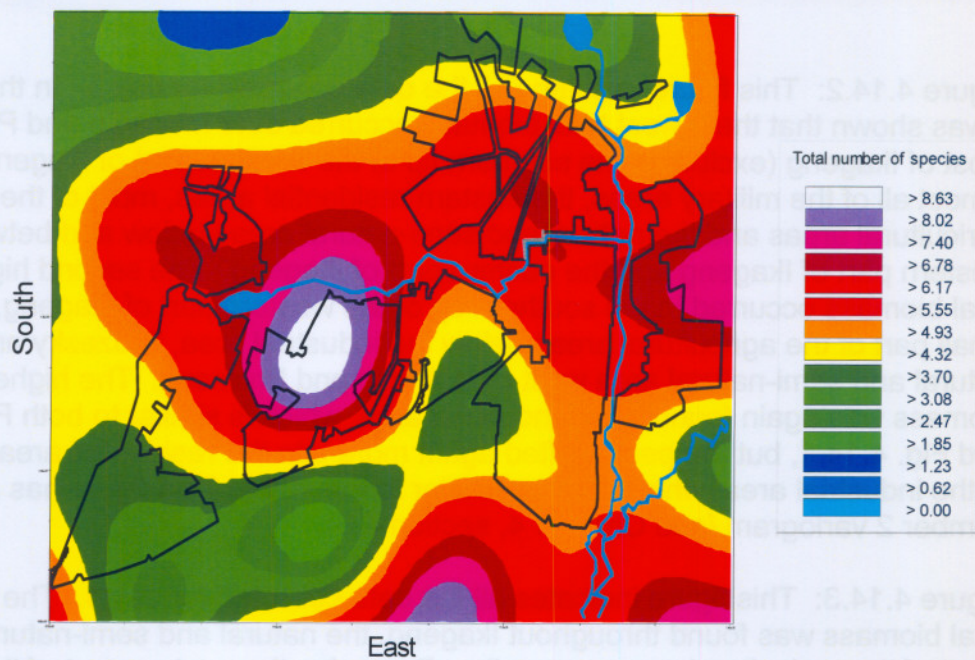


Figure 4.15: The total number of granivorous species, interpolated over Potchefstroom

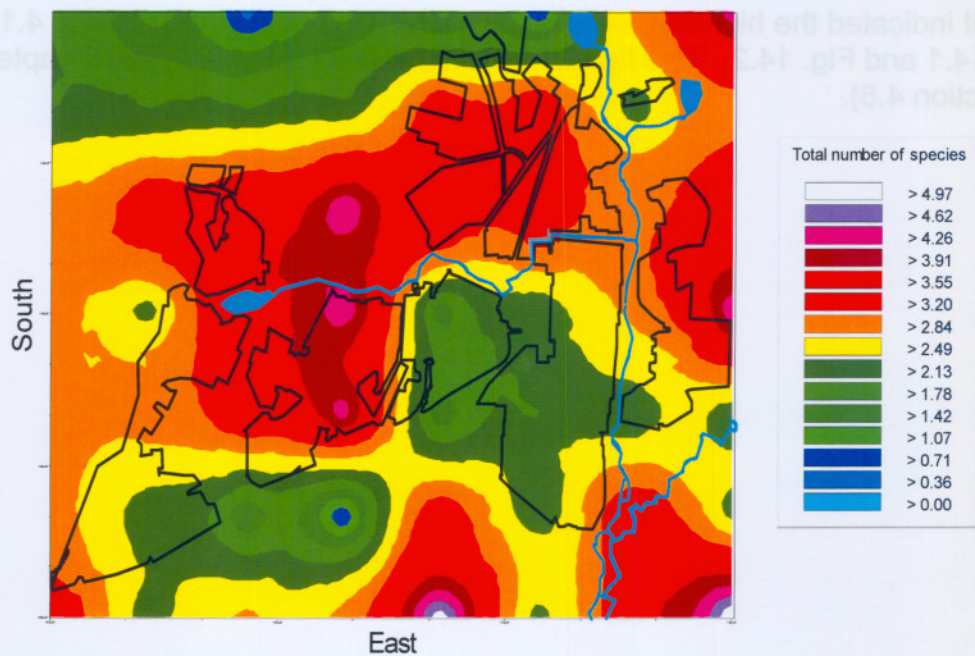


Figure 4.15.1: The total number of granivorous species, excluding doves and pigeons, interpolated over Potchefstroom

Results for feeding guilds:

Figure 4.15: The lowest number of granivorous species, were found in the agricultural areas below the eastern part of Ikageng and the top most part of the natural and semi-natural areas. The second lowest number of species were found in most of the industrial area, below the eastern part of the residential areas, the northern part of the military areas, a small part of the residential areas nearest to the industrial area, the majority of the western part of Ikageng, the natural and semi-natural areas west of Ikageng and generally within the agricultural areas. The majority of the residential areas, as well as the military areas, Mohadin and Promosa, the northern tip of the western part of Ikageng, Prozesky and the natural and semi-natural areas to the east and west of Mohadin and Promosa and the military areas all had the second highest number of granivorous species. The greatest number of species occurred in the lower parts of the agricultural areas, the eastern part of Ikageng and the natural and semi-natural areas just above it and the areas just outside the eastern part of the residential areas. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.15.1: Dove and pigeon species were also excluded from this data set so as to determine the contribution of other granivorous species. There was not much of a difference between this figure and Fig. 4.15. The lowest total number of species was once again found in the industrial area, the agricultural areas below the eastern part of Ikageng, most of the southern part of the western part of Ikageng, the majority of the residential area nearest to the industrial area, the southern part of the eastern residential areas and the most northern parts of the natural and semi-natural areas above Mohadin and Promosa. However, the second highest number of species was now found in the majority of the western part of Ikageng, whereas in Fig. 4.15, some of the lowest numbers of species were found here. The second highest number of species was again found in the military areas. The highest number of species also occurred in most of the same areas as those in Fig. 4.15 namely, the eastern part of the residential areas, Mohadin and Promosa, the natural and semi-natural areas above the eastern part of Ikageng and the lower parts of the agricultural areas. Prozesky, however, had only the second highest number of species in Fig. 4.15, but in this figure, Prozesky had one of the highest numbers of species. This figure has a number 2 variogram (see Chapter 4, section 4.5).

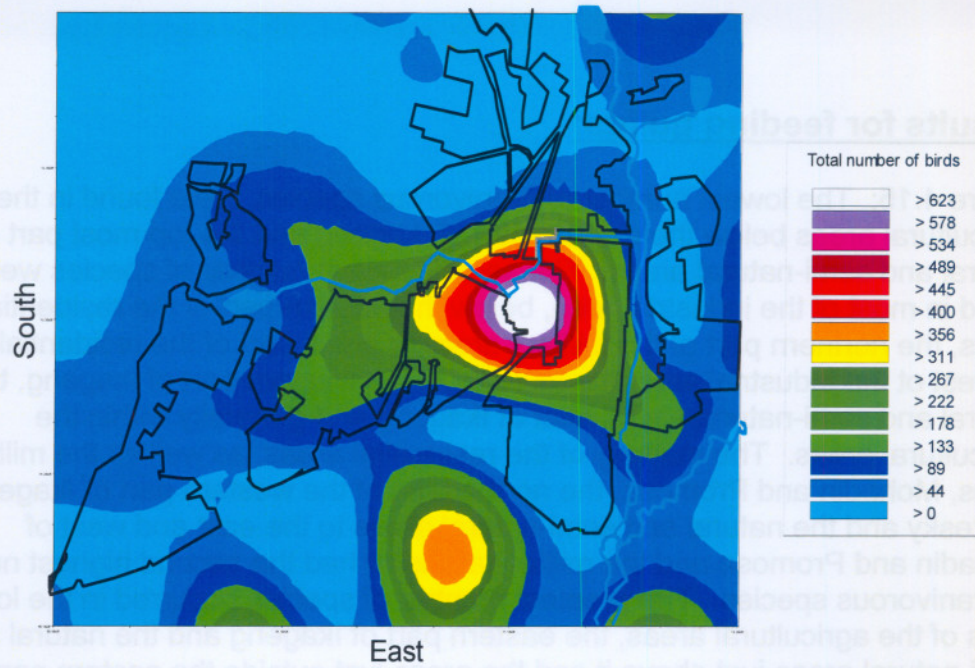


Figure 4.16: The total number of granivores interpolated over Potchefstroom

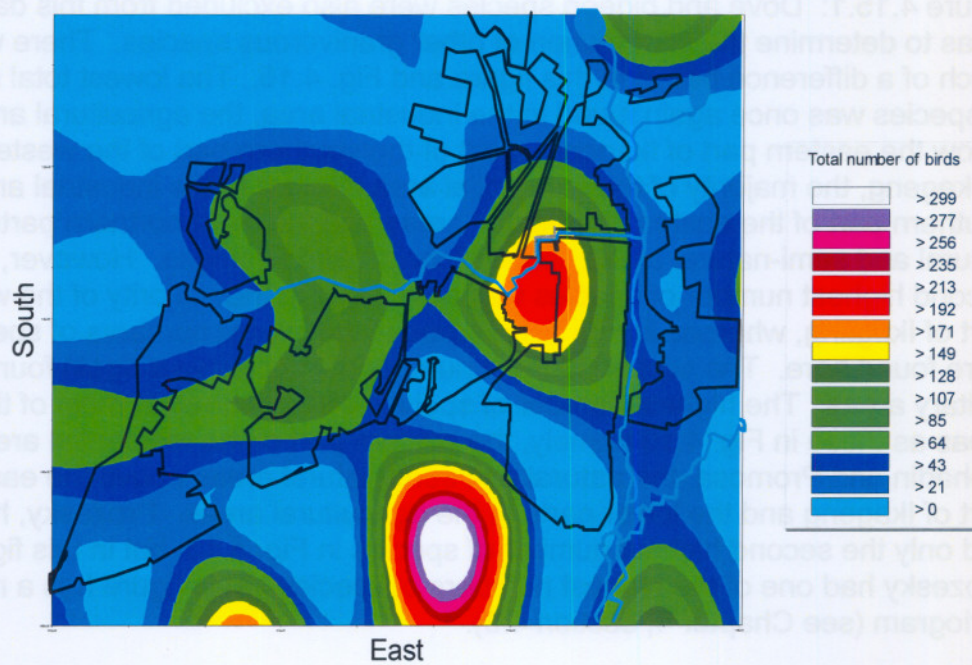


Figure 4.16.1: The total number of granivores, excluding doves and pigeons, interpolated over Potchefstroom

Figure 4.16: This figure indicates the total number of granivores. The lowest number of granivores (birds), was found throughout the western part of Ikageng, Promosa and Mohadin, the natural and semi-natural areas, some of the agricultural areas, the eastern part of the residential areas and generally throughout the military areas. The second highest total number of birds occurred in Prozesky, the agricultural areas directly below the industrial area and a small part below Ikageng, the natural and semi-natural areas just above and including the eastern part of Ikageng nearest to the industrial area. The industrial area, the residential areas closest to it and the southern tip of the military areas had the highest number of birds. This figure has a number 3 variogram (see Chapter 4, section 4.5).

Figure 4.16.1: In this figure, the total number of doves and pigeons was excluded from this data set in order to examine the contribution of other granivores. In general, this figure does not differ all that greatly from Fig. 4.16, however, the peak for the highest total number of birds has shifted in this figure. The lowest total number of birds was again found in most of the military areas, most of the natural and semi-natural areas, the eastern part of the residential areas and in some parts of the agricultural areas. The lowest number of birds was also found in most of the industrial area (which had the highest number of birds in fig. 4.16), the southern part of the residential area nearest to the industrial area, the western part of Ikageng (excluding the central part) and the western section of Mohadin and Promosa. The eastern part of Ikageng nearest to the industrial area, the natural and semi-natural areas directly above it, the central section of the western part of Ikageng, Prozesky, the agricultural areas below Ikageng and the area on the eastern side of the military areas, all had the second highest total number of birds that were granivores. The eastern part of the industrial area, most of the southern part of the military areas and the residential areas closest to the industrial area also had the second highest total number of birds, however, in Fig. 4.16, the industrial area and the nearest residential area had the highest number of birds. In this figure, the highest total number of birds occurred in the agricultural areas below the industrial area, whereas in Fig. 4.16, this same area had only the second highest number of birds. This figure has a number 3 variogram (see Chapter 4, section 4.5).

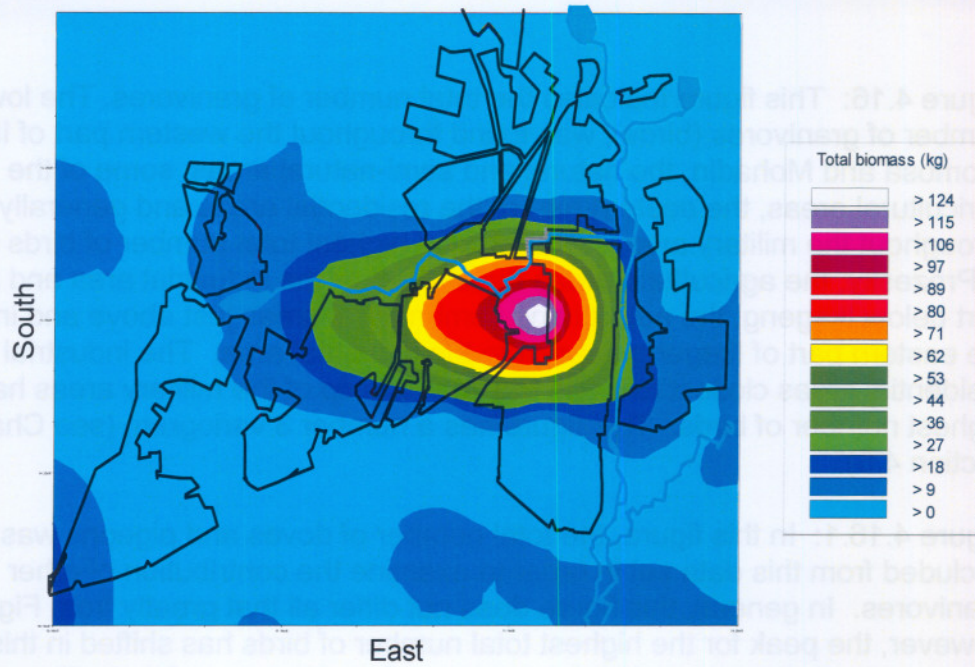


Figure 4.17: The total biomass for granivores interpolated over Potchefstroom

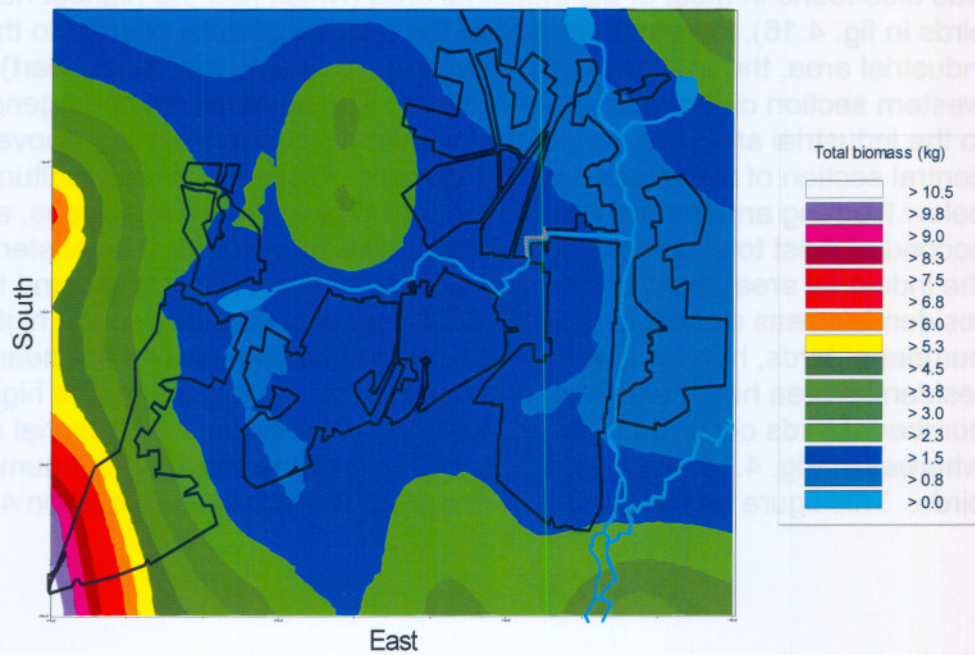


Figure 4.17.1: The total biomass for granivores, excluding doves and pigeons, interpolated over Potchefstroom

Figure 4.17: In this figure, the total biomass of the granivores was used to obtain this map. This figure indicated that the lowest total biomass for this feeding guild was found in the eastern part of the residential areas and the southern part of the western residential areas, the entire western part of Ikageng, Promosa and Mohadin, and most of the eastern part of Ikageng. The natural and semi-natural areas, almost all of the military areas, Prozesky and the agricultural areas also had the lowest total biomass for granivores. The second highest total biomass was located in the southern tip of the military areas, most of the eastern part of Ikageng and in the natural and semi-natural areas directly above this part of Ikageng. The industrial area and the northern part of the residential area closest to it had the highest total biomass for granivores. This figure has a number 3 variogram (see Chapter 4, section 4.5).

Figure 4.17.1: For this figure, the total biomass of all doves and pigeons were excluded in order to determine the contribution of the other granivorous birds present. This figure differed drastically from the previous Fig. 4.17. The lowest total biomass was now found throughout the military areas, all the residential areas, the industrial area, the eastern part of Ikageng, most of the agricultural areas directly below the industrial area and the eastern part of Ikageng, Mohadin and Promosa, and through most of the natural and semi-natural areas. The second highest total biomass for granivores occurred in Prozesky (which was one of the areas with the lowest total biomass in Fig. 4.17), a small part of the agricultural areas, as well as a small part in the natural and semi-natural areas (both of which also had the lowest total biomass in Fig. 4.17), most of the natural and semi-natural areas to the west of Ikageng, Promosa and Mohadin, the southern part of Ikageng and the area just below it, all had the lowest biomass totals in Fig. 4.17. The natural and semi-natural area to the far west of Mohadin and Promosa, and the south-western tip of Ikageng had the highest total biomass for granivores, however, in Fig. 4.17, the highest total biomass was found in the industrial area and the residential area closest to it. This figure has a number 3 variogram (see Chapter 4, section 4.5).

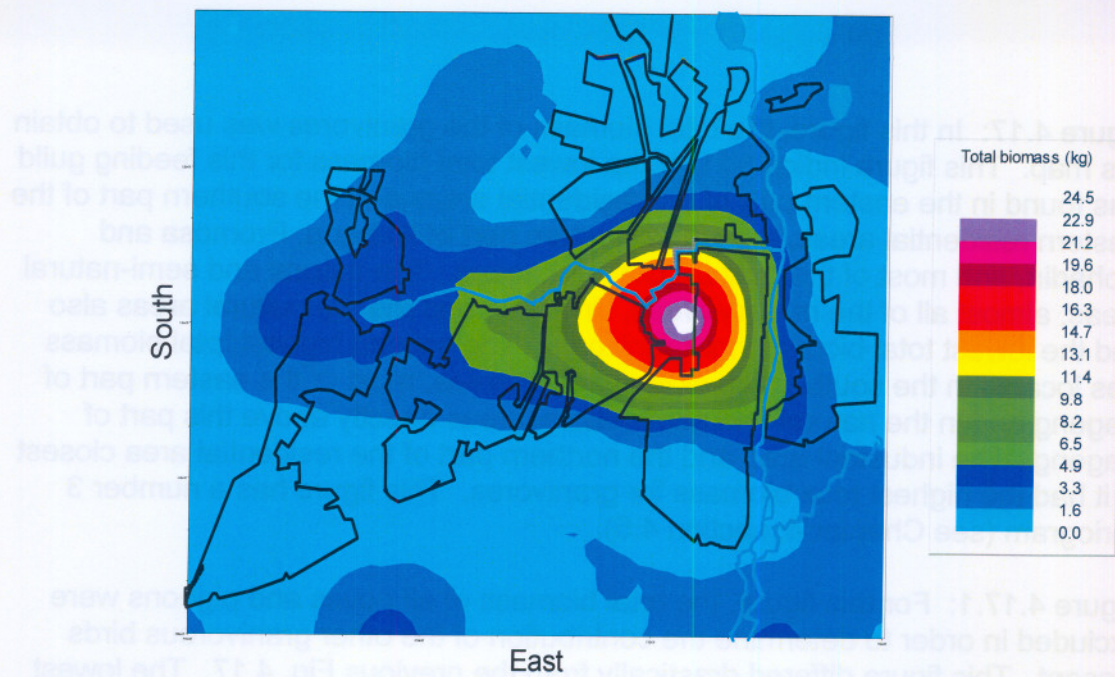


Figure 4.18: The total biomass for granivores, for sampling day 1, interpolated over Potchefstroom

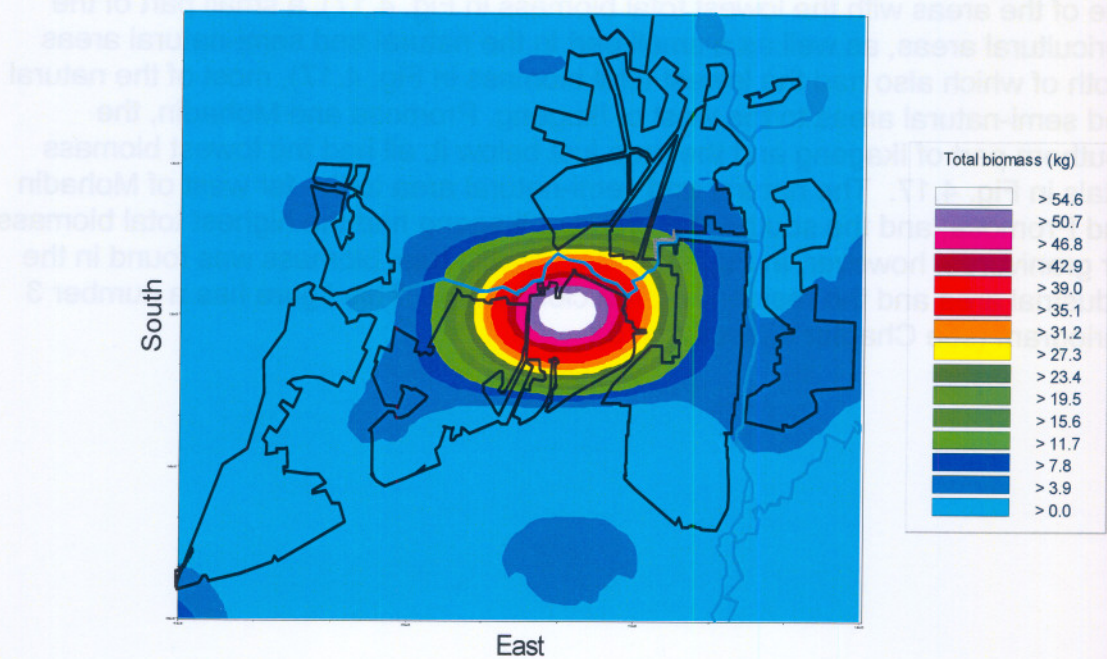


Figure 4.18.1: The total biomass for granivores, for sampling day 2, interpolated over Potchefstroom

Figure 4.18: The figures 4.18 – 4.18.3 are all based on the biomass data collected over all four days for the feeding guild granivores, however, the data has been divided into each individual sampling day. In this figure, the lowest total biomass for granivores on day 1 was found throughout the eastern part of the residential areas, the agricultural areas, Prozesky, Promosa and Mohadin, the natural and semi-natural areas, most of the military areas and the agricultural areas. The top section of the eastern part of Ikageng, the natural and semi-natural areas just above it, the southern section of the military areas all had the second highest total biomass. The highest total biomass for day 1 occurred in the industrial area and the northern part of the residential area nearest to the industrial area. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.18.1: This figure obtained for sampling day 2 does not differ much from the figure obtained for day 1 (Fig. 4.18). The lowest total biomass was also found throughout the agricultural areas, the eastern part of the residential areas, Prozesky, Promosa and Mohadin, the natural and semi-natural areas, the majority of the military areas, which is the same for Fig. 4.18. The second highest total biomass occurred in the top section of the eastern part of Ikageng, the natural and semi-natural areas directly above it, the southern part of the military areas and in the northern part of the residential areas nearest to the industrial area. This is practically the same as was found in Fig. 4.18, however, the northern part of the residential areas closest to the industrial area, had the highest total biomass in Fig. 4.18. The highest total biomass in this figure occurred in the industrial area and in a small section of the northern part of the residential area closest to it. This is the same for Fig. 4.18, however, the peak found in Fig. 4.18, shifted more centrally into the industrial area in this figure. This figure has a number 2 variogram (see Chapter 4, section 4.5).

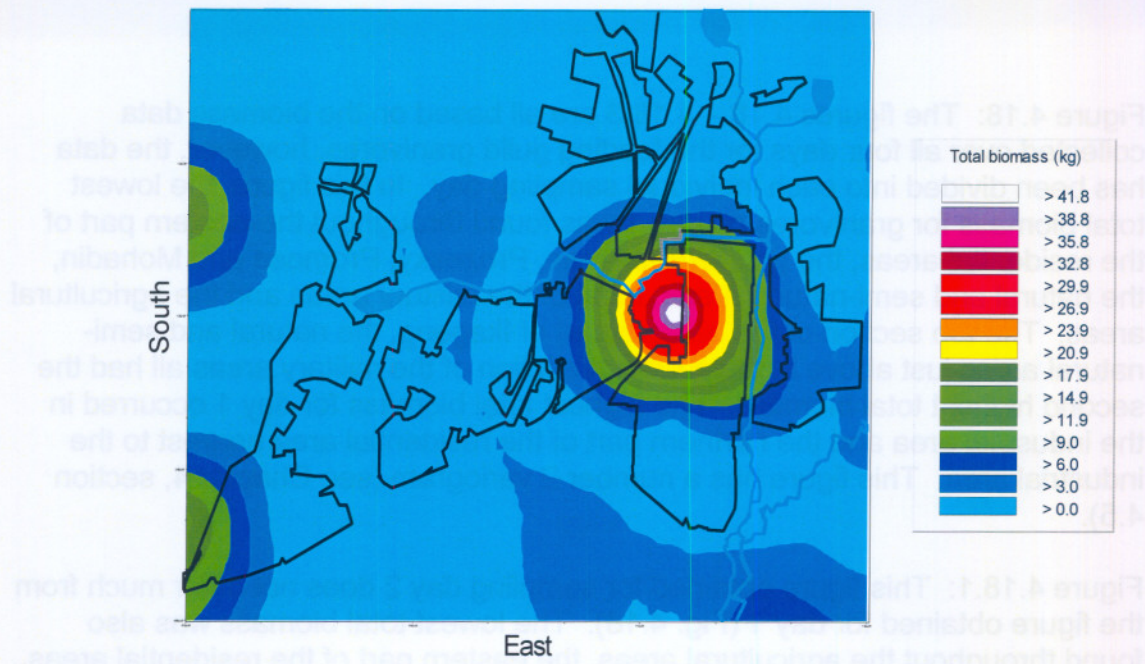


Figure 4.18.2: The total biomass for granivores, for sampling day 3, interpolated over Potchefstroom

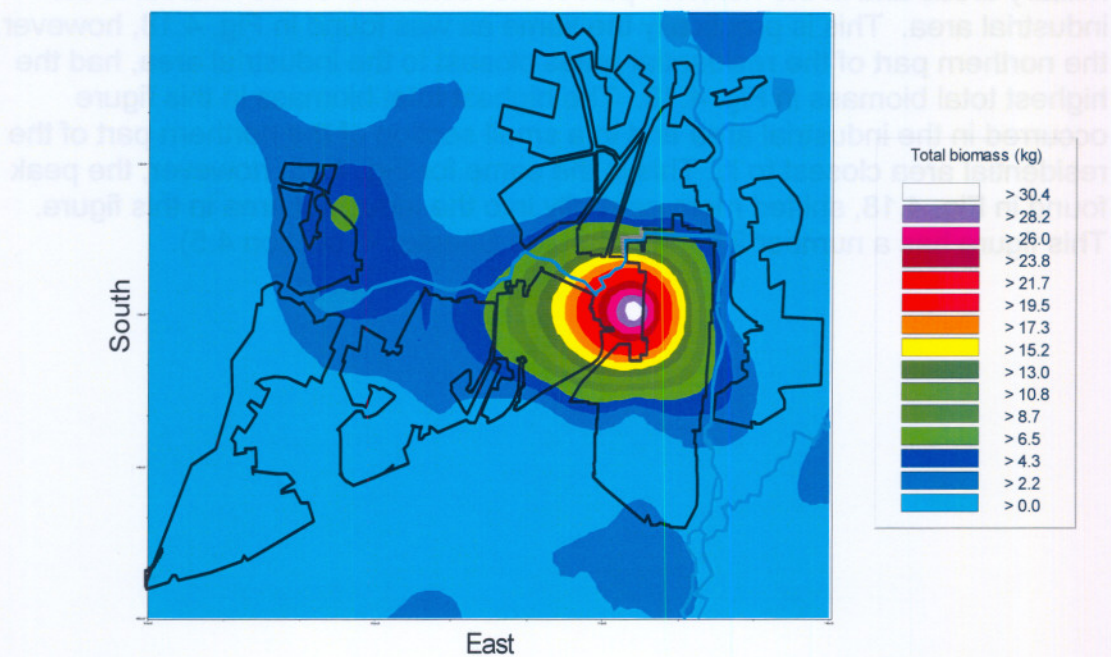


Figure 4.18.3: The total biomass for granivores, for sampling day 4, interpolated over Potchefstroom

Figure 4.18.2: The figure for sampling day 3 differs slightly when compared to Fig. 4.18 and Fig. 4.18.1. In this figure, the lowest total biomass was found in the eastern part of the residential areas, the agricultural areas, most of the natural and semi-natural areas, Promosa and Mohadin and most of the military areas, which is the same for Fig. 4.18 and Fig. 4.18.1. In this figure, the natural and semi-natural areas to the west of Mohadin and Promosa had the second highest total biomass, including the southern tip of the western part of Ikageng and Prozesky. All these areas had the lowest total biomass in Fig. 4.18 and Fig. 4.18.1. The highest total biomass was again found in the industrial area and the northern part of the residential area nearest to it, which was the same in the previous two figures, however, the peak, which was more central in the industrial area in Fig. 4.18.1, shifted nearer to the residential area in this figure. This figure has a number 2 variogram, as does Fig. 4.18.3 (see Chapter 4, section 4.5).

Figure 4.18.3: The figure obtained from the data collected on sampling day 4, showed more similarities with Fig. 4.18 and Fig. 4.18.1, except for a small difference at Mohadin and Promosa, than with fig. 4.18.2. The lowest total biomass occurred throughout the eastern part of the residential areas, the agricultural areas, Prozesky, most of the military areas, the majority of the natural and semi-natural areas, most of the eastern part of Ikageng, as well as the western part of Ikageng. This coincides exactly with Fig. 4.18 and Fig. 4.18.1, with only a minor difference with regard to the southern tip of Ikageng and the natural and semi-natural areas west of Mohadin and Promosa in Fig. 4.18.2. The second lowest total biomass for day 4 was found primarily on the eastern side of Mohadin and Promosa, which was not seen on Fig. 4.18, Fig. 4.18.1 or Fig. 4.18.2. The top part of the eastern part of Ikageng, the natural and semi-natural areas above it and the southern parts of the military areas also had the second highest total biomass, which was also found in Fig. 4.18 and Fig. 4.18.1, but not in Fig. 4.18.2. The highest total biomass however occurred in the same areas for all four days, namely in the industrial area and the northern part of the residential areas.

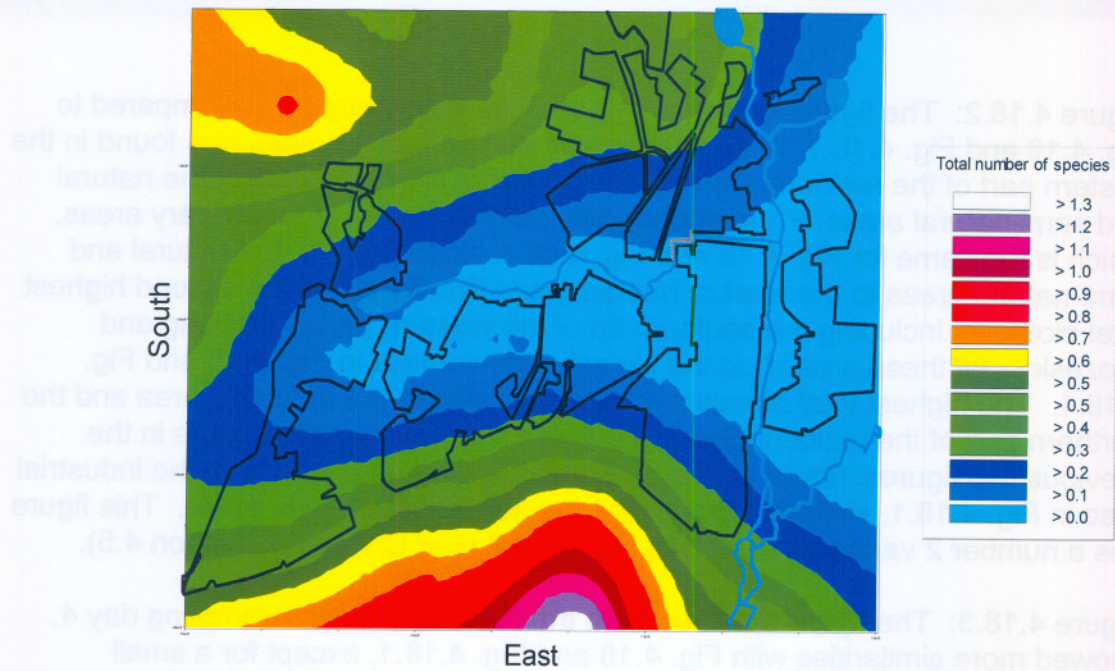


Figure 4.19: The total number of carnivorous species interpolated over Potchefstroom

Figure 4.19: This figure is based on the data collected for the----- carnivores. In this figure, the lowest number of carnivorous species was found throughout the eastern part of the residential areas, most of the southern half of the military areas, most of the residential areas close to the industrial area, including the industrial area itself, most of the eastern part of Ikageng, as well as the natural and semi-natural area above it, the southern half of Mohadin and Promosa, and most of the western part of Ikageng. The second highest number of species was found along the southern edges of the residential area nearest to the industrial area, the southern edge of the eastern part of Ikageng, the whole lower section of the western part of Ikageng, most of the natural and semi-natural areas, the northern part of Mohadin and Promosa, Prozesky and the northern part of the military areas. The north-western part of the natural and semi-natural area and the agricultural areas had the highest number of carnivorous species present. This figure has a number 2 variogram (see Chapter 4, section 4.5).

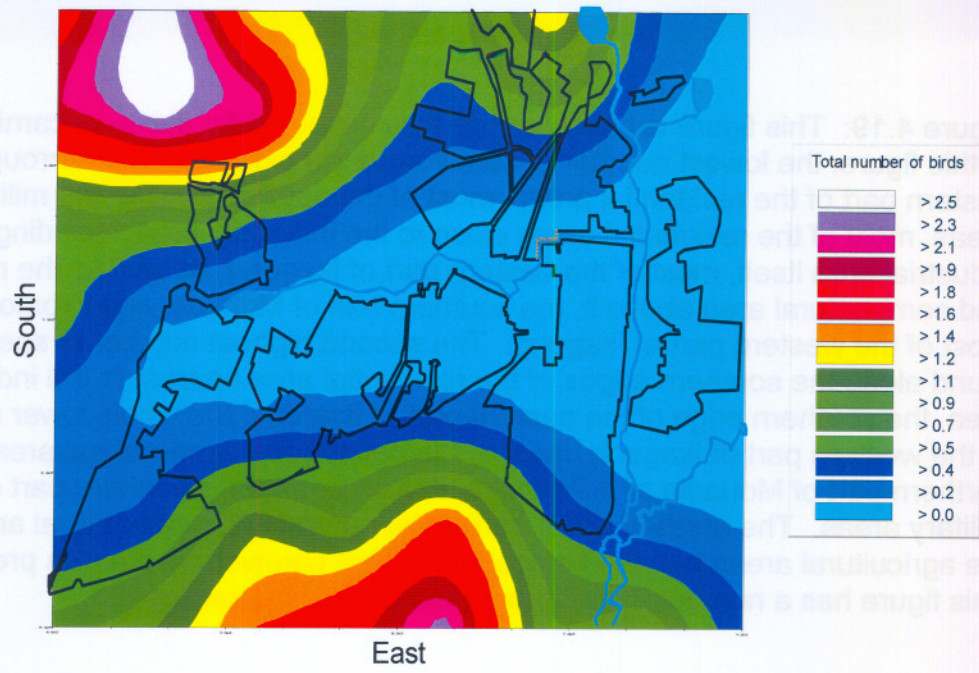


Figure 4.20: The total number of carnivores interpolated over Potchefstroom

Figure 4.20: This figure shows much similarity when compared to Fig. 4.19. In this figure, the lowest number of birds that are carnivores, was found in the eastern part of the residential areas, the majority of the southern half of the military areas, the residential areas closest to the industrial area, the industrial area itself, almost all of the eastern part of Ikageng, including the natural and semi-natural area above it, the majority of the western part of Ikageng and the southern half of Mohadin and Promosa. These areas of lowest bird numbers are very similar to the areas of lowest species found in Fig. 4.19. The northern parts of the military areas, the northern part of Mohadin and Promosa, half of the natural and semi-natural areas between the two, some of the agricultural areas (those that outline Ikageng, the industrial area and the residential area), and Prozesky had the second highest number of birds. The highest number of birds, was found in the north-western part of the natural and semi-natural areas (with sections touching Mohadin and Promosa) and in most of the central parts of the agricultural areas. This figure has a number 2 variogram (see Chapter 4, section 4.5).

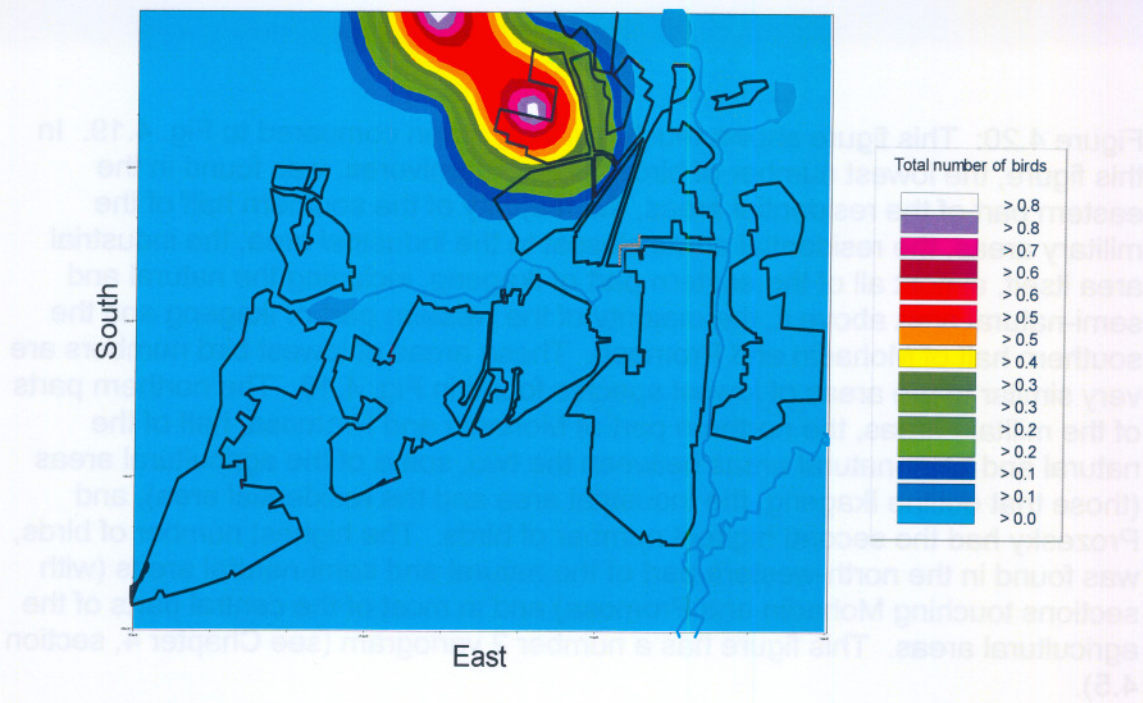


Figure 4.21: The total number of scavengers interpolated over Potchefstroom

Figure 4.21: This figure indicates the total number of scavengers. The amount of data collected for the feeding guild scavengers, was little and an insufficient amount for the GS+ programme, therefore figures for the total number of species and total biomass are not included for the scavengers. In this figure, the lowest number of birds was found throughout both the western and eastern parts of Ikageng, Mohadin and Promosa, the industrial area, the residential areas nearest to the industrial area, the eastern part of the residential area, Prozesky, the eastern part of the military areas, the agricultural areas and the majority of the natural and semi-natural areas. Most of the central part of the military areas and in the natural and semi-natural areas to the west of this area had the second highest total number of birds. The highest total number of birds was located in the north-western part of the military areas and to the north-west of these areas in the natural and semi-natural. This figure has a number 2 variogram (see Chapter 4, section 4.5).

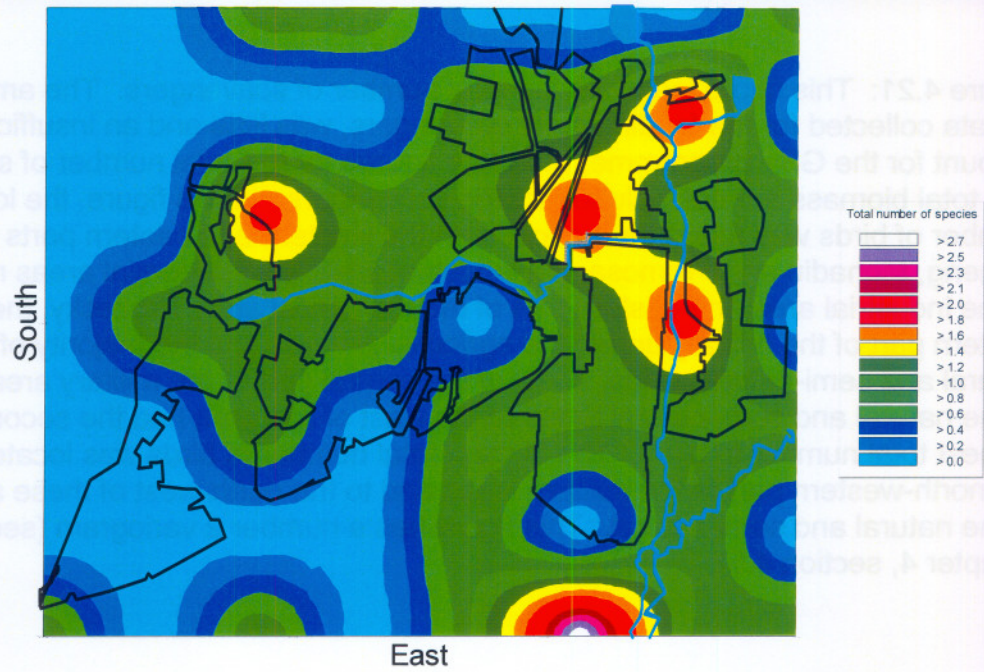


Figure 4.22: The total number of omnivorous species interpolated over Potchefstroom

Figure 4.22: This figure indicates the total number of omnivorous species. The lowest number of species was located primarily in the industrial area, the northern section of the eastern part of Ikageng, most of the western part of Ikageng (excluding the southern tip and northern section), the agricultural areas below Ikageng, the most northern parts of the military areas, most of the natural and semi-natural areas and in some small areas along the eastern border of the figure. The second lowest number of species was found in the top northern section of the western part of Ikageng, as well as the eastern part of Ikageng, most of the military areas excluding the eastern side, the natural and semi-natural areas to the west of the military areas, the western side of Mohadin and Promosa, the majority of the southern half of the residential area nearest to the industrial area, the agricultural areas below the industrial area, Prozesky and most of the eastern part of the residential areas. The eastern part of Mohadin and Promosa, the eastern side of the military areas and the northern parts of the residential areas, all have the second highest total number of species that are omnivores. The highest number of species was located in the agricultural areas directly below the residential area nearest to the industrial area. This figure has a number 1 variogram (see Chapter 4, section 4.5)

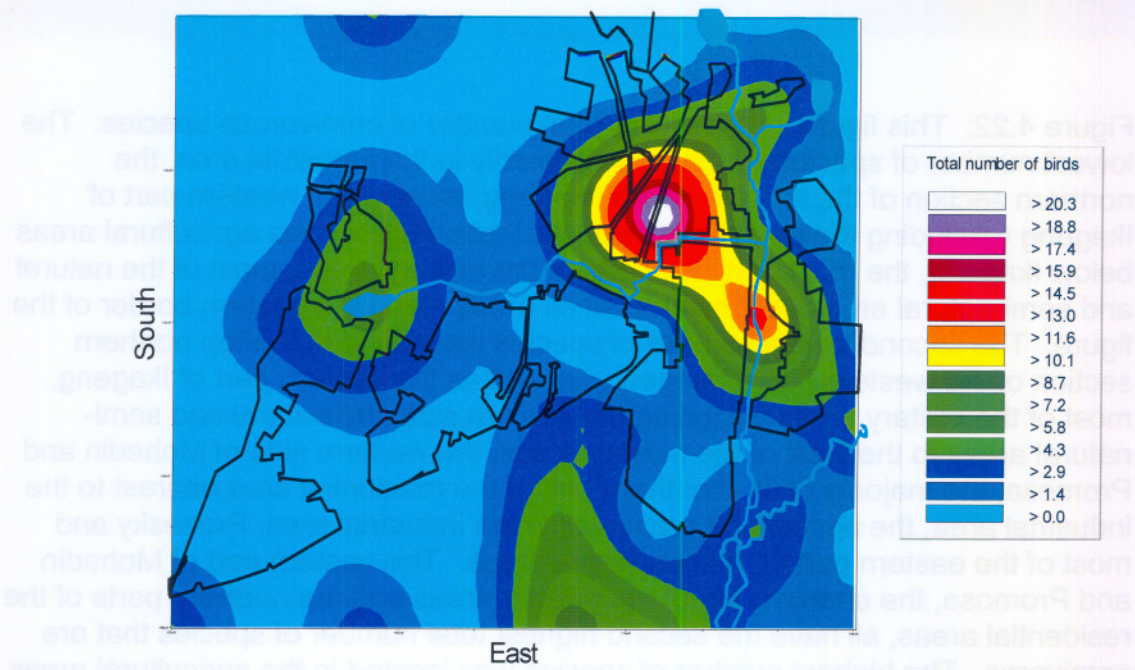


Figure 4.23: The total number of omnivores interpolated over Potchefstroom

Figure 4.23: In this figure, the lowest total number of omnivores was found in most of the agricultural areas below Ikageng, the eastern part of Ikageng, the western part of Ikageng (excluding the northern tip), the western part of Mohadin and Promosa, the industrial area, the natural and semi-natural areas, the northern parts of the military areas, the top section of the eastern residential areas, the southern parts of the residential area nearest to the industrial area and in Prozesky. The second lowest number of birds was located in the southern end of Promosa and Mohadin, the northern tip of Ikageng, the agricultural areas below the industrial area and the residential area closest to it, most of the eastern residential areas and to the east of the military areas. The northern part of the residential areas nearest to the industrial area had the second highest number of birds, which also spreads into the eastern residential areas. The highest total number of birds occurred in the northern most parts of the residential areas and the southern parts of the military areas. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.24: The total number of omnivores recorded over Potchefstroom

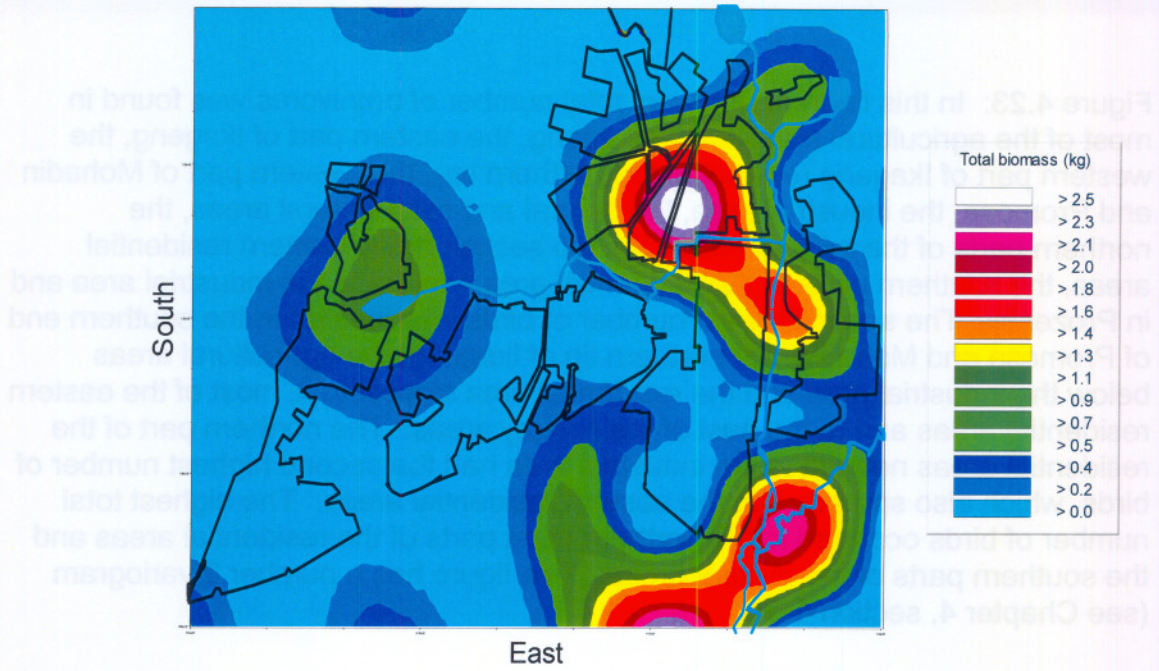


Figure 4.24: The total biomass for omnivores interpolated over Potchefstroom

Figure 4.24: In this figure, the lowest total biomass for omnivores was found throughout the industrial area, the eastern part of Ikageng (except for the north-western tip of it), the western part of Ikageng (excluding the northern part of it), the north-western part of Mohadin and Promosa, almost all of the natural and semi-natural areas, the agricultural areas below both parts of Ikageng, the northern and north-western parts of the military areas, the lower half of the residential area nearest to the industrial area and the northern and southern tip of the eastern part of the residential area. The second lowest total biomass occurred in the agricultural areas below the industrial area, to the east of the military areas, the southern half of Mohadin and Promosa, the top northern section of the western part of Ikageng and the natural and semi-natural areas to the east of the latter two areas. The majority of Prozesky, the lower part of the agricultural areas, the northern part of the residential areas closest to the industrial area and the central section of the eastern part of the residential areas, had the second lowest total biomass. The central part of the military areas had the highest total biomass for omnivores. This figure has a number 3 variogram (see Chapter 4, section 4.5).

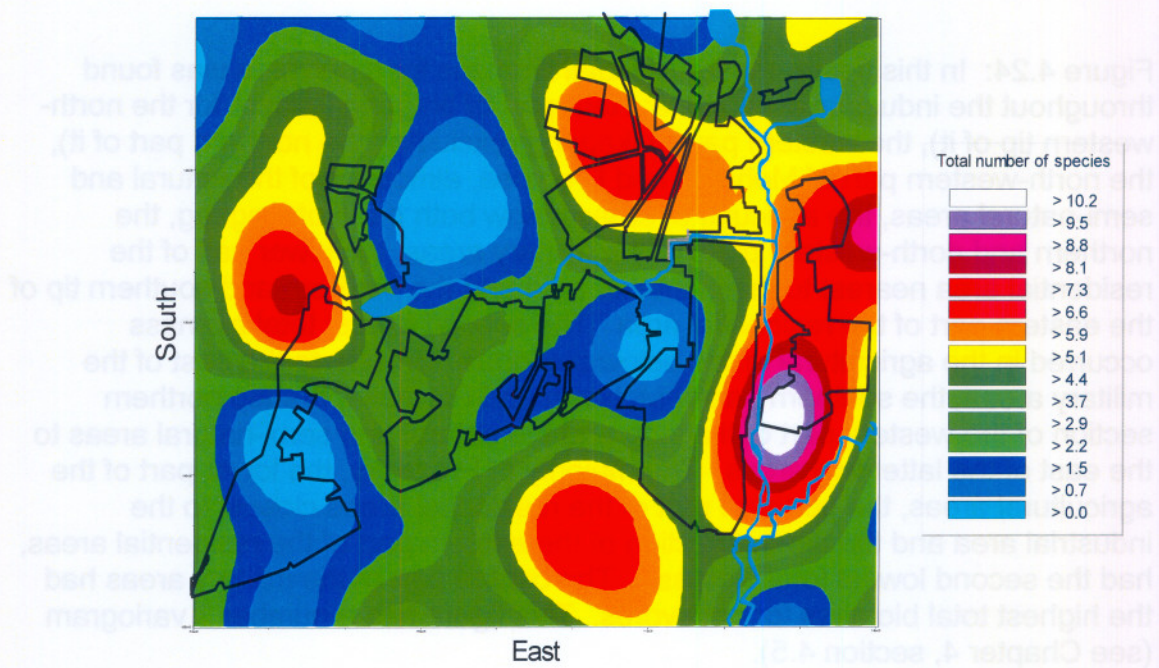


Figure 4.25: The total number of insectivorous species interpolated over Potchefstroom

Figure 4.25: This figure indicates the total number of insectivorous species. The lowest total number of species was found in most of the industrial area, the natural and semi-natural areas to the east of Mohadin and Promosa, the southern half of the western part of Ikageng, the agricultural areas below the western part of Ikageng, a small part of Prozesky, the eastern part of Mohadin and Promosa and the top most part of the natural and semi-natural areas. The second highest total number of insectivore species was located in the majority of the eastern part of Ikageng, the northern section of the western part of Ikageng, the western part of Mohadin and Promosa, most of the natural and semi-natural areas to the west and north of the western part of Ikageng, the agricultural areas (excluding those below the western part of Ikageng), Prozesky, the western half of the residential areas closest to the industrial area, the upper section of the eastern part of the residential areas and the whole of the military areas. The highest total number of species was located in the southern section of the eastern part of the residential areas and the areas just below it. This figure has a number 3 variogram (see Chapter 4, section 4.5).

Figure 4.25: The total number of insectivores recorded over Potchefstroom

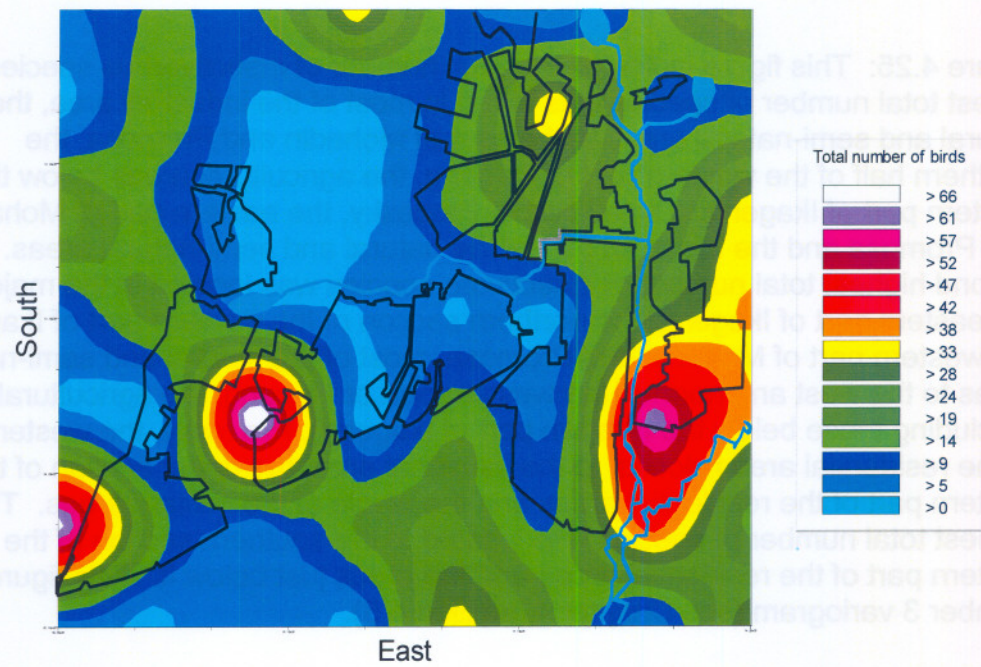


Figure 4.26: The total number of insectivores interpolated over Potchefstroom

Figure 4.26: This figure indicates the total number of insectivores. The lowest total number of birds was found in the industrial area (excluding the southern tip), the eastern half of the eastern part of Ikageng, the entire Mohadin and Promosa, the natural and semi-natural areas between Mohadin and Promosa, and the military areas, the central section of the western part of Ikageng and the natural and semi-natural areas to the west of this part of Ikageng, the agricultural areas below Ikageng, the lower western half of the residential area nearest to the industrial area, the far northern part of the military areas, a small part to the east of the military areas and a small section in the lower part of Prozesky. The second highest total number of birds occurred in most of the military areas, the northern section of the eastern part of the residential areas, the central half of the residential areas nearest to the industrial area, the agricultural areas below this part of the residential areas, including those below the industrial area and the eastern part of Ikageng. Some of the natural and semi-natural areas to the west of Mohadin and Promosa, in two small northern parts of the natural and semi-natural areas also had the second highest total number of birds. The highest total number of birds was located in the bottom half of the eastern part of the residential areas and the areas just below it (Prozesky), the southern tip of the western part of Ikageng and the natural and semi-natural areas just west of this part of Ikageng and in the natural and semi-natural area between the two parts of Ikageng, including the western section of the eastern part of Ikageng. This figure has a number 2 variogram (see Chapter 4, section 4.5).

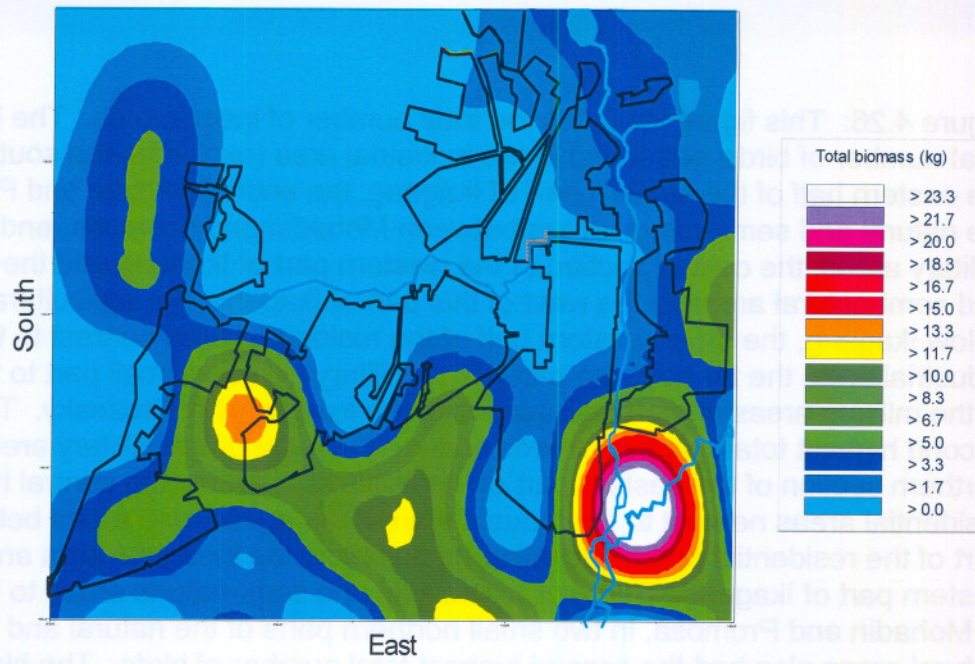


Figure 4.27: The total biomass for insectivores interpolated over Potchefstroom

Figure 4.27: The lowest total biomass for insectivores was indicated in this figure. The lowest total biomass was located throughout the military areas, the areas to the east of the military areas, almost the whole of the eastern part of the residential areas, the majority of the residential areas (excluding the lower eastern part) nearest to the industrial area, a small section of the agricultural areas below this part of the residential areas, the industrial area (excluding the southern tip), most of the eastern part of Ikageng, Mohadin and Promosa, the eastern half of the western part of Ikageng, the natural and semi-natural areas to the west of this part of Ikageng, the agricultural areas (below the western part of Ikageng and some of the eastern part of Ikageng) and in most of the natural and semi-natural areas excluding a small section to the west of Mohadin and Promosa. The second highest total biomass was found in a small part of the natural and semi-natural areas to the west of Mohadin and Promosa, the southwestern section of the western part of Ikageng, the western half of the eastern part of Ikageng, the natural and semi-natural areas between the two, the agricultural areas below the eastern part of Ikageng and the industrial area, and in the areas east of the eastern part of the residential areas. The eastern end of the residential areas nearest to the industrial area and the majority of Prozesky had the highest total biomass for insectivores. This figure has a number 2 variogram (see Chapter 4, section 4.5).

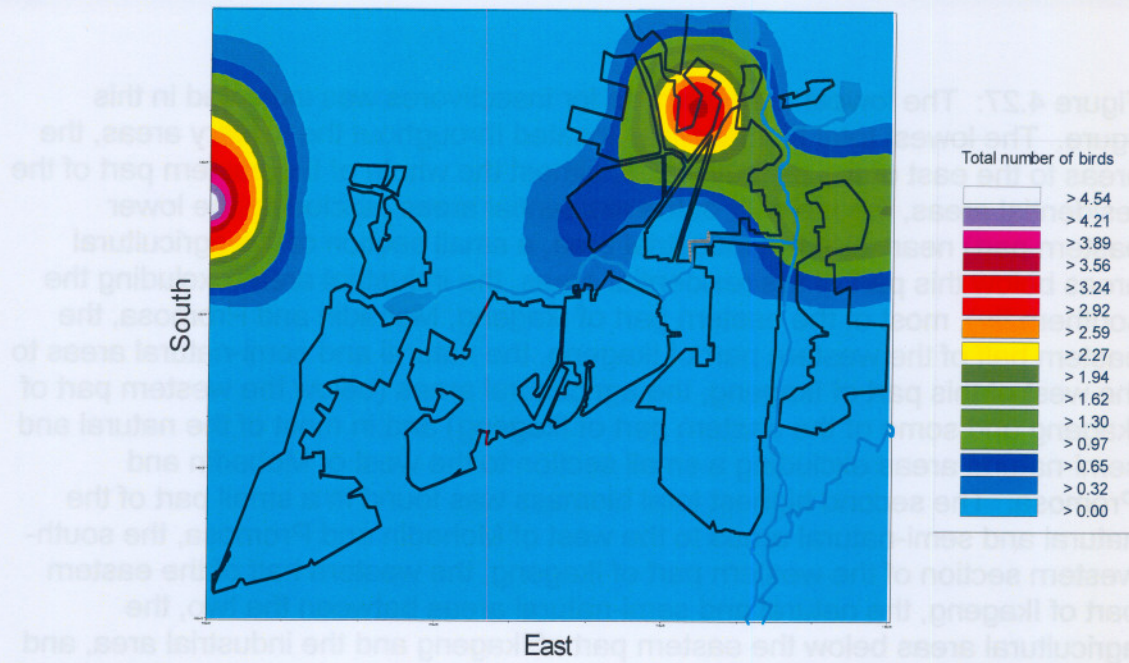


Figure 4.28: The total number of frugivores interpolated over Potchefstroom

Figure 4.28: This figure indicates the total number of frugivores. The data collected over four days for the ----- frugivores, was insufficient for the GS+ programme to be able to generate figures for the total number of species and total biomass. The lowest total number of birds was found throughout Mohadin and Promosa, Ikageng, the industrial area, the residential areas nearest to the industrial area, the lower half of the eastern part of the residential area, the lower half of the eastern part of the residential areas, Prozesky, the areas to the east of the military areas, the agricultural areas and the natural and semi-natural areas, excluding those to the far west of Mohadin and Promosa. The second highest total number of birds was located in the top part of the eastern residential areas, the areas surrounding it and in the military areas. The natural and semi-natural areas to the far west of Mohadin and Promosa had the highest total number of frugivores. This figure has a number 1 variogram (see Chapter 4, section 4.5).

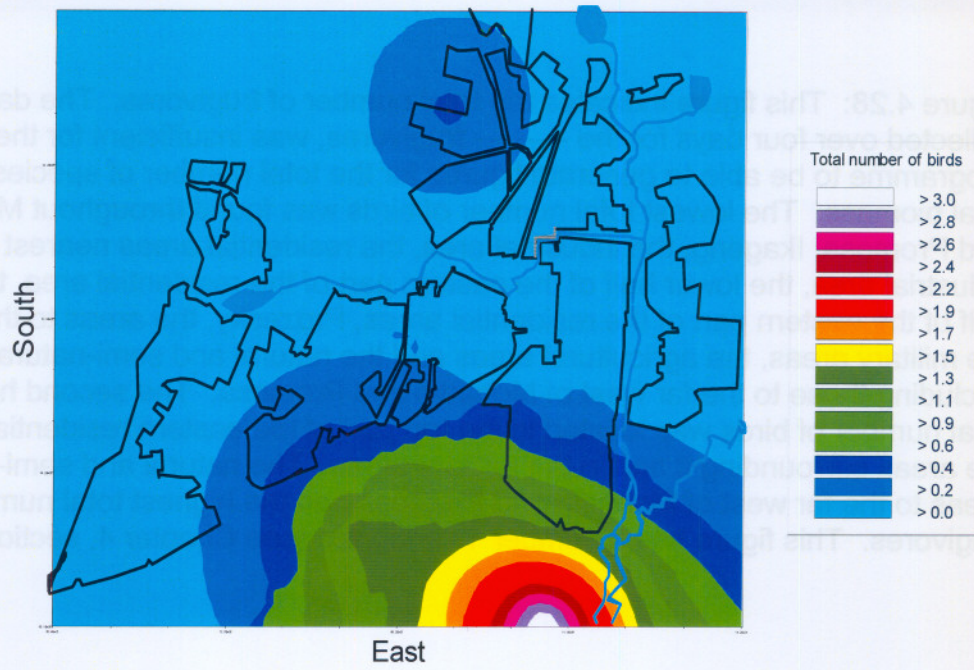


Figure 4.29: The total number of herbivores interpolated over Potchefstroom

Figure 4.29: This figure indicates the total number of herbivores. The data collected over four days for this feeding guild was also insufficient for the GS+ programme to be able to generate figures for the total number of species and the total biomass. The lowest total number of birds was found throughout the natural and semi-natural areas, the military areas, the eastern residential areas, most of the residential areas nearest to the industrial area, the industrial area itself, the whole of Ikageng and the agricultural areas below Ikageng. The second highest total number of birds was found in the lower end of the residential areas closest to the industrial area, Prozesky and the agricultural areas nearest to the industrial area and below the eastern part of Ikageng. The agricultural areas below the residential areas nearest to the industrial area and Prozesky had the highest total number of herbivores. This figure has a number 2 variogram (see Chapter 4, section 4.5).



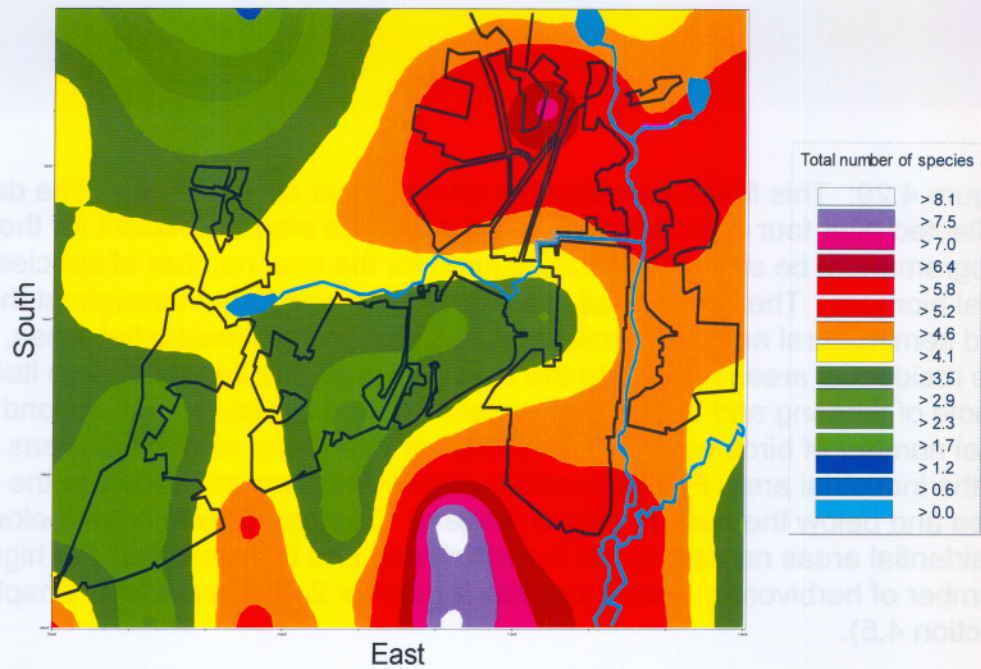


Figure 4.30: The total number of tree nesting species interpolated over Potchefstroom

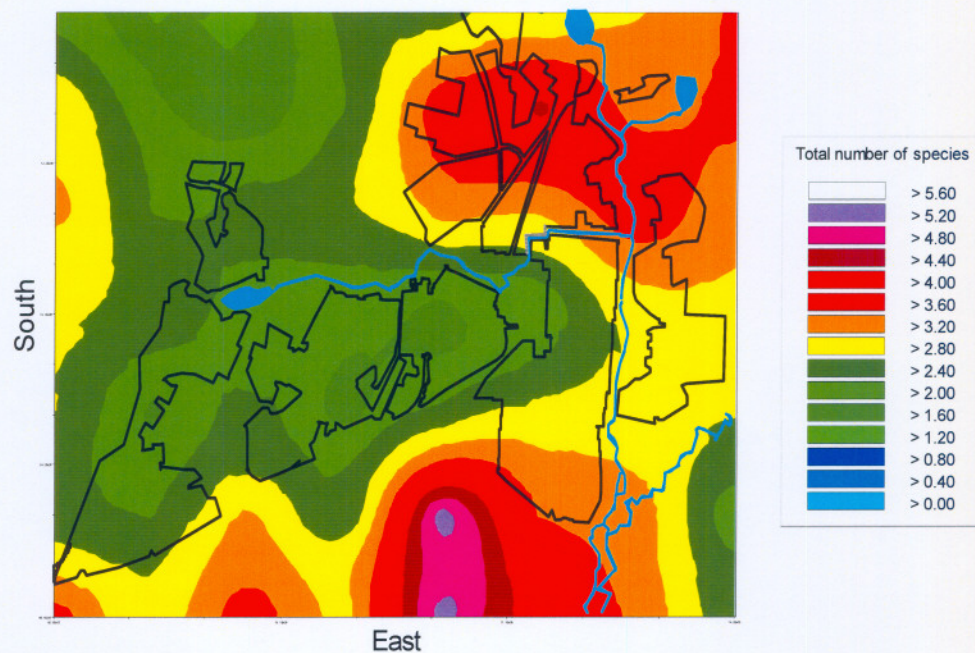


Figure 4.30.1: The total number of tree nesting species excluding doves and pigeons, interpolated over Potchefstroom

Results for nesting guilds:

Figure 4.30: This figure indicates the total number of tree nesting species. The lowest number of species was found in the industrial area, most of the eastern section of the eastern part of Ikageng, the central section of the western part of

Ikageng and the natural and semi-natural areas to the north of Mohadin and Promosa, including the northern part of these two areas. The second lowest number of species was located in the rest of Mohadin and Promosa, the northern and southern sections of the western part of Ikageng, the natural and semi-natural areas to the west of Ikageng, Mohadin and Promosa, the natural and semi-natural areas between the two parts of Ikageng, the southern section of the eastern part of Ikageng, some of the agricultural areas, the eastern part of Prozesky and the majority of all the residential areas. The northern section of the eastern part of the residential areas, the military areas and the areas to the east of them, a small part of the agricultural areas below Ikageng and the western half of Prozesky, all had the second highest total number of species. The highest total number of species was located in the agricultural areas below the industrial area. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.30.1: In this figure, all the dove species that are tree nesters were excluded from this data set in order to determine the contribution of other tree nesting species. The dove species excluded from this data set include, the Red-eyed Doves (*Streptopelia semitorquata*), Cape Turtle-doves (*Streptopelia capicola*), and the Laughing Doves (*Streptopelia senegalensis*). The lowest number of species was found in the central section of the western part of Ikageng, the natural and semi-natural areas to the north of Mohadin and Promosa (which is the same for Fig. 4.30), however, only a small section in the eastern part of Ikageng had the lowest number of species, whereas in Fig. 4.30, most of this area had the lowest number of species. The second lowest number of species occurred throughout Mohadin and Promosa, the northern and southern sections of the western part of Ikageng, the natural and semi-natural areas to the west of Ikageng, Mohadin and Promosa, the natural and semi-natural areas between the two parts of Ikageng and the eastern part of Prozesky, which was the same for Fig. 4.30. In this figure, most of the eastern part of Ikageng also had the second lowest number of species, but in Fig. 4.30, most of this part of Ikageng had the lowest number of species, this includes the industrial area, which had the lowest number of species in Fig. 4.30, but in this figure had the second lowest number of species. The residential areas differ slightly from Fig. 4.30, the eastern residential areas had the second lowest number of species in only the lower part and the residential areas nearest to the industrial area had the second lowest number of species in only the northern part, whereas in Fig. 4.30, the majority of these two areas had the second lowest number of species. The upper part of the eastern residential areas, the military areas, including the areas to the east of them, the lower half of the residential areas nearest to the industrial area, the western half of Prozesky, the agricultural areas between the two parts of Ikageng and some of the natural and semi-natural areas surrounding the western part of the military areas, had the second highest total number of species that were tree nesters. This was practically the same for these areas in Fig. 4.30. The highest total number of species was again located in the agricultural areas below the industrial area, which was the same in Fig. 4.30. This figure has a number 2 variogram (see Chapter 4, section 4.5)

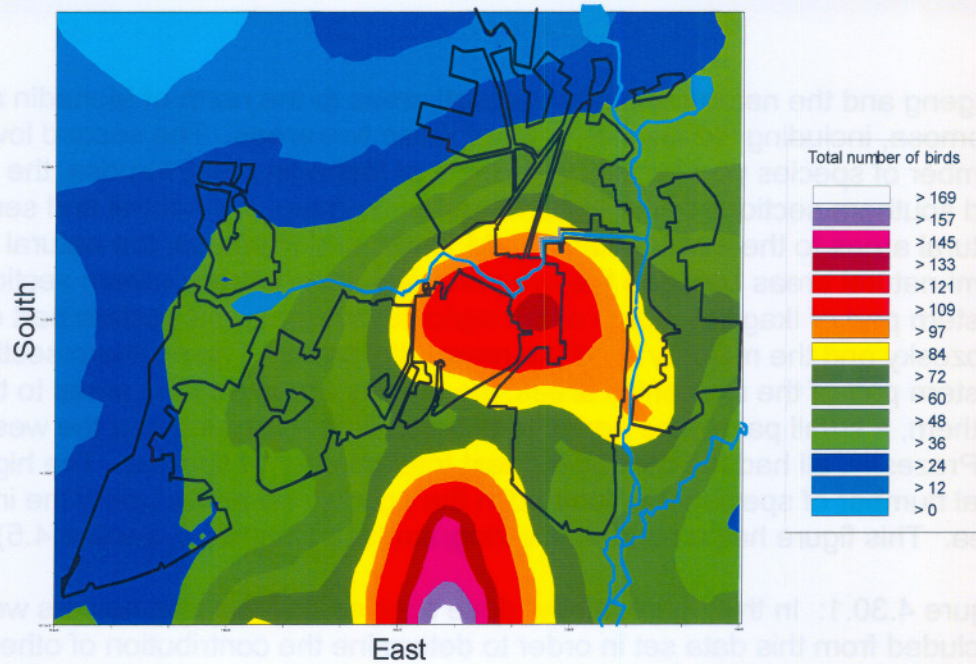


Figure 4.31: The total number of tree nesters interpolated over Potchefstroom

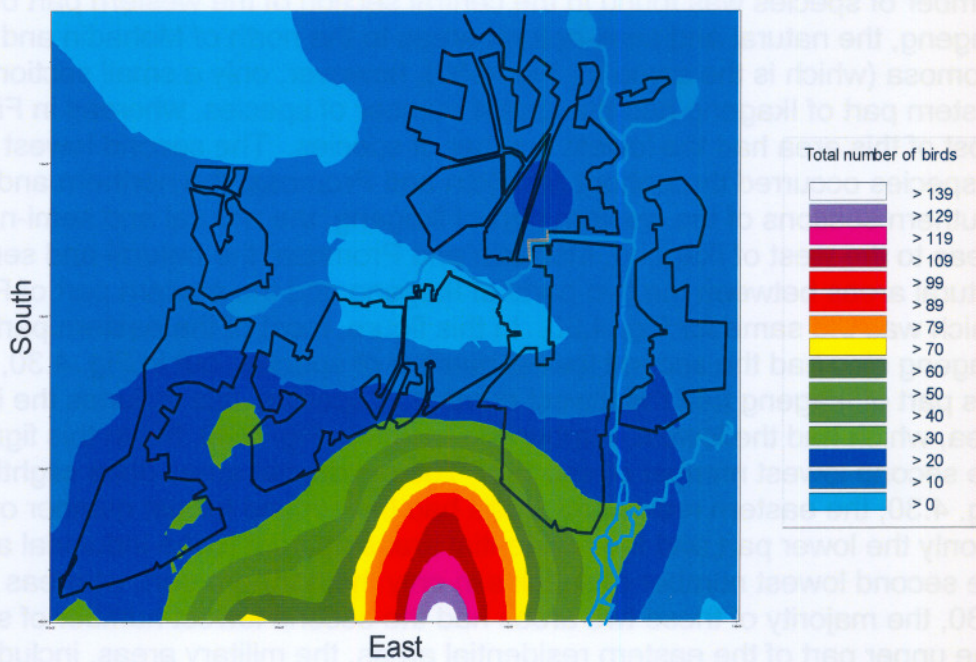


Figure 4.31.1: The total number of tree nesters, excluding doves, interpolated over Potchefstroom

Figure 4.31: This figure indicates the total number of tree nesters. The lowest total number of birds was found throughout Mohadin and Promosa, the western part of Ikageng (excluding a small part in the northern section), the northern half of the military areas including those to the east of the military areas, the natural and semi-natural areas and the agricultural areas below the western part of Ikageng. The second lowest total number of birds occurred in the majority of the eastern part of the residential areas, Prozesky, the lower part of the residential areas nearest to the industrial area, the southern half of the military areas, the eastern part of Ikageng, the agricultural areas below the eastern part of Ikageng and below the industrial area and the natural and semi-natural areas above the eastern part of Ikageng. The upper part of the residential areas nearest to the industrial area, the industrial area itself and the southern tip of the military areas had the second highest total number of birds. The highest total number of birds was located in the agricultural areas below the industrial area. This figure has a number 2 variogram as well as Fig. 4.31.1 (see Chapter 4, section 4.5).

Figure 4.31.1: All the numbers of doves that were tree nesters, were excluded from this data set, which again included Red-eyed Doves, Cape Turtle-doves and Laughing Doves. This figure differs greatly from Fig. 4.31 except with regard to the agricultural areas. The lowest total number of birds was found throughout the eastern part of the residential areas, the upper half of the residential areas closest to the industrial area, the industrial area itself, the upper halves of both parts of Ikageng, Mohadin and Promosa, the eastern half of Prozesky, the military areas and all the natural and semi-natural areas. The second highest total number of birds occurred in the lower parts of Ikageng, the industrial area and the residential areas nearest to the industrial area. The agricultural areas below Ikageng also had the second highest total number of birds. The areas with the second lowest total number of birds in this figure are similar to the areas in Fig. 4.31. The agricultural areas below the industrial area had the highest total number of birds, which was the same in Fig. 4.31.

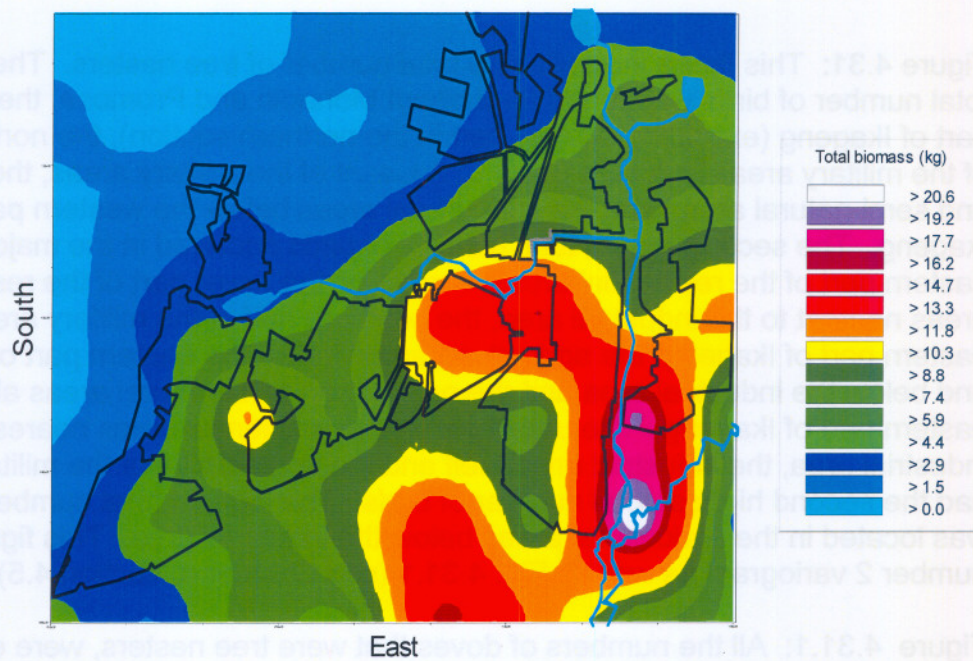


Figure 4.32: The total biomass for tree nester interpolated over Potchefstroom

Figure 4.32: This figure indicates the total biomass for tree nesters. The lowest total biomass occurred in the north-eastern part of the military areas, Mohadin and Promosa, the western half of the western part of Ikageng, the agricultural areas below the western part of Ikageng and most of the natural and semi-natural areas. The second lowest total biomass was found in the northern section of the eastern part of the residential areas, the south-eastern part of the military areas, the eastern part of Ikageng, the eastern halves of the western part of Ikageng, the natural and semi-natural areas between the two, including the agricultural areas below these two parts of Ikageng, a small part of Prozesky, the agricultural areas just below the industrial area and the lower western part of the residential areas nearest to the industrial area. The industrial area, the upper part of the residential areas nearest to it, the lower half of the eastern part of the residential areas and the lower agricultural areas beneath the industrial area all had the second highest total biomass. The highest total biomass was located in the southern corner of the eastern part of the residential areas, the areas below it and the upper part of Prozesky. This figure has a number 2 variogram (see Chapter 4, section 4.5).

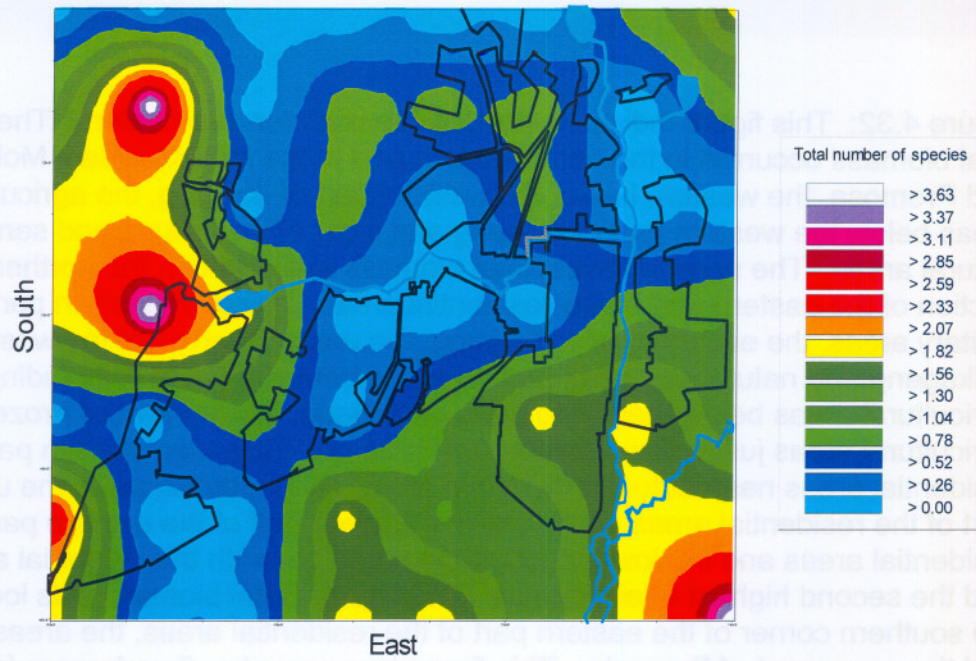


Figure 4.33: The total number of ground nesting species interpolated over Potchefstroom

Figure 4.33: This figure indicates the total number of ground nesting species. The lowest total number of species was found in the industrial area, the majority of the eastern part of Ikageng, most of the military areas, the upper part of the residential areas nearest to the industrial area, the northern part of the eastern residential areas, the agricultural areas below both parts of Ikageng, the areas east of the military areas, the lower and central section of the western part of Ikageng, the natural and semi-natural areas to the west of Ikageng, between the two parts of Ikageng and most of the northern parts. The second lowest and second highest total number of species were located in the central part of the military areas, a small part of the natural and semi-natural areas east of the military areas, the majority of Mohadin and Promosa, the natural and semi-natural areas west of Mohadin and Promosa, including the northern section of the western part of Ikageng, the south-western tip of the western part of Ikageng, the agricultural areas below the eastern part of Ikageng and the industrial area, the lower half of the eastern part of the residential areas and the lower half of the residential areas nearest to the industrial area. The areas just east of Prozesky had the highest total number of species. This figure has a number 1 variogram (see Chapter 4, section 4.5).

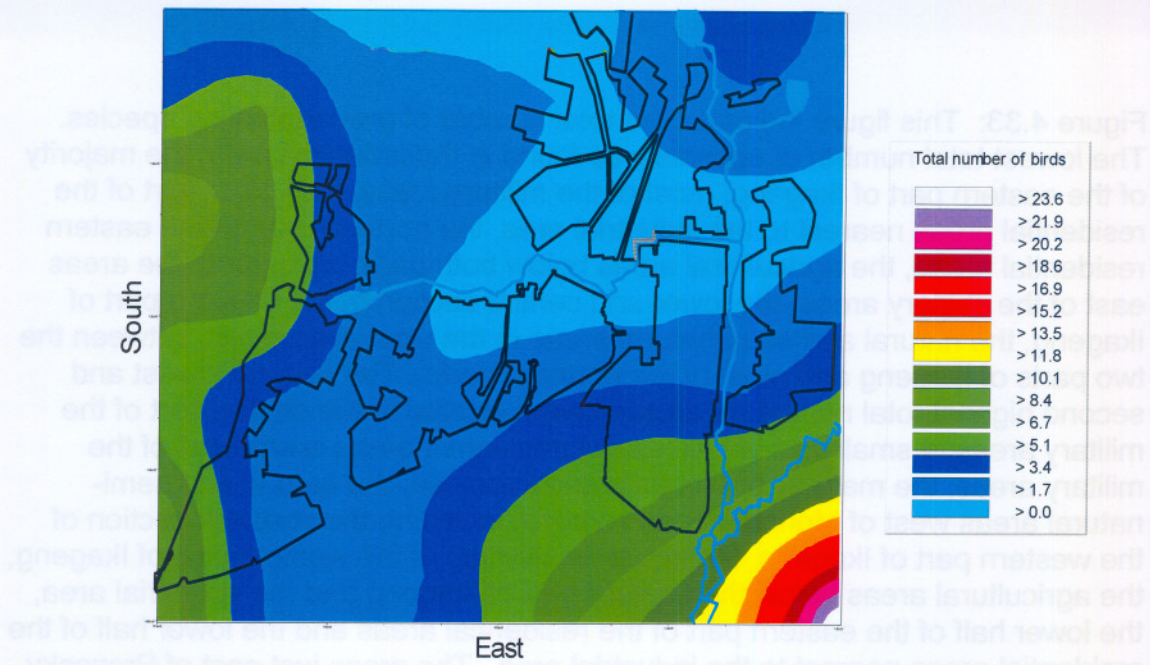


Figure 4.34: The total number of birds for ground nesters interpolated over Potchefstroom

Figure 4.34: This figure indicates the total number of ground nesters. All throughout the military areas, the eastern part of the residential areas, the majority of the residential areas nearest to the industrial area, the industrial area itself, the eastern part of Ikageng, Mohadin and Promosa, practically all of the western part of Ikageng, the agricultural areas excluding those far below the industrial area, the natural and semi-natural areas excluding those west of Mohadin and Promosa and west of Ikageng and the natural and semi-natural areas between the two parts of Ikageng all had the lowest total number of birds. The second highest total number of birds was found in the natural and semi-natural areas west of Mohadin and Promosa, the southern tip of the western part of Ikageng, the natural and semi-natural areas west of this part of Ikageng, the lower part of the residential areas nearest to the industrial area, the lower agricultural areas below the industrial area and the western part of Prozesky. The highest total number of birds was located throughout the rest of Prozesky. This figure has a number 2 variogram (see Chapter 4, section 4.5).

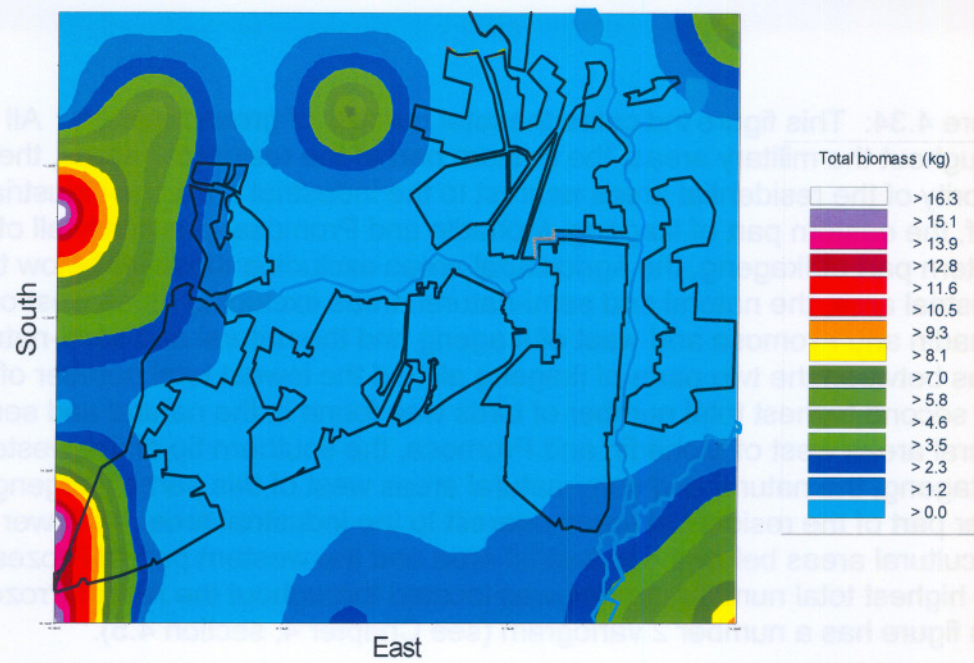
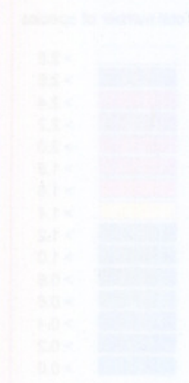


Figure 4.35: The total biomass for ground nesters interpolated over Potchefstroom

Figure 4.35: The total biomass for ground nesters was indicated in this figure. The lowest total biomass occurred within the industrial area, all of the residential areas, the eastern part of Ikageng, the agricultural areas, the western half of Prozesky, Mohadin and Promosa, most of the areas east of the military areas, the military areas themselves, most of the western part of Ikageng and in some of the natural and semi-natural areas. The second highest total biomass was found in the natural and semi-natural areas directly west of the military areas, the far north-eastern corner and in Prozesky. The natural and semi-natural areas west of Mohadin and Promosa and the southern tip of Ikageng, including the natural and semi-natural areas surrounding this point, had the highest total biomass for ground nesters. This figure has a number 3 variogram (see Chapter 4, section 4.5).



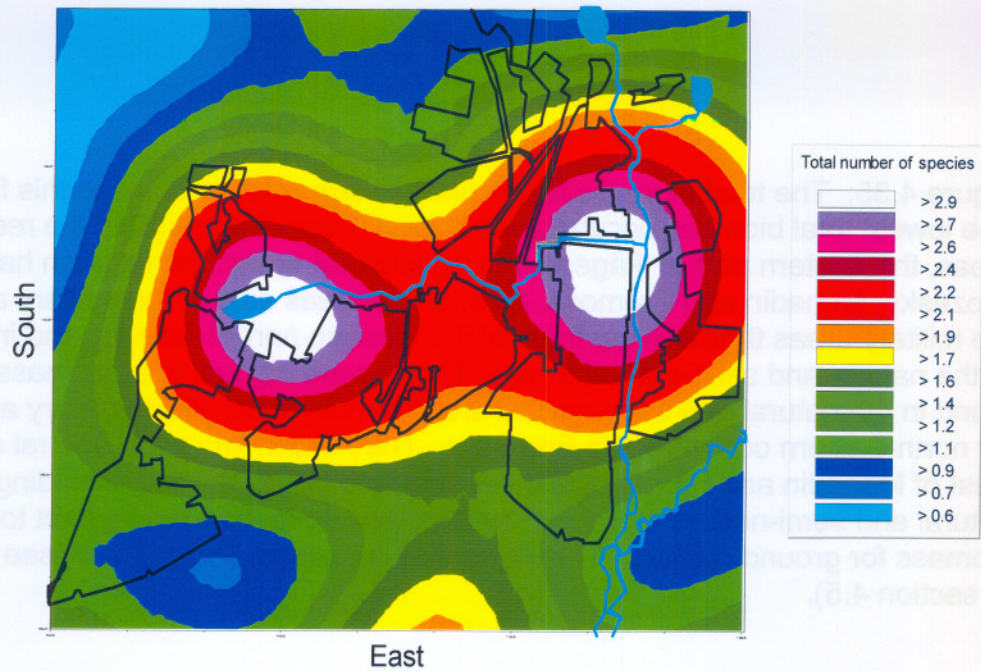


Figure 4.36: The total number of structure or tree nesting species, interpolated over Potchefstroom

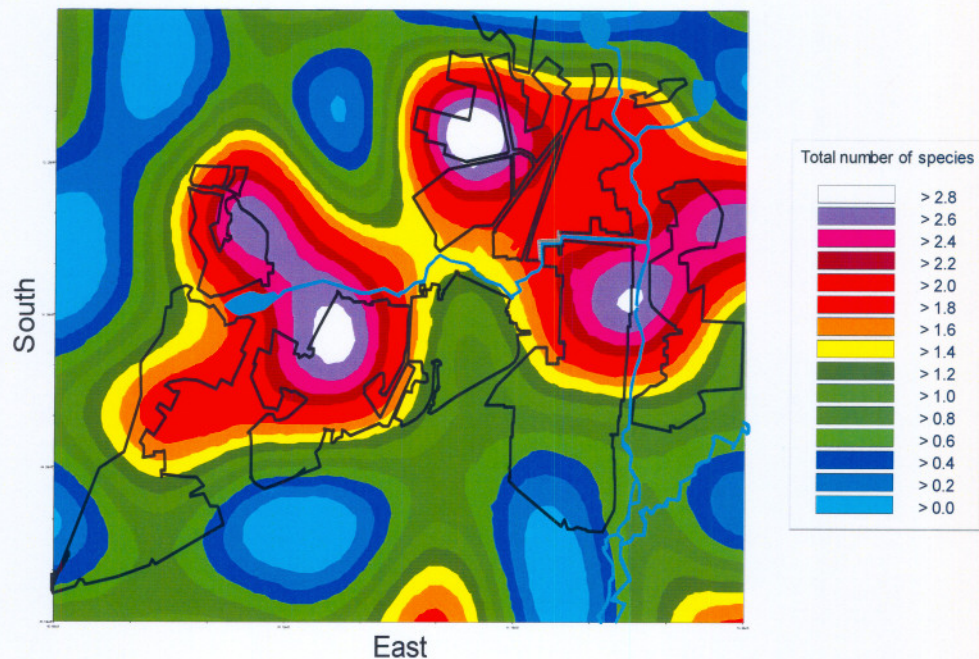


Figure 4.36.1: The total number of structure or tree nesting species, excluding doves and pigeons, interpolated over Potchefstroom

Figure 4.36: This figure indicates the total number of structure or tree nesting species. The lowest number of species was found in the north-eastern part of Prozesky, the agricultural areas below the western part of Ikageng and the eastern part of Ikageng, the south-eastern section of the western part of Ikageng, the northern part of the military areas and the natural and semi-natural areas.

The second lowest total number of species was located in most of the agricultural areas, the majority of Prozesky, the lower part of the residential areas nearest to the industrial area, the southern tip of the eastern part of Ikageng, most of the central and lower section of the western part of Ikageng, the central parts of the military areas and the natural and semi-natural areas to the west of the military areas, as well as to the west just outside the western part of Ikageng and the west of Mohadin and Promosa. The southern parts of the military areas, most of the eastern part of the residential areas, the central part of the residential areas nearest to the industrial area, the industrial areas itself, the majority of Mohadin and Promosa, the upper section of the western part of Ikageng, most of the eastern part of Ikageng, the lower agricultural areas below the industrial area, most of the areas east of the military areas and the natural and semi-natural areas above the industrial area and the eastern part of Ikageng, all had the second highest total number of species. The highest total number of species was found in the northern part of the residential areas nearest to the industrial area, the south-eastern tip of the military areas and with the industrial area appearing to serve as a corridor, in the natural and semi-natural areas between Mohadin and Promosa and the two parts of Ikageng. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.36.1: In this figure, dove and pigeon species that were structure or tree nesters were excluded from this data set, so as to examine the contribution of the other species. Only one species of pigeon was structure or tree nesters, namely the Rock (Speckled) Pigeon, *C. guinea*. This figure does not differ much from Fig. 4.36. The lowest and second lowest total number of species were found throughout Prozesky, the lower half of the residential areas nearest to the industrial area, the lower section of the eastern part of Ikageng, most of the central and the southern half of the western part of Ikageng, throughout the agricultural areas, the majority of the natural and semi-natural areas and the most northern parts of the military areas. This is much the same for Fig. 4.36, the only differences were found in the industrial area, which had the second highest number of species in Fig. 4.36, but in this figure, it only has the second lowest number of species, the upper part of the western part of Ikageng also had the second highest number of species, but in this figure, the western half of this part had the second lowest number of species and another difference occurred in the military areas, in Fig. 4.36, the military areas had the second lowest total number of species throughout its central part, but in this figure the central part had the second highest total number of species. The second highest total number of species in this figure was found in the central and southern parts of the military areas, the northern parts of both residential areas, most of the eastern part of Ikageng, the majority of Mohadin and Promosa, the natural and semi-natural areas between Mohadin and Promosa and the southern parts of the military areas and the eastern section of the top western part of Ikageng. This was generally the same for Fig. 4.36, however, the highest total number of species was now found outside the eastern part of the residential areas. This figure has a number 2 variogram (see Chapter 4, section 4.5).

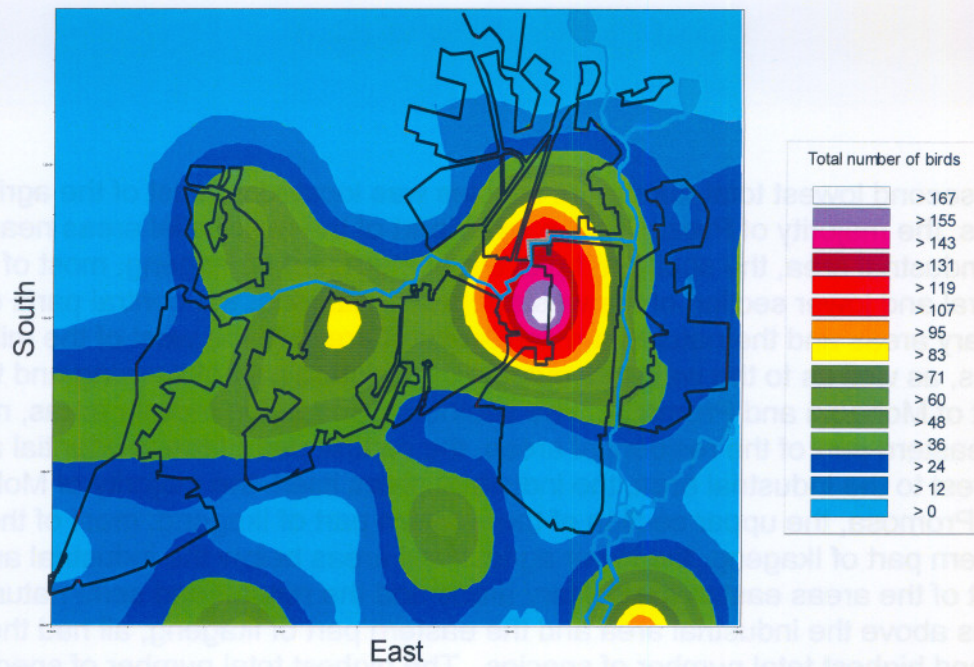


Figure 4.37: The total number of structure or tree nesters, interpolated over Potchefstroom

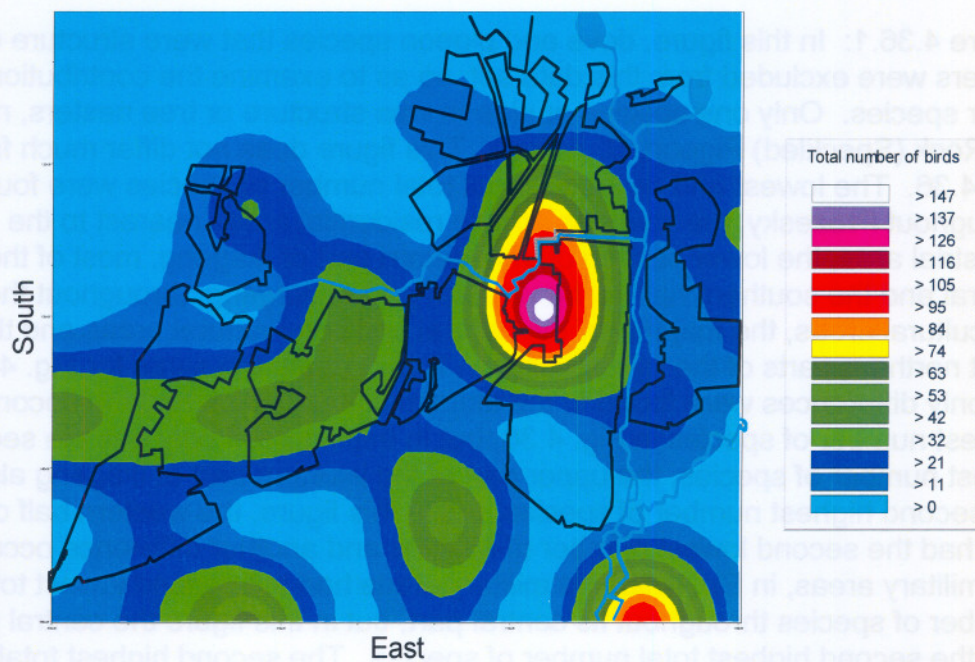


Figure 4.37.1: The total number of structure or tree nesters, excluding pigeons, interpolated over Potchefstroom

Figure 4.37: This figure indicates the total number of structure or tree nesters. The lowest total number of birds was found throughout the western part of Ikageng (excluding a small section of the central part), most of the agricultural areas, the lower half of the residential areas nearest to the industrial area, the

southern tips of the industrial area, the southern end of the eastern part of Ikageng, the majority of the natural and semi-natural areas, most of the military areas, the northern part of Prozesky and the eastern part of the residential areas, excluding the south-western tip. The second lowest total number of birds was found in Mohadin and Promosa, most of the eastern part of Ikageng, the natural and semi-natural areas between the two parts of Ikageng and those west of the central section of the western part of Ikageng, the natural and semi-natural areas above the eastern part of Ikageng and east of Mohadin and Promosa, the majority of the industrial area and in some of the agricultural areas below Ikageng and the industrial area. The second highest total number of birds occurred in the lower parts of Prozesky and the north-western corner of the eastern part of Ikageng. The southern parts of the military areas, the north-eastern part of the industrial area and most of the upper part of the residential area nearest to the industrial area together, had the highest total number of birds. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.37.1: This figure also indicates the total number of birds, however, the total numbers of the Rock (Speckled) Pigeons, *C. guinea*, were excluded from this data set in order to determine the contribution of the other birds. This figure is similar to Fig. 4.37 with regard to all the total numbers of birds. The lowest total number of birds was again found throughout the western part of Ikageng (excluding a broader section of the central part), most of the agricultural areas, the lower half of the residential areas nearest to the industrial area, the eastern half of the industrial area, the southern end of the eastern part of Ikageng, the majority of the natural and semi-natural areas, most of the military areas, the northern part of Prozesky, the eastern part of the residential areas, excluding the south-western tip and in Mohadin and Promosa. In Fig. 4.37, most of the industrial area, Mohadin and Promosa and a smaller section of the central part of the western part of Ikageng had the second lowest total number of birds whereas in this figure, they had the lowest number of birds. The second lowest total number of birds occurred in all of the eastern part of Ikageng, the natural and semi-natural areas between the two parts of Ikageng and those west of the central section of the western part of Ikageng, the natural and semi-natural areas above the eastern part of Ikageng, a small part in the north-eastern part of Mohadin and Promosa and in certain parts of the agricultural areas below the industrial area and the western part of Ikageng. This was also similar to Fig. 4.37, excluding the second lowest total number of birds found in Mohadin and Promosa in Fig. 4.37 and the second highest section found in the eastern part of Ikageng. The second highest total number of birds was found only in Prozesky in this figure, but in Fig. 4.37, the north-eastern section of the eastern part of Ikageng also had the second highest total number of birds. The highest total number of birds occurred again in the southern parts of the military areas, the north-eastern part of the industrial area and most of the upper part of the residential area nearest to the industrial area together. This figure has a number 2 variogram (see Chapter 4, section 4.5).

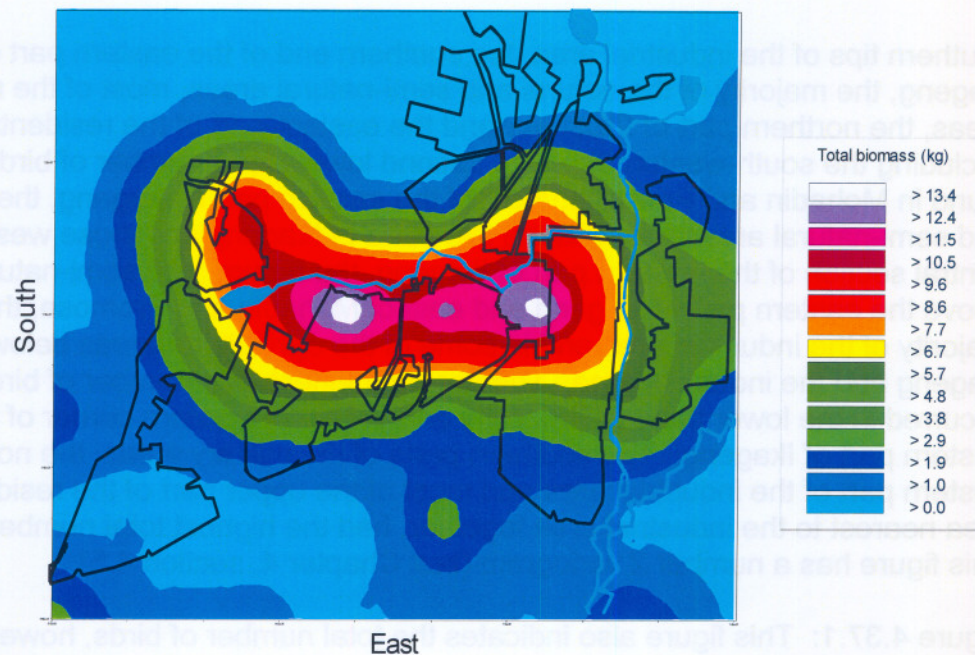


Figure 4.38: The total biomass for structure or tree nesters interpolated over Potchefstroom

Figure 4.38: This figure indicates the total biomass for structure or tree nesters. The lowest total biomass was located in the agricultural areas just below the eastern part of Ikageng and the industrial area, the north-eastern part and the western part of the military areas, the natural and semi-natural areas nearest to the western part of the military areas, most of the north-western parts of the natural and semi-natural areas and a small part of Prozesky. The second lowest total biomass was found throughout the western part of Ikageng, the lower half of the eastern part of Ikageng, the southern tips of the industrial area, the lower part of the residential areas nearest to the industrial area, most of the eastern part of the residential areas (excluding its southern end), the central part of the military areas, most of Prozesky, the majority of the agricultural areas and the rest of the natural and semi-natural areas. The northern half of the residential areas nearest to the industrial area, the southern end of the eastern residential areas, most of the industrial area, the southern end of the military areas, the central section of the eastern part of Ikageng, Mohadin and Promosa, and the natural and semi-natural areas between the top parts of Ikageng and the east of Mohadin and Promosa had the second highest total biomass. The highest total biomass was found in the top end of the eastern part of Ikageng and the industrial and residential areas together. This figure has a number 3 variogram (see Chapter 4, section 4.5).

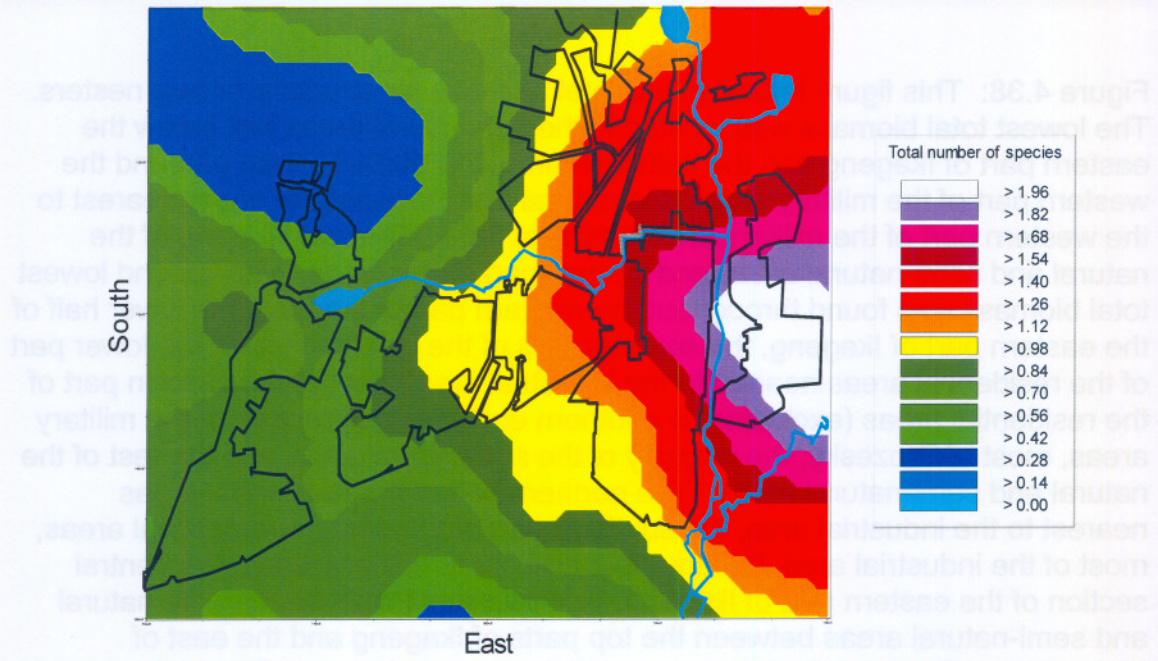


Figure 4.39: The total number of structure nesting species interpolated over Potchefstroom

Figure 4.39: This figure indicates the total number of structure nesting species. The lowest total number of species was found in Mohadin and Promosa, most of the lower half of the agricultural areas, most of the lower half of the western part of Ikageng and most of the natural and semi-natural areas surrounding Mohadin and Promosa, as well as to the north of these two areas. The second lowest total number of species was located throughout the eastern part of Ikageng, the majority of the western half of Ikageng, the natural and semi-natural areas between these two and those west of the western part of Ikageng, the upper half of the agricultural areas, the western half of the industrial area, the western half of the military areas, the natural and semi-natural areas outside this half of the military areas, the lower south-western part of the residential areas nearest to the industrial area and in the lowest part of Prozesky. The second highest total number of species occurred in the eastern half of the military areas, the eastern half of the industrial area, the areas to the east of the military areas, most of the residential areas nearest to the industrial area, the rest of Prozesky and the top section of the eastern residential areas. The highest total number of species occurred in the rest of the eastern part of the residential areas. This figure has a number 2 variogram (see Chapter 4, section 4.5).



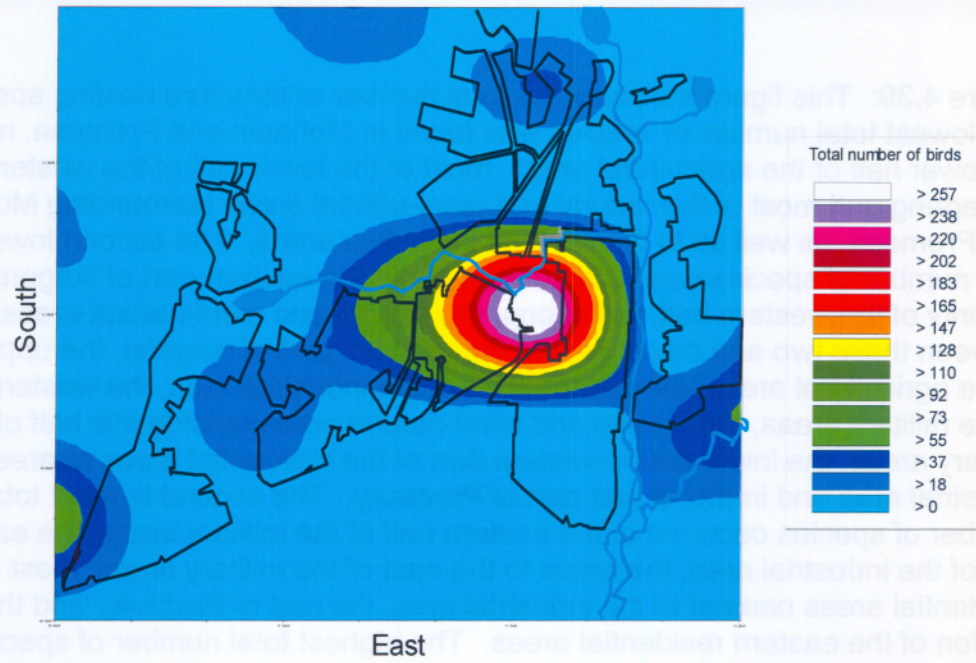


Figure 4.40: The total number of structure nesters interpolated over Potchefstroom

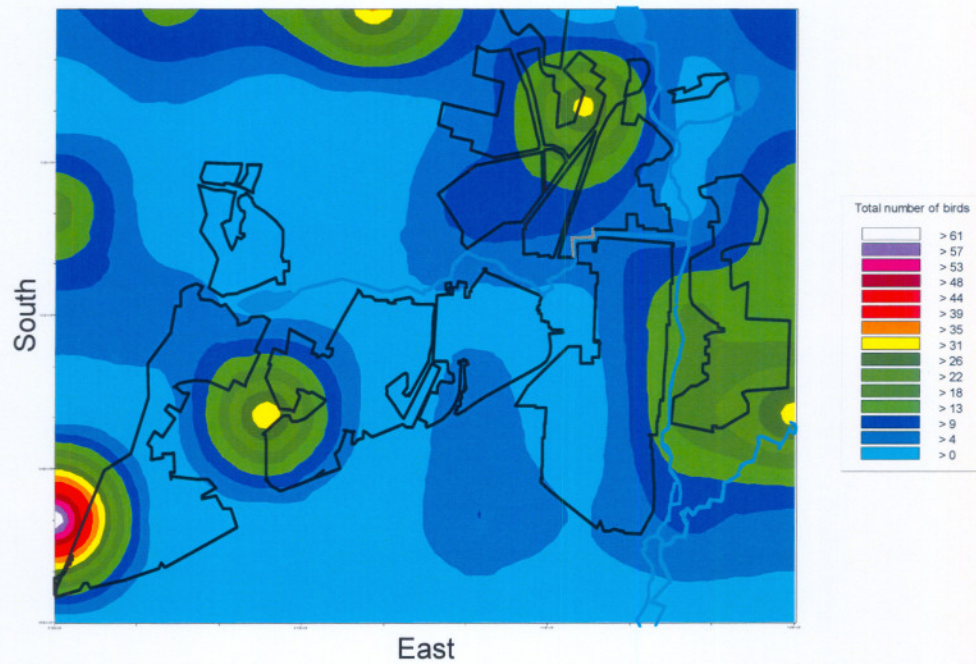


Figure 4.40.1: The total number of structure nesters, excluding pigeons, interpolated over Potchefstroom

Figure 4.40: This figure indicates the total number of structure nesters. The lowest total number of birds for this nesting guild was found throughout the majority of the natural and semi-natural areas, Mohadin and Promosa, most of the eastern part of Ikageng, the majority of the western part of Ikageng, the southern tip of the industrial area, the lower half of the residential areas nearest to the industrial area, almost all of the eastern part of the residential areas, most of the military areas, Prozesky and the agricultural areas. The second highest total number of birds was located in small areas in the eastern part of Ikageng, a small area in the lower south-western section of the western part of Ikageng, some of the industrial area, small sections of the natural and semi-natural areas between the two parts of Ikageng, just outside of the western part of Ikageng and to the far north, a small part in the northern section of the military areas as well as the southern part and in the lower southern part of the eastern residential areas, including the areas just below it. The highest total number of birds was located in the industrial area and the upper half of the residential areas nearest to it. This figure has a number 2 variogram (see Chapter 4, section 4.5).

Figure 4.40.1: This figure indicates the total number of birds for structure nesters excluding those pigeon species that were structure nesters. The Feral Pigeons, *C. livia*, were excluded from this data set in order to examine the contribution of the other structure nesting birds. The lowest total number of birds was found throughout Mohadin and Promosa, the majority of the western half of Ikageng, most of the eastern part of Ikageng, most of the military areas, Prozesky, the agricultural areas and the majority of the natural and semi-natural areas, which was the same for Fig.4.40. However, in this figure, the lowest total number of birds was also found throughout the industrial area, the residential areas nearest to it and the northern section of the eastern residential areas. In Fig. 4.40, smaller sections of these areas had the lowest total number of birds. The second highest total number of birds was found again in small areas of the eastern part of Ikageng, in a small area of the lower half of the western part of Ikageng, small sections of the natural and semi-natural areas between the two parts of Ikageng and to the far north, in the northern section of the military areas and the lower half of the eastern residential areas, which is also similar to Fig. 4.40, however, in this figure, the a small part of the natural and semi-natural areas west of Mohadin and Promosa, now have the second highest total number of birds whereas in Fig. 4.40, this part the lowest number of birds and in this Fig. 4.40, the eastern residential areas and the areas below, had smaller sections containing the second highest total number of birds. In this figure, the highest total number of structure nesters, were found in the natural and semi-natural areas just outside the lower western half of the western part of Ikageng. In Fig. 4.40, this area only had the second highest total number of birds and the industrial area and the residential areas nearest to it had the highest total number of birds. This figure has a number 1 variogram (see Chapter 4, section 4.5).

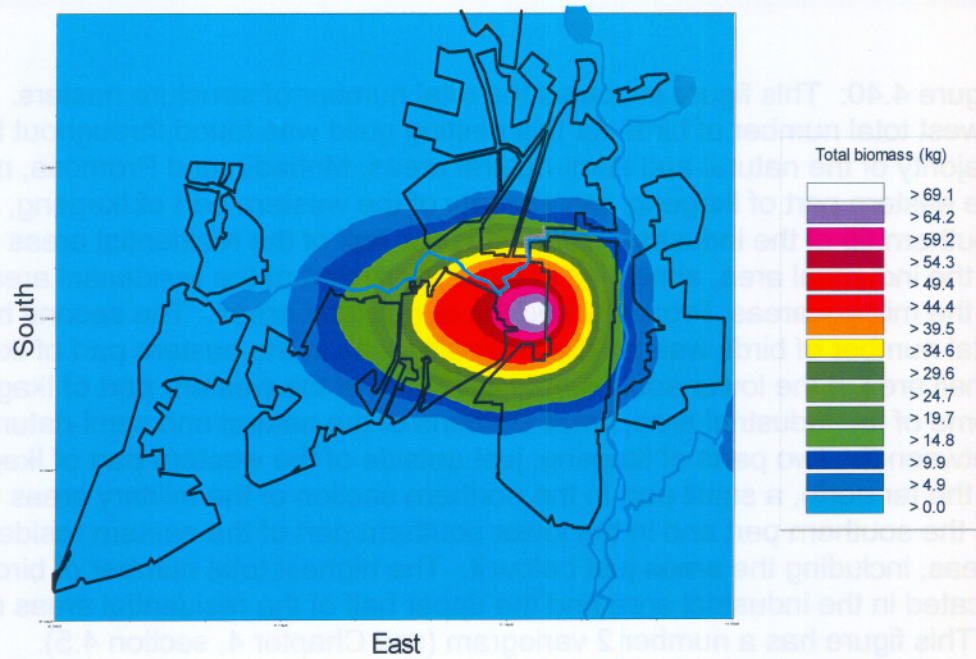
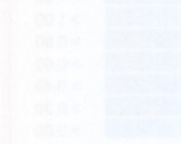


Figure 4.41: The total biomass for structure nesters interpolated over Potchefstroom

Figure 4.41: This figure indicates the total biomass for structure nesters. The lowest and second lowest total biomass was located throughout the natural and semi-natural areas, Mohadin and Promosa, the western part of Ikageng, the agricultural areas, the military areas, the eastern residential areas, Prozesky, some of the residential areas nearest to the industrial area and in the eastern part of Ikageng. The second highest and highest total biomass for structure nesters was found throughout the industrial area. This figure has a number 2 variogram (see Chapter 4, section 4.5).



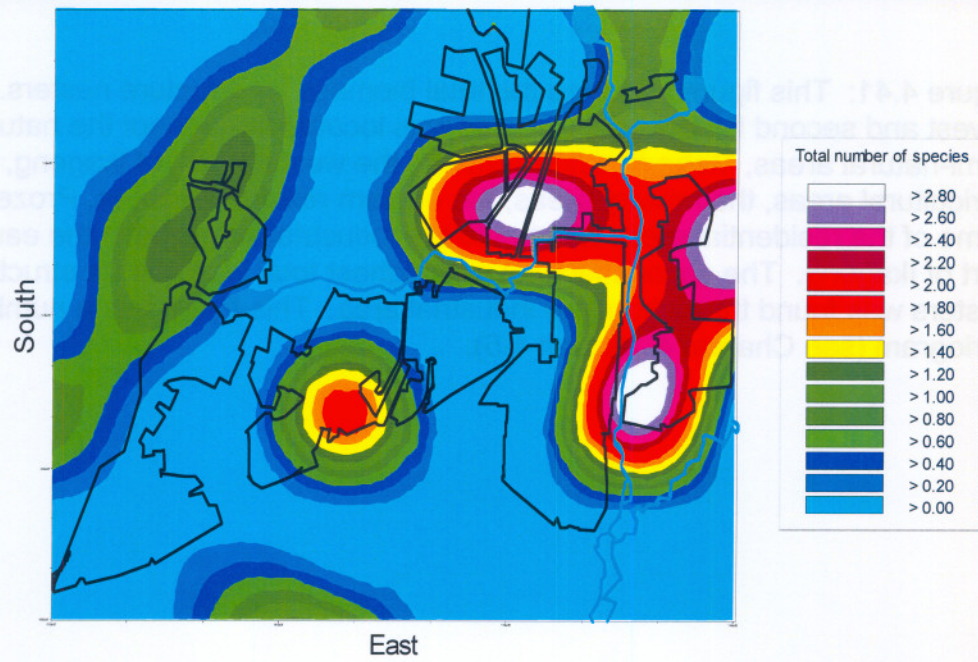


Figure 4.42: The total number of shrub or tree nesting species interpolated over Potchefstroom

Figure 4.42: This figure indicates the total number of shrub or tree nesting species. The lowest total number of species was located almost throughout both parts of Ikageng, most of the agricultural areas, Prozesky, the industrial area, the upper half of the military areas, the lower western half of the residential areas nearest to the industrial area and in most of the natural and semi-natural areas. The second lowest number of species was found in the rest of the natural and semi-natural areas, a small part of the agricultural areas, most of Mohadin and Promosa, the central parts of the eastern part of Ikageng, the central section of the military areas and in the eastern half of the residential areas nearest to the industrial area. The second highest number of species for this nesting guild was located in most of the eastern residential areas, the lower parts of the military areas and the upper corner of the residential areas nearest to the industrial area. The highest total number of species occurred in the lower central part of the military areas, the western tip of the eastern residential areas and in the upper section of the eastern residential areas, spreading into the areas just east of this section. This figure has a number 3 variogram (see Chapter 4, section 4.5).

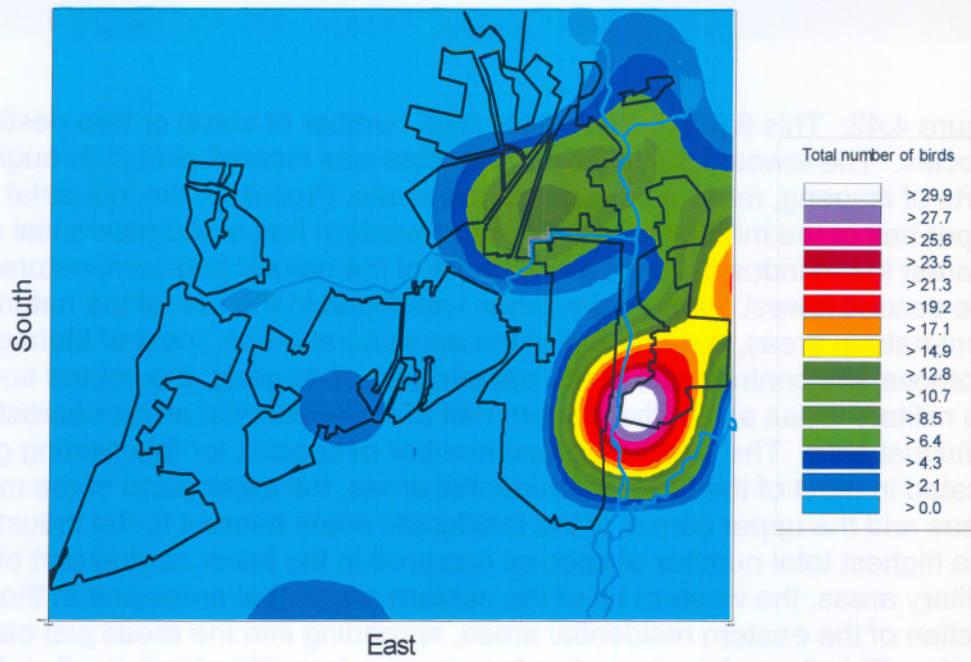
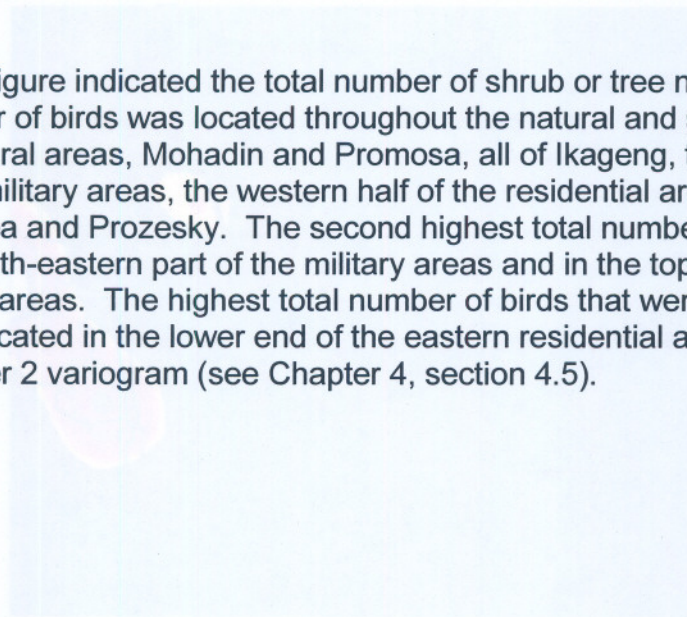
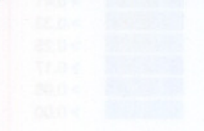


Figure 4.43: The total number of shrub or tree nesters interpolated over Potchefstroom

Figure 4.43: This figure indicated the total number of shrub or tree nesters. The lowest total number of birds was located throughout the natural and semi-natural areas, the agricultural areas, Mohadin and Promosa, all of Ikageng, the industrial area, most of the military areas, the western half of the residential areas nearest to the industrial area and Prozesky. The second highest total number of birds, occurred in the south-eastern part of the military areas and in the top parts of the eastern residential areas. The highest total number of birds that were shrub or tree nesters was located in the lower end of the eastern residential areas. This figure has a number 2 variogram (see Chapter 4, section 4.5).



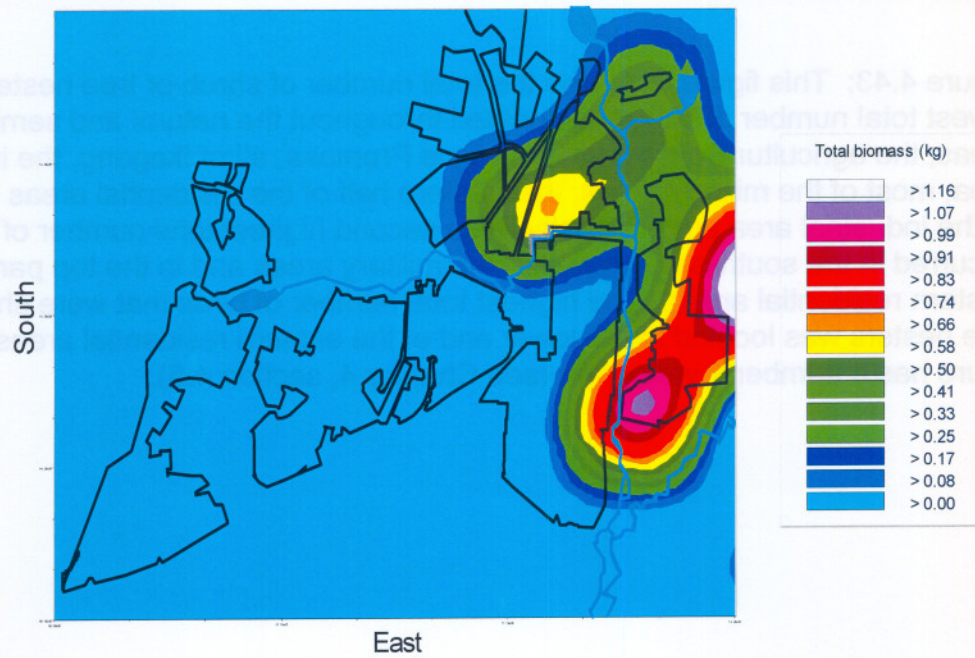


Figure 4.44: The total biomass for shrub or tree nesters interpolated over Potchefstroom

Figure 4.44: This figure indicates the total biomass for shrub or tree nesters. This figure is very similar to the figure for the total number of birds (Fig. 4.45). The lowest total biomass was located throughout the agricultural areas, the natural and semi-natural areas, both parts of Ikageng, Mohadin and Promosa, the industrial area, Prozesky, the western half of the residential areas nearest to the industrial area and in most of the military areas. The second lowest total biomass was found in the rest of the military areas, the areas just east of them and in the northern part of the eastern residential areas. The second highest total biomass occurred in the lower half of the eastern residential areas, and the highest total biomass for this feeding guild was found in the areas just east of the eastern residential areas. This figure has a number 2 variogram (see Chapter 4, section 4.5).

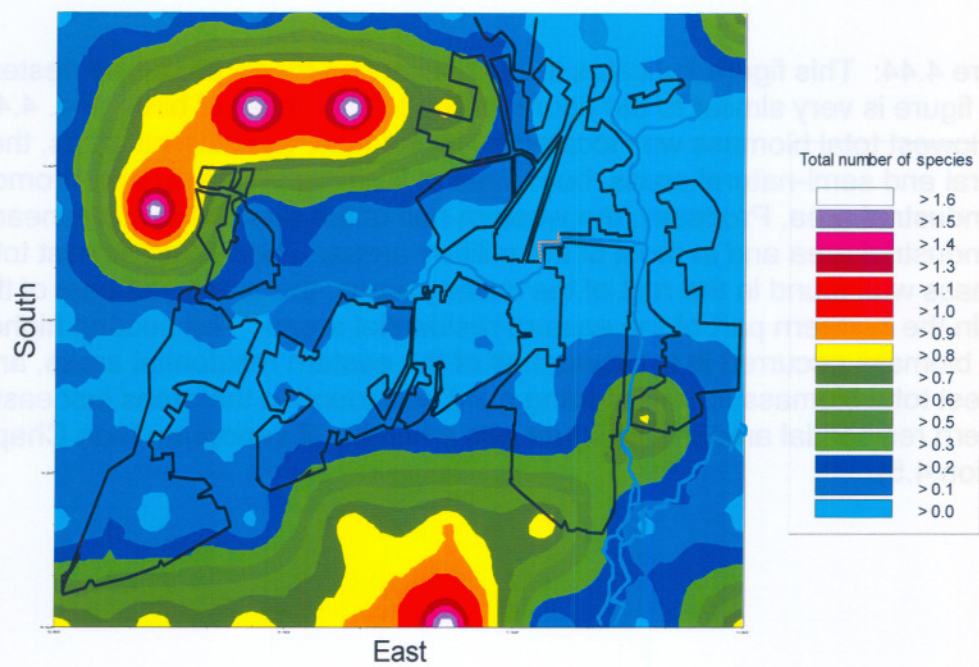


Figure 4.45: The total number of shrub nesting species interpolated over Potchefstroom

Figure 4.45: This figure indicates the total number of shrub nesting species. The lowest total number of species for this nesting guild was found throughout the central part of the study area. This included almost the entire western part of Ikageng, the eastern part of the Mohadin and Promosa, all of the eastern part of Ikageng, the industrial area, almost all of the military areas, most of the residential areas nearest to the industrial area, almost all of the eastern residential areas, most of Prozesky, the areas east of the military areas and the natural and semi-natural areas surrounding both parts of Ikageng and the industrial area. The second highest total number of species was located in the upper parts of the agricultural areas, the southern part of the residential areas nearest to the industrial area, the southern tip of the eastern residential areas, the top western part of the military areas and in the natural and semi-natural areas to the west of the military areas. The highest total number of species occurred in the lower parts of the agricultural areas and the centre of natural and semi-natural areas surrounded by those with the second highest total number of species. This figure has a number 1 variogram (see Chapter 4, section 4.5).

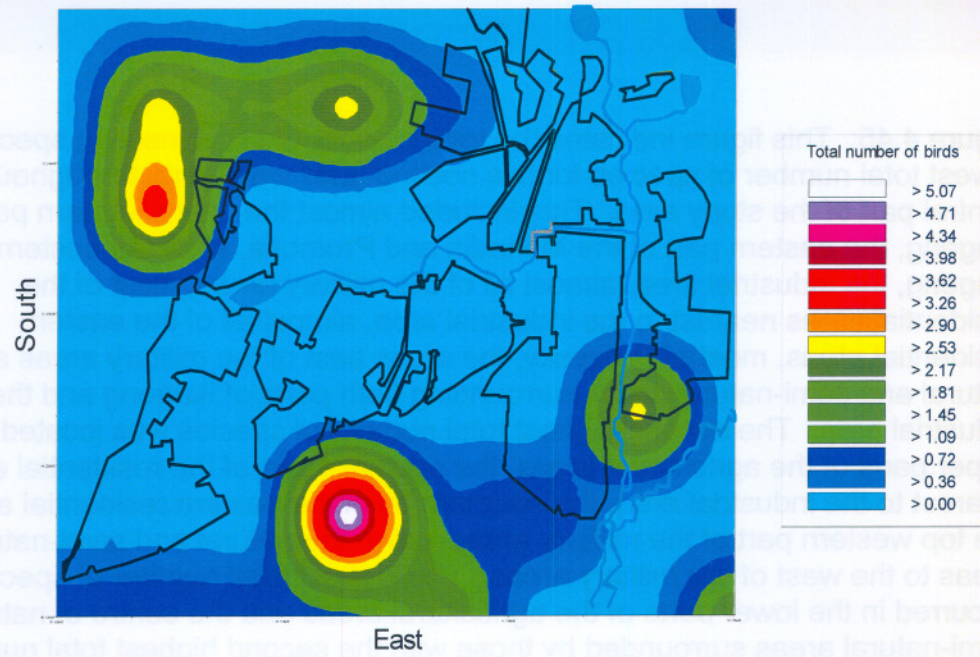


Figure 4.46: The total number of shrub nesters interpolated over Potchefstroom

Figure 4.46: This figure indicates the total number of shrub nesters. The lowest total number of birds was found throughout both parts of Ikageng, the industrial area, the military areas, most of Mohadin and Promosa, the majority of the residential areas nearest to the industrial area, most of the eastern residential areas, Prozesky, most of the agricultural areas and in most of the natural and semi-natural areas. The second highest total number of birds was located in the south-eastern tip of Prozesky, the southern end of the residential areas, a small part just below it, a minor part of the residential areas nearest to the industrial area, a large part of the natural and semi-natural areas west of the military areas, the top western part of Mohadin and Promosa, the natural and semi-natural areas west of Mohadin and Promosa and in the agricultural areas below the eastern part of Ikageng and the industrial area. The highest total number of birds occurred in the agricultural areas below the eastern part of Ikageng, surrounded by the second highest total number of birds. This figure has a number 3 variogram (see Chapter 4, section 4.5).

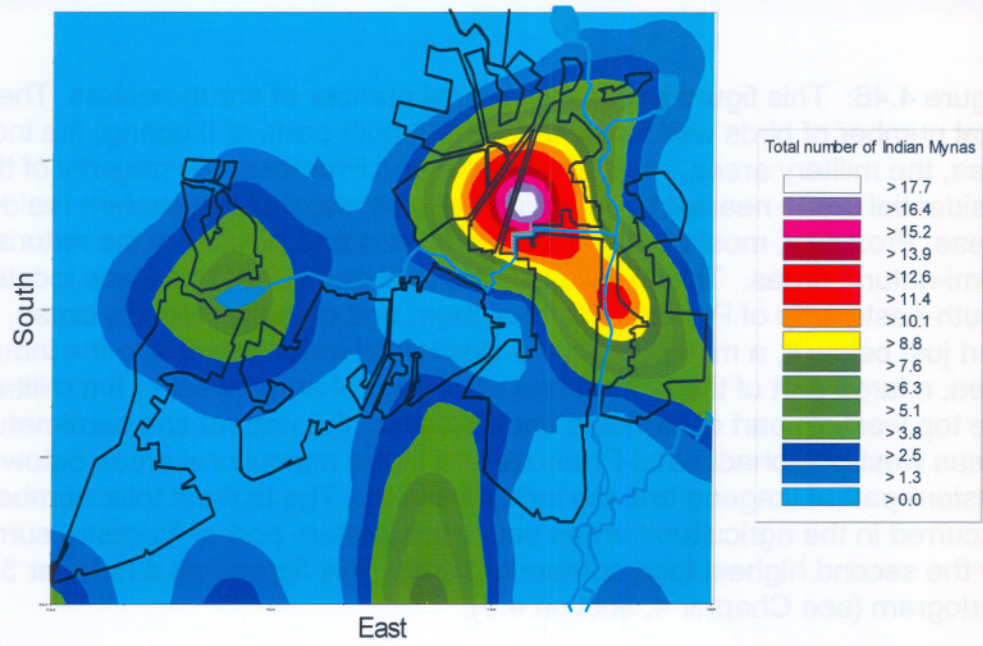


Figure 4.47: The total number of Indian Mynas, *A. tristis*, interpolated over Potchefstroom

Figure 4.47: This figure indicates the total number of Indian Mynas, *A. tristis*. The lowest total number of birds was found throughout the industrial area, Prozesky, the majority of the eastern part of Ikageng, most of the western part of Ikageng, the northern parts of Mohadin and Promosa, the lower half of the residential areas nearest to the industrial area, the northern tip of the eastern residential areas, the northern part of the military areas, most of the agricultural areas and the majority of the natural and semi-natural areas. The second highest total number of birds was located in the agricultural areas below the industrial area, the lower half of Mohadin and Promosa, the northern section of the western part of Ikageng including the natural and semi-natural areas surrounding these two areas, the central part of the military areas, most of the eastern residential areas and the northern part of the residential areas nearest to the industrial area. The highest total number of birds occurred in the southern part of the military areas and the upper tip of the residential areas nearest to the industrial area. This figure has a number 2 variogram (see Chapter 4, section 4.5).



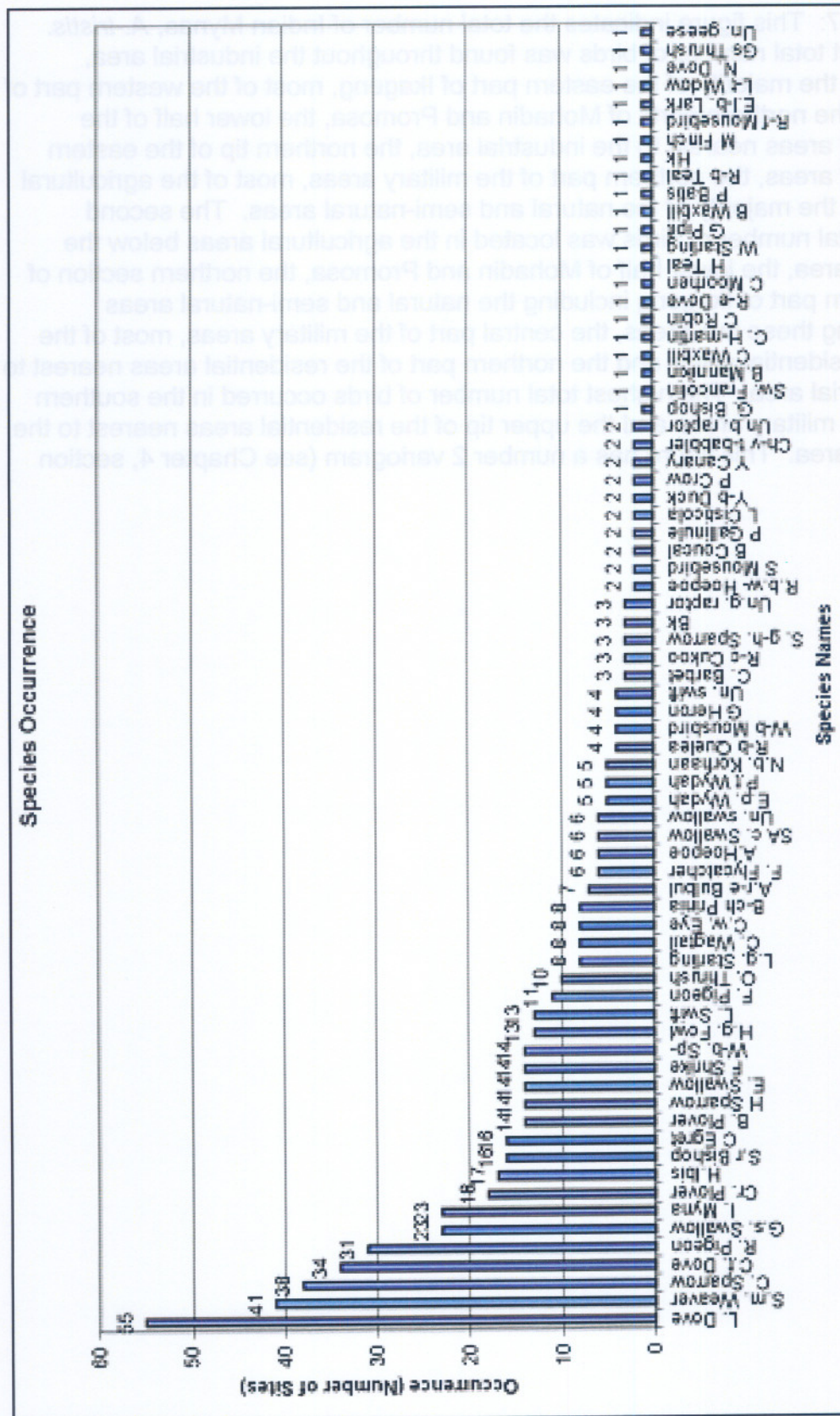


Figure 4.48: The number of sites each species occurred in

Figure 4.48: This figure indicates in how many of the sites, a bird species occurred. The greatest generalists appeared to be the Laughing Doves, *S. senegalensis*, as they were found in fifty-five of the fifty-six sites. The Southern Masked Weavers, *P. velatus* Cape Sparrows, *P. melanurus*, Cape Turtle Doves, *S. capicola* and Rock Pigeons, *C. guinea* also occurred in at least up to thirty or more of the sites. A very large number of the species identified occurred in ten sites or less, with species such the Namaqua Dove, *O. capensis*, Bronze Mannikin, *L. cucullata*, Swainson's Francolin, *P. swainsonii*, Groundscraper Thrush, *T. litsitsirupa* etc. found only in one of the fifty-six sites. Species such as the swallows, swifts, plovers, mynas etc. occurred in anything from eleven of the sites, up to twenty-three of the sites.





Figure 4.49: The mean number of species per biotope

Figure 4.49: This figure indicates the mean number of species that were observed. The greatest mean number of species was observed in parks, which represent the managed green space biotope. The residential areas had a mean number of twelve species and the natural and semi-natural areas a mean number of almost ten species. The lowest mean number of species occurred in the man-made water body biotope. The industrial area only had a slightly higher number of species than in the man-made water body biotope.



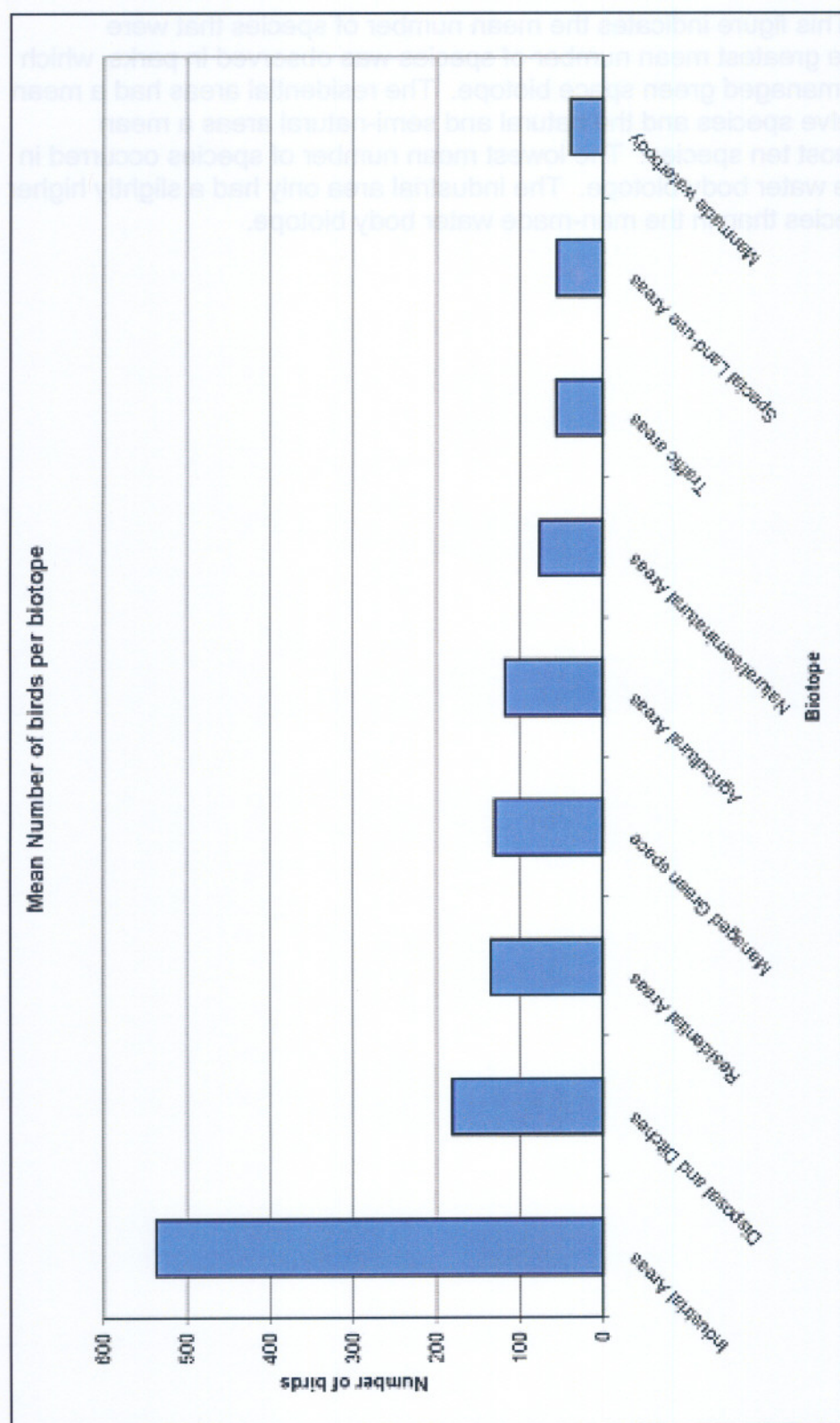


Figure 4.50: The mean number of birds per biotope

Figure 4.50: This figure indicates the mean number of birds that were observed in this study. In this figure, the industrial area had the greatest mean number of birds. (In Fig. 4.49, the industrial area had the second lowest number of mean species). The residential areas and agricultural areas both had just over a hundred mean numbers of birds, and the natural and semi-natural areas had less than a hundred mean number of birds. The lowest mean number of birds was located in the man-made water body biotope.



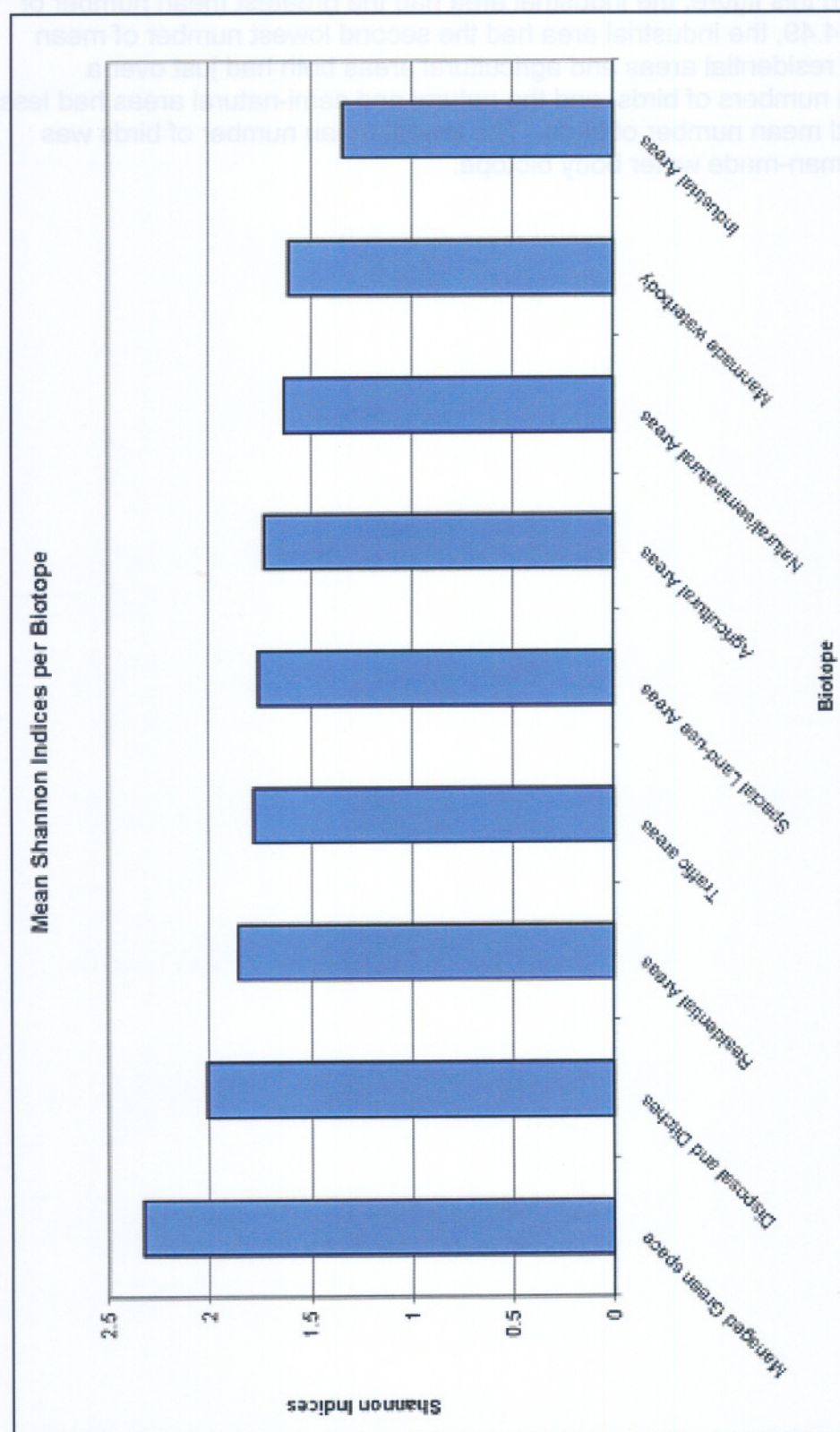


Figure 4.51: The Shannon index for birds per biotope

Figure 4.51: This figure indicates an index for the mean number of species per biotope. The Shannon index was used to obtain these results. The area (biotope) with the greatest diversity appeared to be the managed green space biotope, with the residential areas only having the third highest diversity. In Fig. 4.49, the managed green spaces also had the highest mean number of species, with the residential areas also having the third highest number of species in the same figure. In this figure, the industrial area had the lowest diversity present, but had the highest mean number of birds in Fig. 4.50. The agricultural and natural and semi-natural areas had the sixth and seventh highest diversity, however, in Fig. 4.49, the agricultural areas had the fourth highest mean number of species.

Chapter 5

Discussion and Conclusion

5.1 Discussion of results

As mentioned in Chapter 2, section 2.6, the hypothesis for this study stated that as a result of the mobility of birds, together with their ability to use multiple biotopes for different purposes (e.g. for nesting and feeding), urban bird communities or bird demography will show patterns different from vegetation and structure-based biotopes alone, and could therefore be considered as avitopes. As a reminder, in the same chapter, under section 2.7, the primary aim of this research, to address the hypothesis, was to determine the patterns of avian diversity in Potchefstroom. The secondary aims for this study included:

- Determine the bird species distribution in Potchefstroom using point counts
- Determine the distribution of feeding and nesting guilds in Potchefstroom
- Determine whether it is possible to identify urban avian indicators with this type of research
- To investigate, develop and define the concept of “active-habitat selectors” (AHS)
- To introduce, develop and define the concept of “avitopes”

When looking at the maps that have resulted from this study, the concept of “avitopes” has been considered for this study due to the mobility of birds, their patterns of demography, “active-habitat-selection” and due to the possibility that the distinction of species, guilds, etc. may more or less be constrained by biotopes (e.g. when looking at Fig. 4.16, granivores are not limited only to a single biotope, but can be found in more than one biotope). As mentioned in

Chapter 1, section 1.7, birds are considered to be “active-habitat-selectors” (AHS), and are thus not necessarily restricted to any single biotope.

According to various chapters in this study, it is possible to say that “avitopes” would stretch across various biotopes and not be constrained by any single biotope. For this reason, “avitopes” would differ from biotopes in terms of definition and location.

5.2 General patterns

5.2.1 Results of the total number of species

When looking at the presence and movement of the highest number of bird species throughout the study area (Fig. 4.1-Fig. 4.1.1), two patterns were observed. These patterns remained the same even with dove and pigeon species removed. One of the patterns spread from the military areas, through the residential areas and into the agricultural areas. The other pattern was found in the lower parts of Mohadin and Promosa, and in the natural and semi-natural areas just outside of this area. The greatest number of species is probably found in these areas as they contain food, water and nesting material. Even when looking at a series of each day (Fig. 4.8-Fig. 4.8.3), much the same pattern could be observed, however in some cases such as on day 2, the presence of species in Mohadin and Promosa, and natural and semi-natural areas was lower than on day 1 and even lower on day 3 and day 4. This could be attributed to weather (some of the days were overcast) or to the time of the morning when the observations were made.

5.2.2 Results of the total number of species for alternative sites

The figure obtained from using only the data of each alternative site (Fig. 4.2), did not indicate any information that correlated with any of the other results,

except for an increase of species from west to east. The option of using less sampling sites for this study is therefore insufficient in order to obtain detailed information of data, however, what can be concluded, is that by increasing the number of sampling points, a more detailed map of the bird distributions across the study area, could be obtained. Using only alternative sites thus cannot be used in order to derive "avitopes".

5.2.3 The results from various indices

The various indices used in this study indicated the diversity of the various areas in this study (Fig. 4.3-Fig. 4.6). The greatest diversity correlated with the patterns found in Fig. 4.1-Fig. 4.1.1 and Fig. 4.8-Fig. 4.8.3, which was where the greatest number of species occurred. All these indices have indicated the greatest diversity to occur primarily in the residential areas, the military areas, the agricultural areas and north-western parts of the natural and semi-natural areas west of Mohadin and Promosa (see Fig. 4.2.1 and Table 4.2.1), which sometimes include Mohadin and Promosa itself. It appears that these areas are able to provide adequate resources for various numbers of species. Three indices have been used to analyse diversity for this study, namely the Simpson index, the Margalef index and the Shannon index. Below I will present arguments regarding which of the three indices would be best suited to this study.

- According to Magurran (1988), the Simpson index is weighted towards the abundances of the most common species, rather than providing a measure of species richness i.e. it is less sensitive to species richness. The Simpson index does not appear to be a good indicator of diversity in this study, as the patterns found in this figure do not correlate with the patterns found in the other indices. The weightedness of the index towards the most common species (i.e. doves and pigeons) could thus be the reason for the patterns not correlating with any of the other patterns

obtained from the other indices. For this reason, the Simpson index thus appears not to be a good diversity indicator for this specific study.

- The Margalef index is simple but is an index that is sensitive to sample size. It also indicates diversity by making use of species richness. According to Magurran (1988), species richness alone is not as sensitive a measure of environmental disturbance as the distribution of species abundances. This index does, however, show a relatively good correlation with the observed patterns, especially if only diversity is the primary concern.
- The Shannon index is based on the proportional abundances of species and takes both species richness and evenness (i.e. abundances) into account (Magurran, 1988). According to Magurran (1988), diversity measures play an important part in environmental assessment and that diversity is a primary concern of conservationists. A study carried out had indicated that conservationists have something to gain by taking into account both the diversity/variety of species and their relative abundance. From the argumentation in Magurran (1988), there is evidence that information on species abundance patterns will improve conservation strategies or ecological assessments.

The Shannon index therefore appears to be the best index to have used in order to determine the diversity of the study area as it takes both the diversity as well as the abundances of the species into account, all of which was observed during this study. Intuitively the Shannon index also has the greatest correlation with what was observed during this study. I have therefore decided to concentrate on the Shannon index for the rest of this thesis.

5.2.4 Results of the total number of birds

When looking at the presence and movement of the greatest number of birds, they were located in the industrial area and spread into the residential area nearest to it (Fig. 4.10). A large number of birds was also found in the agricultural areas, however, this fluctuation was the result of a Red-billed Quelea, *Quelea quelea*, flock. When a series of each day was made (Fig. 4.11-Fig. 11.2), the greatest number of birds remained in the industrial area and the residential areas nearest to it over all four days. Doves and pigeons were greatest in number in this area and made up the enormous totals found in the various figures. Doves and pigeons are granivores and belong to any one of three types of nesting guilds, namely, tree nesters, structure nesters, or tree or structure nesters. One of the sampling areas was near the King Korn factory, which provided ample food sources and the industrial area also provides ample nesting sites for structure nesters and structure or tree nesters. Trees are present in the industrial area, however, with the residential area directly next to it, tree nesters are also provided with sufficient nesting sites with a nearby food source. As mentioned, the series of figures for each day (Fig. 4.11-Fig. 4.11.3) provides the same information, however, on day 3 there was a large peak in the agricultural areas, which was the result of Red-billed Quelea, *Q. quelea*.

5.2.5 Results of the total biomass for birds

When looking at total avian biomass (Fig. 4.13), the greatest biomass was located in the industrial area and spread into the residential area nearest to it. A lower total biomass pattern was found in Prozesky and the agricultural areas. Because of the greater number of larger birds in the industrial area, the results seem rather obvious. The agricultural areas and Prozesky, although these two areas do not have nearly the same high biomass as the industrial area, also have a few of the larger bird species (thus with a larger biomass as other species), but in lower numbers present, such as the Grey Heron, *Ardea cinerea*, Purple

Gallinule, *Porphyrio madagascariensis*, Cattle Egret, *Bubulcus ibis*, Yellow-billed Ducks, *Anas undulata* etc. When doves and pigeons were removed from the data set, the result was a very different figure. In this figure (Fig. 4.13.1), the greatest biomass was located in Prozesky and in the agricultural areas, with the industrial area having the lowest total biomass. As mentioned previously, these two areas now have the highest biomass due to the larger species present here. A series was also done for biomass over all four days and the pattern remained much the same (Fig. 4.14-Fig. 4.14.3). The industrial area continued to have the greatest biomass with lower totals in the agricultural areas and in Prozesky. Day 1 showed a much lower biomass for the latter two areas, than on any of the other three days, however, day 1 was overcast and slightly windy, which could explain the low presence of birds. In some of the figures, a low value for biomass was found in the natural and semi-natural areas (see Fig. 4.2.1 and Table 4.2.1). Most of the birds found in this area were smaller species, which were few and far between.

5.2.6 Results of the Indian Myna, *Acridotheres tristis*

The total number of Indian Mynas, *A. tristis*, was separated from the data set (Fig. 4.47) in order to determine their presence and movement throughout the study area. The greatest number of Indian Mynas occurred in the lower military areas and spread into the upper parts of the residential areas nearest to the industrial area and through most of the eastern residential areas (see Fig. 4.2.1 and Table 4.2.1). Although there appears to be very little Indian Mynas present, many were observed in other parts of the study area. However, the time of day i.e. when the observations were done, affected when and where these birds were identified.

5.2.7 Conclusion of general patterns

When looking at the general patterns resulting from the analysis of species, numbers of birds and the biomass of birds (Fig. 4.1–4.1.1, Fig. 4.7, Fig. 4.9, Fig. 4.9.1, Fig. 4.10, and Fig. 4.13), the greatest presence of species and their number of birds in Potchefstroom, would be found in the predominantly white residential areas and in the agricultural areas. The highest focal points for most of these analyses were found in these two types of areas. The reason(s) for this could possibly be the result of the urban areas providing sufficient nesting sites, as well as adequate foraging areas for various types of species, along with their various guilds. Further research is required, but it may also be possible that one area serves as a nesting site and the other, as a source of food and water.

5.3 Feeding Guilds

5.3.1 Results of the total number of granivorous species, total number of birds and total biomass

The greatest number of granivorous species was found in the agricultural areas, the eastern part of Ikageng (where the focal point occurred) and in some of the natural and semi-natural areas surrounding it and in the upper parts of the residential areas and most of the eastern residential areas (Fig. 4.15). Prozesky also had some of the highest totals for granivorous species. This part of Ikageng is located next to the industrial area and seems to be of a higher social and economic standard than the western part of Ikageng. Although not quantified, very few nests for these granivorous species were found in these two areas and most of the species were observed while flying over in the direction of the industrial area or in the direction of Prozesky. It is thus possible that although the greatest number of species was found here, only a few of the species actually occur or nest in these two areas and were only passing through towards the industrial area and residential areas where more sufficient sources were

available. In the agricultural areas, it would be expected to find a high presence of granivores as these areas often consist of grain or various other crop fields, they have an ample supply of water due to irrigation used in farming and the area in turn also provides plenty of nesting sites in trees, shrubs etc. Prozesky on the other hand is a wetland near to the agricultural areas and provides nesting sites for reed or grass nesters, which include species such as the Southern Red Bishop, *E. orix* and the Golden Bishop, *E. afer*. The residential areas are also able to provide ample nesting sites through trees, structures and shrubs, and have greater available food sources around them (e.g. the industrial area). Humans also often provide food in certain forms for these species within the residential areas themselves. When excluding the dove and pigeon species which are also granivores (Fig. 4.15.1), almost the same pattern was observed, however, the peak shifted towards the agricultural areas and high numbers of species were again found in the eastern part of Ikageng, spreading into the residential areas and Prozesky. Doves and pigeons seem to have made up the greater number of granivorous species found in this part of Ikageng, which could explain the shifting of the peak to the agricultural areas. As mentioned before, the agricultural areas provide a sufficient food and water supply, as well as nesting sites, and Prozesky also provides nesting sites for some granivorous species and has a close enough food source. The residential areas had a smaller area covered by granivores when doves and pigeons were removed, also indicating that these species tend to make up a great deal of the species found in the residential areas. However, now the presence and movement of other granivorous species can be observed. Some of the other granivorous species found in Ikageng, the agricultural areas, Prozesky and the residential areas (see Fig. 4.2.1 and Table 4.2.1) include the Southern Masked Weaver, *P. velatus*, House Sparrows, *P. domesticus*, Cape Sparrows, *P. melanurus*, Bronze Mannikin, *L. cucullata*, White-Browed Sparrow-Weaver, *P. mahali* etc.

When looking at where the greatest number of granivores was found (Fig. 4.16), it is not surprising that the highest numbers were again found in the industrial

area, spreading into the residential area and a lower peak was found in the agricultural areas. Doves and pigeons occurred in their hundreds in the industrial area probably due to the presence of the corn mill and ample nesting sites. Other granivorous birds also occurred here but in much lower numbers. The lower peak found in the agricultural areas could be explained by the fact that a Red-billed Quelea, *Q. quelea* swarm was present on one of the sampling days. When dove and pigeon numbers were excluded from the data set (Fig. 4.16.1), the greatest number of birds was found in the agricultural areas and the lower peak in the industrial area. The occurrence in the industrial area could again be explained by the fact that most of the granivores in the area are doves and pigeons, thus the exclusion of these species causes a drop in bird numbers (see Fig. 4.2.1 and Table 4.2.1). The fact that the agricultural areas now have the highest total number of granivores could again be explained due to the presence of the quelea swarm.

The highest total biomass of the granivores (Fig. 4.17) was found in the industrial area, which is self-explanatory. However, when the biomass of the doves and pigeons was excluded from the data set (Fig. 4.17.1), a rather drastic difference was found in the pattern. The industrial area now had the lowest total biomass due to the absence of the biomass of the larger species, but the natural and semi-natural areas now had the greatest total biomass. This could be the result of the presence of Helmeted Guinea Fowl, *N. meleagris*, which were present in the natural and semi-natural areas.

5.3.2 Results of the total number of carnivorous species and number of birds

The greatest number of carnivorous species (Fig. 4.19), was found in the upper natural and semi-natural areas, the lower agricultural areas spreading into Prozesky, and a smaller number in the military areas (see Fig. 4.2.1 and Table 4.2.1). Major patterns of low numbers were found throughout the central section

of the study area. These carnivores are all unidentified raptors and were thus found on the outskirts of the urban areas, as it is uncommon to find raptors present in actual urban areas when using the survey method, as in this study. The total number of birds for carnivores (raptors) found was few, but the majority was found in the upper natural and semi-natural areas. This area has some of the least human disturbance occurring within it, and also has a sufficient water supply and food source consisting of small mammals. As these raptors were not identified, data for determining the biomass of this feeding guild was not available.

5.3.3 Results of the total number of scavenging birds

Very little data was obtained for the scavengers, as only one species was found, namely the Pied Crow, *C. albus*. A figure to indicate the total number of species that was found is unavailable as the data is too little for the programme to produce a result; the same was true for the total biomass. A figure (Fig. 4.21) indicating the total number of birds that were scavengers was obtained and shows that the highest number of birds was found in the lower parts of the military areas spreading into the natural and semi-natural area. A major absence of scavengers occurred throughout the rest of the study area.

5.3.4 Results of the total number of omnivorous species, total number of birds and total biomass

The highest number of omnivorous species (Fig. 4.22) was found in the agricultural areas spreading into Prozesky. Slightly lower numbers of species were found in the residential areas, the military areas and in the natural and semi-natural areas just east of Mohadin and Promosa. Some of these species include Indian Mynas, *A. tristis*, Common Moorhen, *G. chloropus*, Glossy Starling, *L. nitens*, etc. These areas probably provide adequate resources for omnivorous species i.e. nesting sites and food and water supplies. A major

pattern of low numbers of omnivorous species was found in the upper and lower western half of the study area, the industrial area, the upper parts of the military areas, and in the lower tip of the residential areas nearest to the industrial area. Reasons for these low numbers, especially in some parts of the residential areas and in the industrial area, need to be investigated.

The highest number of omnivorous birds (Fig. 4.23) formed a focal point almost in the centre of the military areas, moving down into the eastern residential areas. The northern section of the residential areas nearest to the industrial area seems to act as a corridor between these two areas. Major patterns of low numbers of birds occurred throughout almost all of the rest of the study area. Although the figure only shows the presence of omnivores to occur in these two areas, omnivores were observed almost throughout the rest of the study area when not observing for study purposes.

The highest total omnivore biomass (Fig. 4.24) was found in the central parts of the military areas, moving down into the eastern residential areas, which coincides with Fig. 4.23. Another focal point, however, was also found in the agricultural areas moving into Prozesky. The first focal point does not need much explanation, as the central military areas are where the greatest number of birds occurred. The second focal point, which mostly occurs in Prozesky, did not have many birds present in Fig. 4.23, however, this could be explained due to the presence of much larger omnivores, such as the Common Moorhen, *G. chloropus*, the Purple Gallinule, *P. madagascariensis* etc., which are much heavier than the omnivores normally found in the urban areas. Major patterns of low values of biomass were found primarily in the western half and some of the central parts of the study area.

5.3.5 Results of the total number of insectivorous species, total number of birds and total biomass

The highest total number of species for this feeding guild was found at two focal points, located in the southern tip of the eastern residential areas and just outside the topmost part of these residential areas (Fig. 4.25). It is possible that the central parts of the eastern residential serve as a corridor between these two points. Three smaller focal points are also visible and occurred in the central western part of the military areas, the agricultural areas and in the natural and semi-natural areas just west of the upper section of the western part of Ikageng (see Fig. 4.2.1 and Table 4.2.1). The reason as to why insectivores have been found primarily in these areas need to be further researched. Major patterns of low numbers of insectivores occurred in some parts of the natural and semi-natural areas, the lower parts of Ikageng, the industrial area, and in a small part of Prozesky.

The highest total number of insectivorous birds was found at three focal points, which were found in the southern tip of the eastern residential areas, in the natural and semi-natural areas between the two parts of Ikageng and in the natural and semi-natural areas just west of the southern tip of the western part of Ikageng (Fig. 4.26). Major patterns of low numbers of birds were located in larger parts of the natural and semi-natural area, the agricultural areas, a small part of Prozesky, the industrial area, some of the residential areas nearest to it and in some parts of Ikageng. Why so few species and such a large number of birds are located in these parts of the natural and semi-natural areas will also need to be further investigated.

When looking at the total biomass (Fig. 4.27), a focal point for the highest biomass occurred in the southern most tip of the eastern residential areas and included some of the upper parts of Prozesky. A smaller biomass focal point was found in the natural and semi-natural areas between the two parts of Ikageng.

Major patterns of low values of biomass occurred almost throughout the entire northern parts of the study area, as well as most of the central parts. However, low values were also found in the agricultural areas and in Ikageng. As to why biomass is so low in so much of the study area, needs to be further investigated.

5.3.6 Results of the total number of frugivores

The highest total number of frugivores (Fig. 4.28) occurred in a small part of the far north-western part of the natural and semi-natural areas and in the military areas. It is possible that these two areas may be able to supply adequate nesting sites and water; however, it is possible that these birds forage in other areas. Further research is required in order to determine their presence in these areas.

The data collected was too little in order to be able to produce maps of the total number of species and the total biomass of this feeding guild.

5.3.7 Results of the total number of herbivores

The highest number of herbivores (Fig. 4.29) was found in Prozesky. The herbivorous species observed during this study include Yellow-billed Ducks, *A. undulata*, Red-billed Teal, *A. erythrorhyncha*, etc. Prozesky is a wetland, thus explaining the presence of such herbivores in this area. Prozesky provides adequate nesting sites, as well as foraging sites for these herbivores. Major patterns of low numbers were located throughout the rest of the study area. Herbivorous species were also observed in other parts of the study area; however, these observations were not for study purposes.

The data collected for this feeding guild was also too little in order to be able to produce figures/maps of the total number of species and the total biomass of this feeding guild.

5.4 Nesting Guilds

5.4.1 Results of the total number of tree nesting species, total number of birds and total biomass

The greatest number of tree nesting species was found in the agricultural areas below the industrial area, with slightly lower peaks found in Prozesky, the military areas and the upper parts of the eastern residential areas (Fig. 4.30). Most of the tree nesting species included the granivores, with only a few species from any other feeding guild. The major focal point found in the agricultural areas could thus be the result of granivorous species that are also tree nesters, being present in the agricultural areas. When looking at the location of the granivorous species (Fig. 4.15), a focal point was located in the agricultural areas. Although the agricultural area provides a sufficient food supply, nesting sites did not seem to be abundant in these areas, as few nests were observed. However, this part of the agricultural areas is close to the residential areas, which is where the majority of these species probably nest and only come to feed down in the agricultural areas. Most of the tree nesting species observed in the military areas were in flight, however, nests were observed from time to time. It is possible that many of these species forage in other areas, but may nest in some parts of the military areas. The species found in the upper parts of the residential areas were possibly the result of the sufficient nesting sites being available, as well as a sufficient food and water supply being present. Rather low numbers of tree nesting species were found throughout the western half of the study area, as well as the central parts of the study area, including the central parts of the residential areas. This could be due to little food supply in Ikageng and the natural and semi-natural areas. The reason for the lack of species in the central parts of the residential areas could possibly be the result of time constraints (ie. the fact that only a limited amount of time was used per survey and that only morning observations were done), but will have to be investigated further in another study. The industrial area has few trees and is often busy with commuters and other

forms of human disturbances. So although food supply may be abundant for many of the tree nesting species, nesting sites may be insufficient in this area. When doves were excluded from the data set (Fig. 4.30.1), the greatest number of species, were again found in the agricultural areas, with the focus point nearer to the residential areas. However, numbers also became visible in the lower, more western parts of the agricultural areas.

A slightly lower number of species was again found in the military areas and the upper eastern residential areas. The highest focal point in the agricultural areas could again be explained by sufficient food and water supply, with more nesting sites available in the nearby residential areas. Even with doves removed, the military areas still had a high number of species, which could still possibly be the result of foraging in other areas, whilst some species have found sufficient nesting sites in these areas. The residential areas in turn, again are able to provide sufficient nesting sites, food and water. The low numbers of tree nesters were again found throughout the western half of the study area, however, the low number of species in the central parts of the study area, including the central parts of the residential areas, appeared to be much greater. A possible reason for this could be that dove species had made up the greater number of tree nesting species found in those areas.

The greatest number of tree nesting birds was located in the agricultural areas, with slightly lower numbers found in the industrial area and the upper parts of the residential areas nearest to it (Fig. 4.31). Many of the tree nesting birds found in the agricultural areas, could be explained by the presence of Red-billed Quelea, *Q. quelea*, which are also tree nesters and often occur in flocks. The high numbers also found in the industrial area and the residential areas nearest to it, could be explained by the presence of large numbers of tree nesting doves, which most likely, do not nest in the industrial area, but forage there. Most of the tree nesters are likely to forage in the industrial area and nest in the nearby residential areas. Major patterns of low numbers of tree nesting birds were again

found in the far western parts of the study area, however, most of the northern parts of the study area now had low numbers of birds. In turn, the central parts of the study area now contained some of the highest numbers of birds. These low numbers could again be the result of a lack of suitable nesting sites, as well as insufficient food and water supplies. When dove numbers were removed from the data set, the highest number of birds was located in the agricultural areas (Fig. 4.31.1). This could again be the result of the presence of the Red-billed Quelea, *Q. quelea*. The lowest number of birds, however, was now found throughout the northern half of the study area, a small part of the lower eastern half of the study area and the western half of the study area. This could be explained due to the exclusion of doves from the data set, i.e. doves make up the majority of the tree nester numbers.

The greatest tree nesting biomass was found in the southern tip of the eastern residential areas and the areas just outside the residential areas nearest to the industrial area, with a slightly lower biomass located in the agricultural areas, the industrial area and the residential areas nearest to it (Fig. 4.32). The biomass in the industrial area and the residential area nearest to it, as well as the agricultural areas, could be explained due to the presence of either doves (as in the case of the industrial area and residential area), or very large numbers of birds included with doves (as in the case of the agricultural areas). The two focal points found in the eastern residential areas and the one just below it, will need to be investigated further in order to determine the high biomass found in these two areas.

5.4.2 Results of the total number of ground nesting species, total number of birds and total biomass

The highest number of ground nesting species was found to the east of Prozesky, with slightly lower numbers of species found in the western central lower parts of the natural and semi-natural areas (Fig. 4.33). The majority of the

ground nesters consisted of Helmeted Guinea Fowl, *N. meleagris*, in the non-residential areas, and in some cases, the plovers. Just outside of Prozesky, more agricultural areas can be found, where Helmeted Guinea Fowl, were abundant. The guinea fowl were also abundant in the natural and semi-natural areas. In the areas just outside Prozesky, plovers were also observed. Major patterns of low numbers were found in the industrial area, most of Ikageng, some of the agricultural areas and in some of the northern parts of the study area. In the case of the industrial area, suitable nesting sites for ground nesters are unavailable or possibly of low quality. In the northern natural and semi-natural areas, food and water supplies may be too few. In the case of the agricultural areas, further investigation is required to determine the occurrence of low numbers of ground nesters.

The highest number of ground nesters was located again just outside of Prozesky (Fig. 4.34). This area could possibly provide ample nesting locations, as well as be a sufficient foraging area. Major low numbers were now located almost throughout the rest of the study area, excluding very low numbers found in the western parts of the study area in the natural and semi-natural areas. This could possibly be the result of unsuitable nesting sites or due to a lack of sufficient food and water supplies. Another factor could be the time constraint, which may not have been sufficient in order to observe more ground nesters.

When looking at the total biomass for ground nesters, the highest biomass was found in the western parts of the natural and semi-natural areas, with a slightly lower biomass located outside Prozesky (Fig. 4.35). This high biomass in the natural and semi-natural areas could be the result of larger numbers of guinea fowl present in these areas, with lower numbers along with plovers, occurring just outside of Prozesky. The lowest biomass was also found again almost throughout the rest of the study area.

5.4.3 Results for the total number of structure or tree nesting species, total number of birds and total biomass

The highest number of structure or tree nesting species formed a focal point, which included the south-eastern tip of the military areas, the north-eastern corner of the residential areas nearest to the industrial area and a small part of the eastern residential areas (Fig. 4.36). Another focal point included the north-eastern most tip of western Ikageng, the south-western tip of the eastern part of Ikageng and the south-eastern tip of Mohadin and Promosa. These species are able to utilise both trees and structures for nesting. The first focal point provides sufficient nesting sites, as well as water, due to the river flowing between the three areas mentioned. Food may also be sufficient as residents may provide certain foods, but otherwise, the industrial area, which has an ample supply of granivorous food, is nearby. The second focal point also has sufficient nesting sites available, as well as water. Food in this case, may be provided by the industrial area also; however, the agricultural areas are also nearby. The industrial area itself appears to act as a corridor between these two focal points. A pattern of low numbers of these species, were found in the upper parts of the natural and semi-natural areas, and in small parts of the agricultural areas, including those east of Prozesky. These areas may not provide sufficient nesting or foraging sites. With the Rock Pigeons, *C. guinea* removed from the data, the map did not alter much (Fig. 4.36.1). The highest number of species was still primarily located at the same two focal points, however, a peak was located in the areas just east of the eastern residential areas. Slightly lower numbers of species were found at the two focal points, with these numbers spreading further into both parts of the residential areas at the first focal point and into Mohadin and Promosa and the eastern part of Ikageng at the second focal point. The north-western part of the military areas also had the same number of species found at these two focal points. With the pigeons removed, the industrial area no longer appeared to act as a corridor. Instead, the natural and semi-natural areas just north of the industrial area now seemed to act as a corridor for other species

such as the sparrows. It appears that the pigeons either make use of the industrial area as a corridor to move between the western and eastern halves of the study area, or that pigeons prefer the first focal point and only make use of the industrial area for foraging. More investigation is required in order to determine whether or not these assumptions may be true.

The highest number of structure or tree nesters (Fig. 4.37) was found at a focal point surrounded by the industrial area, the lower parts of the military areas and the upper western part of the residential areas nearest to the industrial area. The high number of birds found here could be the result of sufficient nesting sites provided either by trees or the large number of structures present, as well as a sufficient food supply in the industrial area and sufficient water supply in the residential area. Excluding the central part of the study area, the majority of the rest of the study area had major low numbers of birds. This could either be the result of insufficient nesting sites or nearby foraging areas. When Rock Pigeons, *C. guinea*, were removed from the data set (Fig. 4.37.1), the figure remained practically the same as Fig. 4.37. The same focal point was found in this figure as in Fig. 4.37, with the major absences again occurring in most of the study area, excluding the central parts. The absence of Rock Pigeons, *C. guinea*, did not seem to have a great impact on the distribution pattern, with the primary difference being a lower number of birds at the focal point. The reason for this could be the possibility that only minor numbers of pigeons were observed, or that other structure or tree nesting birds were present in such large numbers, that only a minor difference in numbers occurs when pigeons were excluded. Further investigation is, however, required in order to determine why no major difference has occurred between these two figures.

When looking at the total biomass (Fig. 4.38), the pattern found in this figure shows some similarity to Fig. 4.36. Two focal points were also found in this figure as in Fig. 4.36, however, they did not occur in the same areas. The first focal point was surrounded by the north-eastern corner of the industrial area, the

southern parts of the military areas and the north-western part of the residential areas nearest to the industrial area (which is the same as the focal point found in Fig. 4.37 and Fig. 4.37.1). The second focal point was located in the northern section of the eastern part of Ikageng. A slightly lower biomass was found in Mohadin and Promosa (see Fig. 4.2.1 and Table 4.2.1). The industrial area appeared to serve as a corridor between these two focal points, and the natural and semi-natural area between the eastern part of Ikageng and Mohadin and Promosa, seems to act as a corridor between these two areas. In Fig. 4.36, this part of the natural and semi-natural area was a focal point for the highest number of species.

5.4.4 Results of the total number of structure nesting species, total number of birds and total biomass

The highest total number of structure nesting species (Fig. 4.39) was located in the lower and central parts of the eastern residential areas, with slightly lower numbers of species found in the upper eastern section of the residential areas nearest to the industrial area. The structure nesters species consists of swallows, swifts, martins and Feral Pigeons, *C. livia*. Although many structures can be found throughout the rest of the urbanised areas, the swallows and martins make up the greater number of species and appear to prefer the eastern residential areas. This could be due to fewer disturbances in this area, a sufficient food supply and a nearby water source. Major patterns of low numbers of species were found in the lower agricultural areas, the north-western half of the natural and semi-natural areas and in Mohadin and Promosa (see Fig. 4.2.1 and Table 4.2.1). This could be due to a lack of nesting sites or insufficient foraging suitability. Another reason could again be the timing of the observation.

The highest total number of birds for this nesting guild (Fig. 4.40) was located at a focal point surrounded by the industrial area, the military areas and the residential areas nearest to the industrial area (see Fig. 4.2.1 and Table 4.2.1).

(This focal point is the same as that found in Fig. 4.37, i.e. total number of species for structure or tree nesters). The high numbers for structure nesters primarily consist of the Feral Pigeons, *C. livia*, which were abundant in the industrial area. The pigeons may thus not necessarily nest in the industrial area, but definitely make use of the food availability found in the industrial area. Water is also sufficient, with plenty of nesting sites available in the residential areas. The majority of the rest of the study area had major patterns of absences of birds, which could again possibly be due to a lack of suitable nesting sites or foraging areas. When the pigeon numbers were removed from the data set, the map changed drastically (Fig. 4.40.1). The greatest number of birds was now located in the natural and semi-natural areas just west of the southern most tip of the western part of Ikageng and half those numbers in-between the two parts of Ikageng (see Fig. 4.2.1 and Table 4.2.1), the upper parts of the military areas, the central northern most part of the natural and semi-natural areas and just outside the eastern residential areas. All these focal points consist of species such as the Little Swift, *A. affinis*, Greater Striped Swallows, *H. cucullata*, European Swallows, *H. rustica*, South African Cliff Swallows, *H. spilodera*, etc. The reason(s) as to why these structure nesters were found so abundantly in some of these areas will need to be further researched.

The highest total biomass for structure nesters was found in the industrial area (Fig. 4.41). This is due to the presence of a large number of Feral Pigeons, *C. livia*, within the industrial area, which in turn outweigh the much smaller species of swifts, swallows etc. Major patterns of low numbers of biomass were again found throughout the rest of the majority of the study area. This could maybe be attributed to the larger biomass of the pigeons preventing the much smaller biomass totals of the smaller species of structure nesters from showing up on the map.

5.4.5 Results of the total number of shrub or tree nesting species, total number of birds and total biomass

The highest number of shrub or tree nesting species (Fig. 4.42) was found at three different primary focal points. The first point was found in the lower parts of the military areas, the second in the upper part of the eastern residential areas and the third in the southern tip of the eastern residential areas (see Fig. 4.2.1 and Table 4.2.1). A slightly smaller number of species was located in the lower region of the eastern part of Ikageng. The primary focal points appear to be connected (i.e. a corridor seems to be present). The central part of the eastern residential areas appears to act as a corridor between the second and third focal points, with the upper eastern corner of the residential areas nearest to the industrial area, the lower eastern region of the military areas and the upper part of the eastern residential areas serving as a possible corridor between the first and second focal points. These areas possibly provide adequate nesting sites for these species as well as providing sufficient resources. Major low numbers of species were found throughout the western half of the residential areas nearest to the industrial area, Prozesky, the industrial area, most of Ikageng, the upper half of the military areas, the majority of the agricultural areas and most of the natural and semi-natural areas. Many of these areas lack adequate nesting sites for these species and may thus be a possible reason for their low occurrence in these areas.

The highest number of shrub or tree nesting birds (Fig. 4.43) was found in the southern end of the eastern residential areas, with slightly lower numbers found in a small part of the lower eastern section of the residential areas nearest to the industrial area (see Fig. 4.2.1 and Table 4.2.1). This is probably due to the availability of adequate nesting sites, as well as sufficient foraging areas. Patterns of low number of birds were found throughout the rest of the central and western half of the study area, as well as the upper northern and lower southern parts of the study area. The reason for not finding shrub or tree nesters in any

other areas may thus be due to the time (20 minutes per survey) that observations were done.

The highest total biomass for this nesting guild was located in the areas just outside of the central part of the eastern residential areas, with only a slightly lower biomass found in the southern tip of the eastern residential areas (Fig. 4.44). The slightly lower biomass found in the eastern residential areas coincides with the location of the highest number of birds found in Fig. 4.43. Further investigation is required in order to determine why the highest total biomass was located outside of the eastern residential area.

5.4.6 Results of the total number of shrub nesting species and total number of birds

The highest number of shrub nesting species was found at four different focal points (Fig. 4.45). The first focal point was located in the lower agricultural areas. The other three points were found in the natural and semi-natural areas, one (second focal point) just west of Mohadin and Promosa, one (third focal point) north of Mohadin and Promosa and one (fourth focal point) directly east of the third focal point. The natural and semi-natural areas and agricultural areas have probably provided sufficient shrubs for nesting sites, as well as sufficient foraging sites. However, some of these species were observed during flight and may just have been "passing through". Patterns of low numbers of species stretched from the south-western tip of the study area, moving north-easterly through the central section and ending in the north-eastern corner of the study area. The south-eastern section of the study area also had an absence of species. The reason(s) as to why this central section of the study area contained no shrub nesters would need to be investigated; however, the time observations were made may possibly also have had an effect on the data.

The highest total number of birds for this nesting guild were found in the agricultural areas with lower numbers found just west of Mohadin and Promosa (Fig. 4.46). These two areas appear to provide adequate resources for shrub nesters. Patterns of low numbers of birds were also found throughout the central part of the study area, stretching from west to east. The majority of the natural and semi-natural areas and the agricultural areas also had low numbers of birds. This could possibly again be due to the time of the observations, however, further research is required.

The data obtained for this nesting guild was too little in order to be able to produce a map of the total biomass for shrub nesters.

5.5 Analysis of mean species occurrence, mean number of species, mean number of birds and mean diversity

When looking at where the mean number of species had the highest occurrence (Fig. 4.48), it was found that the Laughing Dove, *S. senegalensis*, had the greatest occurrence as this species was found in all the sites, save one. These doves are generalists and suitable habitats appear to be available throughout the study area. The weavers, sparrows, other dove species and some of the pigeon species had the second highest occurrence, with some of these species occurring in up to at least thirty of the fifty-six sites. These species are also good generalists and are able to utilise most of the resources available in the urban area. Species such as the swallows, plovers, swifts and Indian Mynas, *A. tritis* had the second lowest occurrence, as they only occurred in eleven or more sites, but with a maximum occurrence in twenty-three sites. In the case of the swallows, plovers and swifts, it is possible that many of the sites do not provide sufficient nesting or foraging resources, however, in the case of the Indian Myna, it is possible that they occur in many more of the sites than is indicated in Fig. 4.48. The reason for this being that many of these birds were observed in other areas on various occasions when observations for this study were not being

carried out. Species such as the Namaqua Dove, *O. capensis*, Swainson's Francolin, *P. swainsonii* and the Groundscraper Thrush, *T. litsitsirupa*, were found in very few sites throughout the study area. This could be due to a lack of sufficient resources such as nesting sites or foraging sites, however, further research is required in order to determine their absence in other areas.

When looking at the mean number of species (Fig. 4.49) in the various areas (biotopes), the highest number of species occurred in the managed green space areas (biotopes). These areas often have a sufficient water supply, due to fountains and in some cases, where people picnic, certain foods are made available. Trees and surrounding structures also provide nesting sites for certain species. The residential areas had the third highest mean number of species, which could also be the result of sufficient resources being available to certain species. The natural and semi-natural areas had slightly lower numbers of species, with the industrial area having the second lowest and the man-made water body areas having the least mean number of species. These areas probably do not provide sufficient forms of resources.

The highest mean number of birds occurred in the industrial area (Fig. 4.50). This area had close to six hundred birds that were observed, however, it is very possible that many more birds are present. The industrial area seems to serve as a foraging area, as the grain mills present here provide ample foraging opportunities. The residential area had the third highest mean number of birds present and the agricultural areas the sixth highest mean number of birds present. The residential areas often provide sufficient nesting sites and water, and in some cases sufficient food, however, it is possible that the residential areas are primarily used as nesting sites and the agricultural areas as foraging sites. Further research is required in order to determine if this relationship between these two areas exists. The natural and semi-natural areas had the third lowest mean number of birds and the man-made water body had the lowest mean number of birds present. These two areas appear to provide little

resources that birds can use, especially in the case of the man-made water body area, as most of the birds observed here were in flight.

When using the mean number of species to produce a diversity index (Fig. 4.51), the results indicated that the managed green space had the greatest diversity. This area also had the highest mean number of species in Fig. 4.19. This area could thus obviously provide sufficient resources that birds are able to utilise. The residential areas had the third highest diversity present and also had the third highest mean number of species in Fig. 4.19. The residential areas seem to provide sufficient resources that are able to support a relatively large number of birds. The agricultural areas and the natural and semi-natural areas had a relatively low diversity. Even though the agricultural areas can in some cases support a large number of birds (e.g. Redbilled Quelea, *Q. quelea*), it seems that not a large variety of species were present here. The industrial area had the lowest diversity present. This area, although it provides a large food source for granivores, does not provide many other forms of resources.

It is important to note that during the discussion of the data, some aspects were not investigated during the study as this study was originally intended to determine avian distribution patterns. The observations made at each location were also constrained by time, i.e. only mornings were used for monitoring birds, thus in some cases, the figures/maps may not indicate the presence of certain species or guilds in some areas. However, where these species or guilds were observed during alternative times and were not indicated on the figures/maps, they have been mentioned at the appropriate figures/maps.

Due to the observations of species or guilds that did not appear on the figures/maps, it is obvious that more sites are needed for this type of research in such a large study area and that the amount of time and when (e.g. only morning

counts) the observations are made, could possibly constrain the accuracy/finer details of the distribution of birds. By increasing the number of sites and prolonging the observation time, it is possible that more accurate/detailed information could be obtained from this type of research.

5.6 Conclusion

5.6.1 Objectives 1 & 2: The distribution of bird species, feeding guilds and nesting guilds

As has been previously mentioned in Chapter 1, section 1.6, according to Hostetler (1999), the distribution and abundance of urban birds are affected, amongst others, by various socio-economic factors. It has also been reported that species richness usually decreases, but avian biomass increases with urbanisation (Crooks *et al*, 2004). Under European conditions, according to Jokimäki *et al* (2002), distribution patterns in natural bird communities differ from those found in urban bird communities as urbanisation can lead to uniformity in urban communities. It has also been found that the number of omnivores, granivores and exotic bird species increase with increasing urbanisation, however, the insectivores and native bird species in turn decrease (Stiles, 2002). As this type of study I have carried out is not directly comparable to other studies, this statement cannot be confirmed adequately as too little information for these types of studies exists in South Africa.

It has also been found that the number of omnivores, granivores and exotic bird species increase with increasing urbanisation, however, the insectivores and native bird species in turn decrease (Stiles, 2002).

When looking at species distribution in this study (Fig. 4.1 – Fig. 4.1.1), species were most abundant in the agricultural areas, the eastern residential areas and the military areas. The socio-economic factors affecting the abundance and

distribution of all the species need to be further researched. When looking at the total biomass for this study (Fig. 4.13), biomass is highest in the industrial area, which is probably the most highly urbanised site in the study area. It can thus be agreed with what Crooks *et al* (2004) have reported. The results for species richness (Fig. 4.4 and Fig. 4.6) are also similar to what Crooks *et al* (2004), have stated, as the greatest species richness occurred in the less highly urbanised areas and was lowest in the more highly urbanised (industrial) areas. The lower half of the western part of Ikageng also indicated low species richness even though this is not a highly urbanised area. However, it is possible that conditions in this area are highly unsuitable for bird species due to various reasons such as nesting availability, resource availability, density of people etc.

When looking at the results for granivores, the majority of the species, and more so their numbers, are found primarily in the urbanised areas, with some present in the agricultural areas. However, this could possibly be put down to the fact that the agricultural areas are primarily a foraging area. The high numbers of granivores found in the urban area itself are also congruent with what Stiles (2002) has found. In the case of omnivores (Fig. 4.22 – Fig. 4.24), the highest numbers were found in the military areas and included only a small part of the very top section of the residential areas. The military areas are not highly urbanised areas. However, it is possible that the reason for their low occurrence in the more urbanised areas was due to the insufficient observation time, since omnivores were observed in many of the more urban areas whilst not sampling in those areas. According to Jokimäki *et al* (2002), omnivores and granivores are superior competitors when compared to other species, as they are better able to exploit urban food resources.

In the case of the insectivores, the majority of them was located outside of the more urbanised areas (Fig. 4.25 – Fig. 4.27), however, a focal point did occur in the very southern tip of the eastern residential areas. It is possible that they nest in this part of the residential areas but forage in the nearby agricultural areas.

The findings in this study for insectivores, are however primarily congruent with the statement made by Stiles (2002).

5.6.2 Objective 3: Birds as indicators

Indicators are useful for various reasons, such as increasing accountability and they can aid in ensuring movement towards a common goal. Indicators can also be used for providing feedbacks, improved implementation, as well as improving the chances of successful adaptation (DEAT, 2002).

Birds are recognised as good indicators of environmental change (Chapter 1, section 1.7) due to a relatively large pool of interested data collectors that exist, birds are easy to survey, birds can indicate the condition of a landscape and the public often takes notice of birds. According to U.S. EPA (2002), birds are able to directly indicate the condition of a landscape, as they are collectively sensitive both directly and indirectly to various environmental influences.

It could be possible to identify indicators with this type of research; however, I would suggest a much more detailed study. Rather than only looking at the distribution of the bird species found in an urban area, many more aspects will need to be considered in order to identify indicators (see section 5.7).

5.6.3 Objective 4: The “active-habitat-selectors” (AHS) concept

As mentioned in Chapter 2, section 2.4, based on vegetation, bird species are selective about those they inhabit (Seoane et al, 2004). According to Drickamer *et al* (2002), factors that affect the choice of a habitat could be best understood by determining the reasons why animals are absent from a particular place. Animal species absence could be the result of an inability to disperse (although this is probably not often the case in birds), species may be unable to colonise an otherwise suitable area due to behavioural responses to specific habitat features,

the presence of other factors such as predators, competitors, disease etc., and species distribution could be restricted by both physical and chemical factors, as well as behaviour patterns.

The ideal distribution theory (IDF), has often been used to investigate habitat selection when fitness payoffs are frequency dependent. However, many researchers have not taken into account the possibility that individuals may differ in their ability to compete for resources and in their susceptibility to predators (Grand *et al*, 1999). According to Leturque *et al* (2002), IDF and balanced dispersal do not occur when dispersal is costly. For birds in a small city such as Potchefstroom however, the cost may be small enough.

According to Jokimäki (2000), few studies have addressed the consistency of variability in bird communities across different spatial scales. It has been suggested that population sinks and sources can be distinguished in urban bird populations. These sinks and sources can only be reliably distinguished by demographic parameters. However, they do indicate that most of the territories found in good quality habitats are occupied annually, as a result of high reproductive success, which in turn results in relatively low variability in breeding population densities (Jokimäki, 2000). It could thus be considered that birds select those habitats that are better able to support high reproductive success and fitness.

As previously mentioned in Chapter 1, section 1.7 and Chapter 2, section 2.5 and 2.2.5, after all considerations and discussions, we could consider birds to be “active-habitat-selectors” (AHS), which is probably another reason as to why birds could be used to determine the ecological status of urban environments.

Elements that need to be considered and qualified when deriving a definition of AHS include:

- According to Jokimäki (2000), birds choose habitats that are able to support high reproductive success, which is a prerequisite for adult birds.
- Juvenile birds, that are still dependant on parental care, cannot be considered as individuals that are mobile, and are therefore restricted until they can sustain themselves without parental care.
- According to Drickamer *et al* (2002), birds are able to select multiple habitats through choice (due to comparative knowledge) rather than through automatic responses.
- Birds continuously select habitats that are suitable to their needs, be it foraging, nesting, breeding etc., throughout their lifetime when it is required.

As this concept of AHS has been introduced by means of this study, a preliminary definition for AHS could be the following:

Active habitat selectors are those species of which the adult individuals within their lifetime are almost continuously able to select multiple, suitable habitats for different purposes, through choice, due to their mobility and comparative knowledge of different available habitats that are in range.

This definition contains elements of both the optimal foraging theory and ideal free distribution (IFD). There are however, considerations that need further refinement, before predictions for testing can be derived. This will have to await a follow-up study.

5.6.4 Objective 5: The “avitope” concept

Also introduced in Chapter 2, but in section 2.4, was the concept of “avitopes”. Birds often utilise more than one biotope for various reasons, such as foraging, nesting, etc. Birds are thus not restricted to or by a biotope and their distribution patterns cannot be limited to any single biotope. Because birds are able to utilise

more than one type of biotope at different times of the day and season, the patterns of distribution for birds could differ greatly from the distribution of vegetation and structure-based biotopes. According to Seoane *et al* (2004), vegetation does hold potential for predicting bird distribution, however, models that make use of vegetation predictor variables, often cannot explain perfectly observed distributions.

According to Morrison (2002), birds are good indicators and can be used to examine various ecological questions. In contrast to chemical monitoring methods, birds can directly indicate the condition of a landscape, as birds are collectively sensitive to both direct and indirect environmental influences (U.S. EPA, 2002). Furthermore, birds are valuable indicators as they are integrators of the cumulative effects of multiple environmental influences in a landscape (U.S. EPA, 2002). Conservation of birds and improving their habitat qualities, may improve conditions for fauna in general. Therefore, if “avitopes” can be identified and conserved, conservation strategies and management interventions in general could be made easier.

For these reasons the concept of “avitopes” has been introduced. “Avitopes” could also become significant for ecological functions, especially if “avitopes” contain indicators. Elements that should be considered to be part of an “avitope” definition include:

- Birds are not restricted to one specific area or biotope; they are multiple biotope users (AHS).
- Species richness, abundance of birds or diversity are criteria that should be considered in order to derive “avitopes”. Which one of these three criteria needs to be resolved.
- Generalist, exotic and non-vagrant species are considered unsuitable for derivation of “avitopes”, as these are species common throughout any area and should thus not be taken into account.

A preliminary avitope definition could be:

Avitopes are geographically delineated areas, defined by [species] [abundance] and [diversity indices], and do not take into account non-naturally occurring, non-vagrant, and otherwise generalist bird species.

There are still arguable aspects to this definition, such as the selection of which species to include or exclude, that requires avitopes to be operationally defined. A connection, however, does exist between the concepts of “avitopes” and AHS, namely that “avitopes” make use of “active-habitat-selectors”. There are however, considerations to this definition that need further refinement, before predictions for testing can be derived. This will have to await a follow-up study.

The following figures are maps that indicate preliminary “avitopes” for this study, taking into consideration the three possible criteria, namely species, abundance and indices. These maps have been analysed according to species richness, total number of birds and according to the Shannon diversity index. In the case of the Shannon index, a series of maps with different intervals (i.e. number of colours) have been presented.

Most of the species that have been excluded are omnivores and granivores, which, as previously mentioned, are better competitors in urban areas. I excluded House, Southern Greayheaded and Cape Sparrows (generalists), the Indian Myna (exotic), Redbilled Quelea (vagrant), and all the pigeons and doves (generalists). This seems to some extent to be rather arbitrary, but should suffice for a first approximation. The following maps reflect the data that have now been depleted with the species and numbers as indicated above.

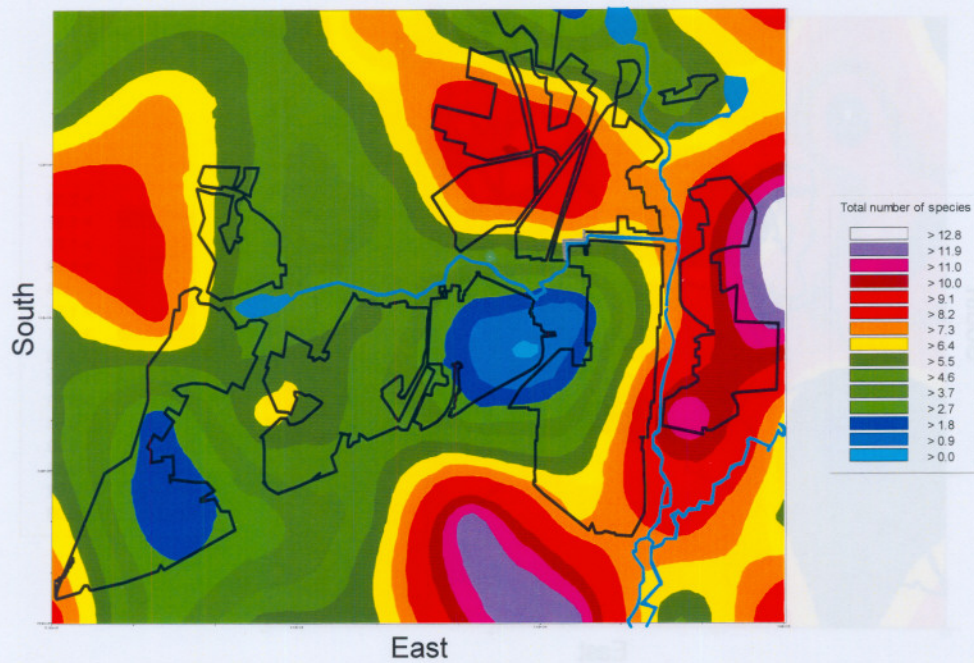


Figure 5.6.4: Avitopes (15 intervals) derived from depleted species richness.

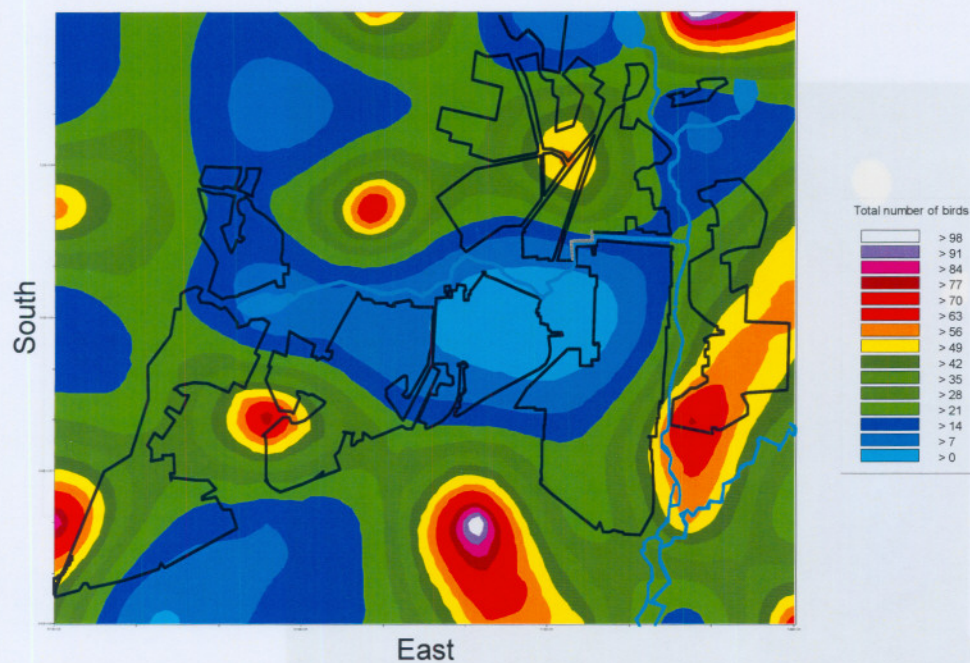


Figure 5.6.4.1: Avitopes (15 intervals) derived from depleted bird abundance.

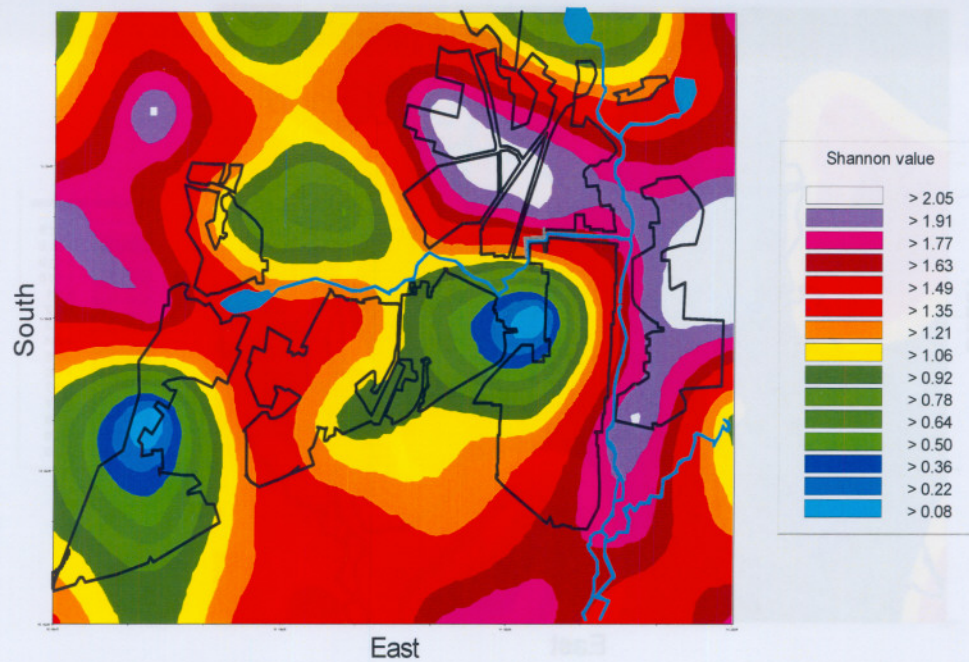


Figure 5.6.4.2: Avitopes (15 intervals) based on the Shannon index, calculated from a depleted data set.

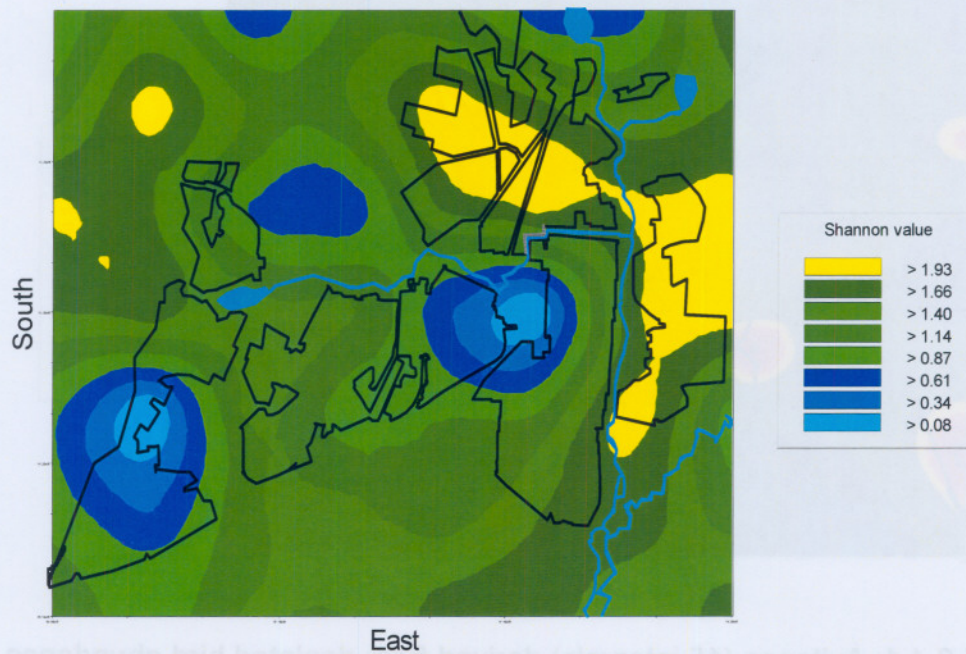


Figure 5.6.4.3: Avitopes (8 intervals) based on the Shannon index, calculated from a depleted data set

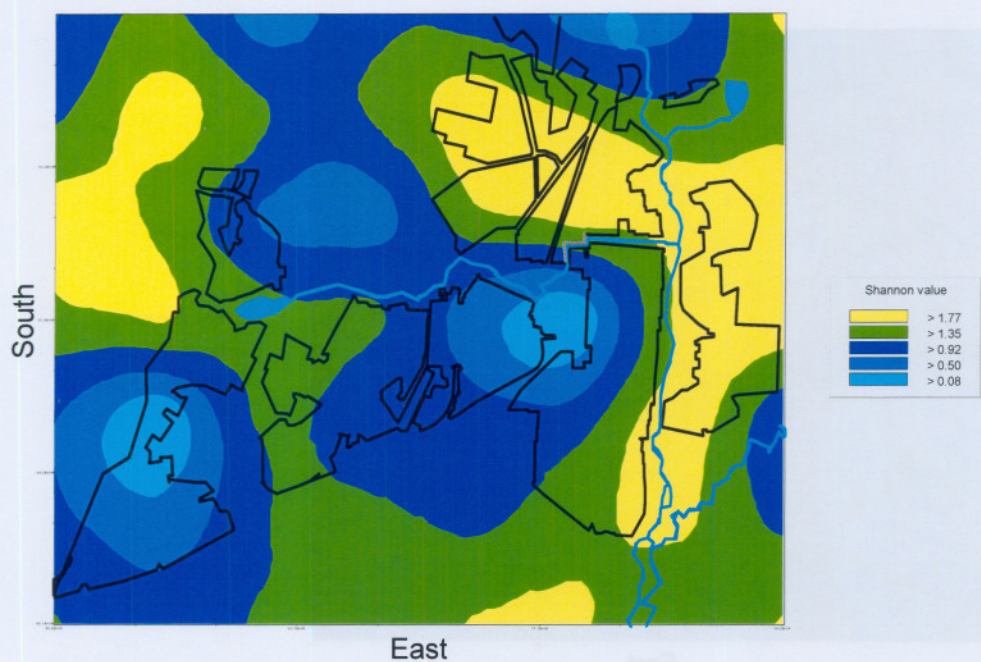


Figure 5.6.4.4: Avitopes (5 intervals) based on the Shannon index, calculated from a depleted data set.

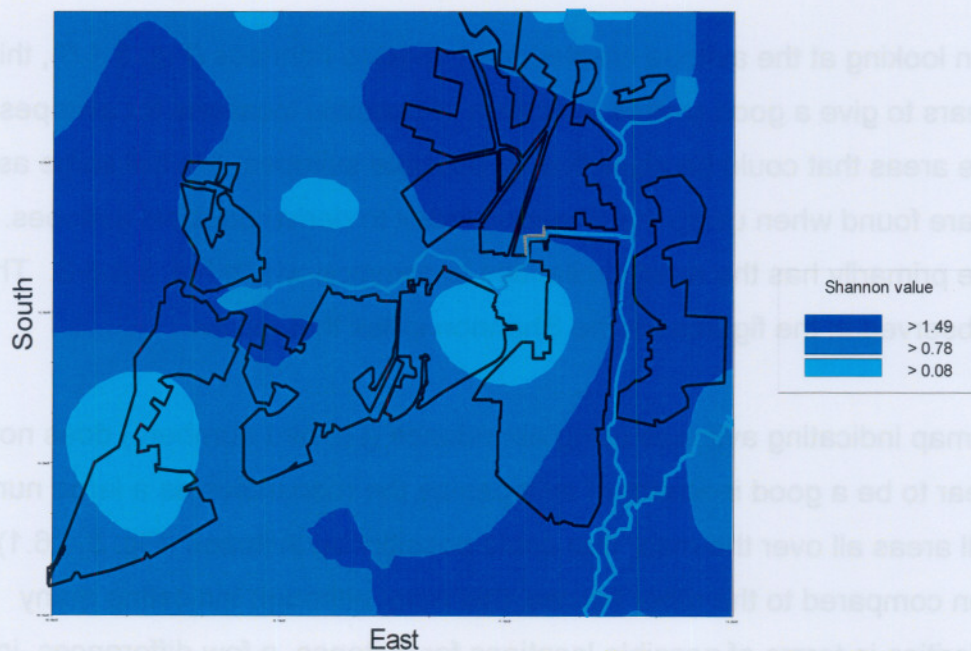


Figure 5.6.4.5: Avitopes (3 intervals) based on the Shannon index, calculated from a depleted data set.

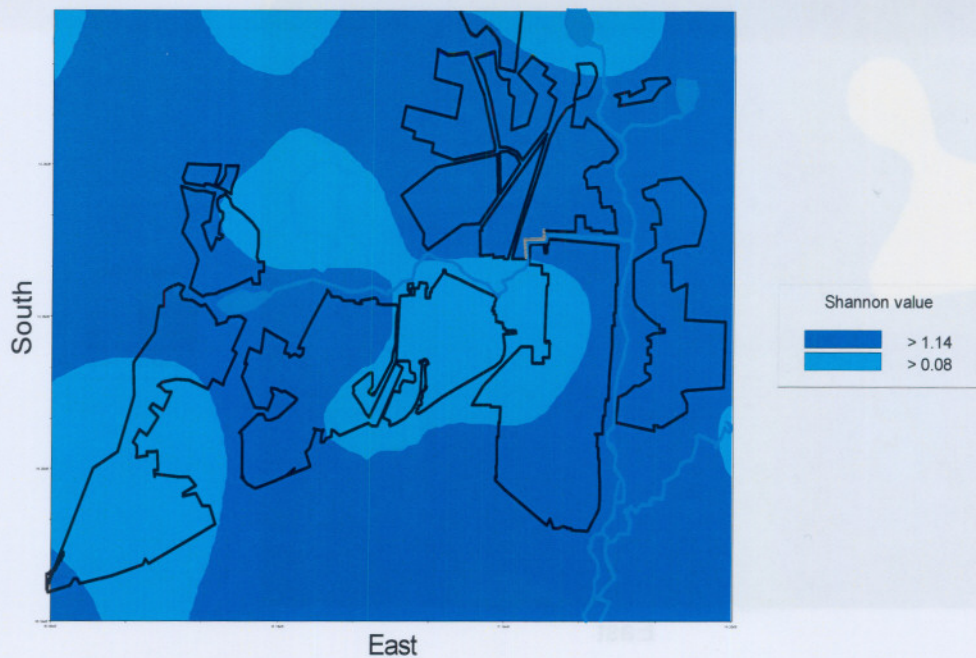


Figure 5.6.4.6: Avitopes (2 intervals) based on the Shannon index, calculated from a depleted data set.

When looking at the avitope created from species richness (Fig. 5.4.6), this figure appears to give a good overall indication of possible locations for avitopes. Many of the areas that could be classified as possible avitopes, are the same as those that are found when using the Shannon index to derive possible avitopes. This figure primarily has the most similarities in common with Fig. 5.4.6.3. This will be observed in the figures for the Shannon index that follow.

The map indicating avitopes using abundance (i.e. bird numbers) does not appear to be a good indicator of avitopes as the map indicates a large number of small areas all over the map, that could possibly be avitopes (Fig. 5.4.6.1). When compared to the other figures, this map, although indicating many similarities in terms of possible locations for avitopes, a few differences, in terms of other possible locations for avitopes, are found on this map, but are not indicated on the other figures. It is possible that these maps using only abundance are not sufficient to derive possible avitopes. However, in combination with other data (e.g. species richness), as in the case of the

Shannon index, this data itself proves to be sufficient, as will be observed in the following figures.

As mentioned previously, out of all the indices used for this study, the Shannon index is probably the best index to use in this case, as the results of patterns or distributions from this index are correlated with what was observed during this study. It is thus also probably the best index to use in order to derive the locations of possible avitopes. Although the Shannon index (Fig. 5.4.6.2), at this stage, appears to be the best method for this derivation, the use of the maximum number of 15 intervals (maximum available on GS+), defines the areas too much, which creates difficulty in defining the diversity of different areas, and in turn the locations of possible avitopes. The information provided by so many intervals is therefore impractical.

Fig. 5.4.6.3, also makes use of the Shannon index to derive avitopes, however, only eight intervals have been used for this map. Reducing the intervals to only eight has already made a much clearer indication of where possible avitopes could be found. However, these intervals may still be too many in order to determine the locations of possible "avitopes". (See similarities with Fig. 5.4.6).

When using only five intervals in a map (Fig. 5.4.6.4), the pattern appears to be less busy. Using a map such as this makes it easier to identify possible avitopes, especially when compared to the previous two figures. In this case, this figure supplies sufficient information in order to derive possible avitopes (i.e. there is not too much or too little information presented). Using five intervals could possibly be the best manner in which to derive avitopes.

In Fig. 5.4.6.5, only three intervals were used to produce the map. In this case, it is almost quite obvious that too little information or detail is available to derive possible avitopes. In other words, it seems that avitope will not be clearly identifiable when using a map such as this.

The last map (Fig. 5.4.6.6) only made use of two intervals. When looking at this map, too little information or detail is available in order to derive possible avitopes. This map does not contain sufficient definition in order to make a good enough distinction between various possible avitopes. As in the case of Fig. 5.4.6.2, this map, when only using two intervals, also indicates that almost the entire map could be a possible avitope. The use of so little intervals is thus not a sufficient means of deriving avitopes.

Based on the above, I propose that for a first approximation, five intervals be used (Fig. 5.4.6.4). These avitopes could provisionally be labelled as Bad > Stressed > Adequate > Good > Excellent. This could provide city managers with intervention targets and programmes, but this will need further refinement.

5.6.5 General conclusion

According to Stiles (2002), by the end of the decade, more than half of humanity will be living in urban areas and for this reason, cities are going to be important for bird conservation in general. As mentioned in Chapter 1, section 1.6 by Hostetler (1999), it is often difficult to study the connection between human decisions and the resulting effects on avian populations, when using birds to study habitat changes. Various socio-economic factors affect the distribution and abundance of birds. It is thus important to have integrated research that incorporates both natural and social sciences, in order to be able to understand the functioning of urban ecosystems. Little has been done though, to include human processes into ecological studies (Hostetler, 1999). However, it could be determined what habitat qualities may still be possible in and near cities by using bird studies, as the results from this type of research could be used to develop guidelines for urban green space corridor construction (Mörtberg *et al*, 2000), or management intervention.

As mentioned in Chapter 1, section 1.9, the motivation for avian urban ecological studies are based on the premise that nature is important to enhance the quality of human life. Urban nature has gained greater recognition as the concept of urban ecology has evolved. The remaining natural environments and their wildlife (including birds), found in urban areas are considered to have aesthetic value. This urban nature improves the quality of life for the residents living in urban areas. According to Clark *et al* (1999), while human communities continue to grow, the quality of life values can be only be maintained if the requirements of various wildlife species can be maintained. Birds are especially important for maintaining the qualities for urban wildlife. It is thought that if the quality for birds in urban areas is improved, there will be a general improvement in quality for all urban wildlife, and therefore also the human experience of their surroundings. According to Stiles (2002), cities can help sustain birds and ecologists can develop solutions that are compatible with human uses, by understanding urban bird ecology.

This study that I have done, appears to be the first complete assessment of birds in any city. As mentioned in Chapter 1, section 1.1, cities in African countries are divided into six categories (O'Conner, 1983). These include Islamic cities, European cities, colonial cities, dual cities, indigenous cities and hybrid cities. Each city thus has its own urban ecological character that differs from each other. This is due to development along different lines, which are dependant on various factors, such as ecology, social history, etc. Different cities may thus require different strategies in order for conservation and sustainable development to be successful.

In Chapter 1, section 1.5, according to UN-HABITAT (2003), there are various guidelines that have been based on cities from around the world that can be used in order to move towards sustainable development. One of these guidelines is that cities should improve environmental strategies and decision-making. If strategies are articulated and publicised in both presentations and

reports, various aspects are typically covered. One of these aspects includes both detailed and summary mapping information. The type of study that I have carried out (i.e. providing mapping information) could then possibly be applied to sustainable development strategies.

Also according to UN-Habitat (2003), various strategies have been suggested in order for cities to move towards sustainable development. These strategies include, improving environmental information and technical expertise, improving environmental strategies and decision-making, improving effective implementation of environmental strategies and make more efficient use of resources for effecting change. As mentioned in Chapter 1, section 1.5, in South Africa, IDPs (Integrated Development Plans) have been formulated in order to facilitate sustainable development. South Africa now also has a comprehensive set of Environmental Management Plans (EMP) that set out environmental policies and legal frameworks, environmental programmes and targets, environmental functions that impact on the environment and specific mechanisms to facilitate co-ordination with other areas of government and stakeholders.

In Chapter 1, section 1.8 and Chapter 2, section 2.2.8, IFD was defined as an optimal foraging model that describes animal distributions across habitat patches (Křivan, 2003). According to Drickamer *et al* (2002), IFD is defined as a model, which predicts how individuals distribute themselves so as to have the highest possible fitness. As mentioned under section 5.5.3, the definition of AHS contains elements of IFD, and in turn, AHS can be used to determine avitopes. For this reason, further progression of a study such as this, should include research on IFD.

According to Brooks *et al* (2001), bird conservation issues are low on the agenda in Africa and three broad issues need to be addressed in order to conserve avifauna, namely; data, planning and implementation. Fortunately, the conservation of biodiversity in urban areas has become a global focus of

research and the important role that urban environments can play in biodiversity conservation is receiving growing recognition (White *et al*, 2004).

In turn, by understanding urban bird ecology, cities could help sustain birds and ecologists would be able to develop solutions compatible with human uses (Stiles, 2002).

As mentioned in Chapter 2, section 2.7, the primary aim of this study was to determine patterns of avian distribution. Secondary objectives included: to determine the bird species distribution in Potchefstroom using point counts, to determine the distribution of feeding and nesting guilds, to determine whether avian indicators could be identified with this type of research, to investigate, develop and define the concept of AHS and lastly, to introduce, develop and define the concept of avitopes. All the objectives that were set out for this study have been reached, although, a number of issues have been identified that needs further study, refinement and development.

5.7 Suggestions

Although distribution patterns have been mapped for this study, there are various factors or aspects that have not been included. The following are suggestions in order to provide guidance to further research.

- It is suggested that when a study is specifically directed towards identifying indicators, the aim should be to establish which avian groups and attributes are regionally most suitable as indicators. It is also important to determine at which scales they are suitable, due to their ability to sensitively distinguish between anthropogenic and natural background conditions (U.S. EPA, 2002).
- One serious observation made about this study, are the constraints that were created by the number sites and the amount of time used to make

observations. In some cases it was clear that the amount of time spent at each site was too short. By increasing the number of sites over such a large study area, the possibility of identifying more birds/species is greater, and less repetitions regarding per site may be required.

Prolonging the time spent at each site is another suggestion. However, by increasing the number of sites, the amount of time spent at each site may not have to be increased drastically.

- Another observation that was also apparent from the literature, shows that both IFD and the optimal foraging theory have an influence on the patterns of distribution and abundance of bird species and numbers. It is thus suggested that both these two concepts be included in this type of study.
- There are many different types of analysis that could be done with this type of study, especially when using the power of geographical statistics. Data could be analysed according to individual species (as was done with the Indian Myna, *A. tristis*), or to groups (e.g. barbets, starlings, sparrows, etc.). Data could also be analysed according to standard deviation (indicating variability), biomass diversity, distance visibility and species that have range restrictions e.g. species with small home ranges.
- Other types of analysis could include social and economic indicators and the plotting of cats and their effects on bird abundance.
- Analysis could also be carried out on tree and roof heights, a much larger or enlarged area, as well as on the optimum spacing of sites.
- More types of analysis could include flight direction, vegetation structure, exclusion of non-fly over birds, and the presence/absence of nests.
- Once avitopes have been established in general, it could be possible to develop different types of avitopes. Some examples of different avitopes could be summer and winter avitopes, which could then be compared with each other for congruency. Winter avitopes would exclude migratory species eg. European Swallow, *H. rustica*. Other avitopes that could be developed include red data avitopes (which would only be based on red data species), nesting avitopes, foraging avitopes and so forth. Another

suggestion would be to exclude water birds from the data set in order to derive terrestrial avitopes.

- Other avitopes could also be based on industrial areas, rural settlements, cities in forests (e.g. Knysna), roads, power lines, railways and coastal cities.

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Appendices

Appendix 1

Rob. No	Abbreviation	English Name	Afrikaans Name	Scientific Name
473	C. Barbet	Crested Barbet	Kuifkophoutkapper	<i>Trachyphorius vaillantii</i>
703	P. Batis	Pririt Batis	Priritbosbontrokkie	<i>Batis pririt</i>
826	G. Bishop	Golden Bishop	Goudgeelvink	<i>Euplectes afer</i>
824	S.r. Bishop	Southern red Bishop	Rooivink	<i>Euplectes orix</i>
567	A.r-e. Bulbul	African red-eyed Bulbul	Rooioogtiptol	<i>Pycnonotus nigricans</i>
746	Bk.	Bokmakierie	Bokmakierie	<i>Telophorus zeylonus</i>
878	Y. Canary	Yellow Canary	Geelkanarie	<i>Serinus flaviventris</i>
677	L. Cisticola	Levaillants Cisticola	Vleitinktinkie	<i>Cisticola tinniens</i>
391	B. Coucal	Burchell's Coucal	Gewone vleioerie	<i>Centropus burchelli</i>
548	P. Crow	Pied Crow	Witborskraai	<i>Corvus albus</i>
377	R-c. Cuckoo	Red-chested Cuckoo	Piet-my-vrou	<i>Cuculus solitarius</i>
354	C.t. Dove	Cape Turtle Dove	Gewone tortelduif	<i>Streptopelia capicola</i>
355	L. Dove	Laughing Dove	Rooiborsduifie	<i>Streptopelia senegalensis</i>
352	R-e. Dove	Red-eyed Dove	Grootringduif	<i>Streptopelia semitorquata</i>
356	N. Dove	Namaqua Dove	Namakwaduifie	<i>Oena capensis</i>
104	Y-b. Ducks	Yellow-billed Ducks	Geelbekeend	<i>Anas undulata</i>
71	C. Egret	Cattle Egret	Veereier	<i>Bubulcus ibis</i>
796	C.w. Eye	Cape White Eye	Kaapse glasogie	<i>Zosterops virens</i>
834	M. Finch	Melba Finch	Gewone melba	<i>Pytilia melba</i>
698	F. Flycatcher	Fiscal Flycatcher	Fiskaalvlieëvanger	<i>Sigelus silens</i>
199	Sw. Francolin	Swainson's Francolin	Bosveldfisant	<i>Pternistes swainsonii</i>
203	H.g. Fowl	Helmeted Guinea Fowl	Gewone tarentaal	<i>Numida meleagris</i>
223	P. Gallinule	Purple Gallinule	Grootkoningriethaan	<i>Porphyrio madagascariensis</i>
81	Hk.	Hamerkop	Hamerkop	<i>Scopus umbretta</i>
62	G. Heron	Grey Heron	Bloureier	<i>Ardea cinerea</i>
451	A. Hoopoe	African Hoopoe	Hoepoep	<i>Upupa africana</i>
452	Rb.w-hoopoe	Redbilled wood-hoopoe	Rooibekkekelaar	<i>Phoeniculus purpureus</i>
94	H. Ibis	Hadedda Ibis	Hadedda	<i>Bostrychia hagedash</i>
239b	N.b. Korhaan	Northern Black Korhaan	Witvlerkkorhaan	<i>Eupodotis afraoides</i>
976	E. I-b. Lark	Eastern Long-billed Lark	Grasveldlangbeklewerik	<i>Certhilauda semitorquata</i>
857	B. Mannikin	Bronze Mannikin	Gewone fret	<i>Lonchura cucullata</i>
530	C.h-martin	Common House-martin	Huisswael	<i>Delichon urbica</i>
226	C. Moorhen	Common Moorhen	Grootwaterhoender	<i>Gallinula chloropus</i>
426	R-f. Mousebird	Red-faced Mousebird	Rooiwangmuisvoël	<i>Urocolius indicus</i>
424	S. Mousebird	Speckled Mousebird	Gevlekte muisvoël	<i>Colius striatus</i>
425	W-b. Mousebird	White-backed Mousebird	Witkruismuisvoël	<i>Colius colius</i>
758	I. Myna	Indian Myna	Indiese spreek	<i>Acridotheres tristis</i>
348	F. Pigeon	Feral Pigeon	Tuinduif	<i>Columba livia</i>
349	R. Pigeon	Rock Pigeon	Kransduif	<i>Columba guinea</i>
716	G. Pipit	Grassveld Pipit	Gewone koester	<i>Anthus cinnamomeus</i>
258	B. Plover	Blacksmith Plover	Bontkiewiet	<i>Vanellus armatus</i>
255	Cr. Plover	Crowned Plover	Kroonkiewiet	<i>Vanellus coronatus</i>
685	B-ch. Prinia	Black-chested Prinia	Swartbandlangstertjie	<i>Prinia flavicans</i>
821	R-b. Quelea	Red-billed Quelea	Rooibekkwelea	<i>Quelea quelea</i>
601	C. Robin	Cape Robin	Gewone Janfrederik	<i>Cossypha caffra</i>

732	F. Shrike	Fiscal Shrike	Fiskaallaksman	<i>Lanius collaris</i>
803	C. Sparrow	Cape Sparrow	Gewone Mossie	<i>Passer melanurus</i>
801	H. Sparrow	House Sparrow	Huismossie	<i>Passer domesticus</i>
804	S. g-h. Sparrow	Southern grey-headed Sparrow	Gryskopmossie	<i>Passer diffusus</i>
799	W-b. Sp-weaver	White-browed Sparrow-weaver	Koringvoël	<i>Plocepasser mahali</i>
764	C.g. Starling	Cape Glossy Starling	Kleinglansspreeu	<i>Lamprolornis nitens</i>
760	W. Starling	Wattled Starling	Lelspreeu	<i>Creatophora cinerea</i>
518	E. Swallow	European Swallow	Europese Swael	<i>Hirundo rustica</i>
526	G.S. Swallow	Greater Striped Swallow	Grootstreepswael	<i>Hirundo cucullata</i>
528	S.A. C. Swallow	South African Cliff Swallow	Familieswael	<i>Hirundo spilodera</i>
417	L. Swift	Little Swift	Kleinwindswael	<i>Apus affinis</i>
107	H. Teal	Hottentot Teal	Gevlekte Eend	<i>Anas hottentota</i>
108	R-b. Teal	Red-billed Teal	Rooibekeend	<i>Anas erythrorhyncha</i>
580	Gs. Thrush	Groundscraper Thrush		
577	O. Thrush	Olive Thrush	Olyflyster	<i>Turdus olivaceus</i>
621	Ch-v. T-babbler	Chestnut-vented Tit-babbler	Bosveldtjeri	<i>Parisoma subcaeruleum</i>
713	C. Wagtail	Cape Wagtail	Gewone Kwikkie	<i>Motacilla capensis</i>
844	B. Waxbill	Blue Waxbill	Gewone Blousysie	<i>Uraeginthus angolensis</i>
846	C. Waxbill	Common Waxbill	Rooibeksysie	<i>Estrilda astrild</i>
814	S.M. Weaver	Southern Masked Weaver	Swartkeelgeelvink	<i>Ploceus velatus</i>
832	L-t. Widow	Long-tailed Widow	Langstertflap	<i>Euplectes progne</i>
862	E.P. Whydah	Eastern Paradise Whydah	Gewone Paradysvink	<i>Vidua paradisaea</i>
860	P-t. Whydah	Pin-tailed Whydah	Koningrooibekkie	<i>Vidua macroura</i>
	Unid. Geese	Unidentified Geese		
	Unid. b. raptor	Unidentified brown raptor		
	Unid. g. raptor	Unidentified grey raptor		
	Unid. Warbler	Unidentified Warbler		

Appendix 2

1. Biotope of central city buildings

2. Biotope of residential areas

2.1 Block of flats	2.1.1 Closed 2.1.2 Open
2.2 Townhouses	
2.3 Large single houses	2.3.1 With large gardens 2.3.2 With smaller gardens
2.4 Small single houses with basic gardens	2.4.1 Sealed areas < ca. 50% 2.4.2 Sealed areas > ca. 50%
2.5 Small single houses with reduced basic services	2.5.1 Permanent houses with electricity 2.5.2 Temporary houses with electricity

3. Biotope of commercial areas

3.1 Predominantly sealed surfaces
3.2 Lesser sealed surfaces with managed ornamental green space
3.3 Lesser sealed surfaces with extensively managed green space

4. Biotope of industrial areas

4.1 Predominantly sealed surfaces
4.2 Lesser sealed and managed surfaces
4.3 Lesser sealed and unmanaged surfaces

5. Biotope of managed green space

5.1 Intensively managed public parks	5.1.1 For passive recreation 5.1.2 For active recreation and sport activities
5.2 Private park-like open spaces	
5.3 Sports fields and grounds	5.3.1 Predominantly sealed surfaces

	5.3.2 Lesser sealed surfaces 5.3.3 Informal sports fields
5.4 Cemeteries	
5.5 Camping sites	
5.6 Botanical garden	

6. Biotope of man-made water bodies

6.1 Lakes
6.2 Ponds
6.3 Channels

7. Biotope of traffic areas

7.1 Railway areas	7.1.1 Railway areas outside stations
	7.1.2 Railway stations
7.2 Roads	7.2.1 Main roads 7.2.2 Local roads with street trees 7.2.3 Local roads without green verges 7.2.4 Unsealed roads 7.2.5 Parking areas 7.2.6 Trails
7.3 Airstrip and hangers	

8. Biotope of agricultural areas

8.1 Crop fields

9. Biotope of plantations

9.1 Eucalyptus dominated plantations

10. Biotope of natural and semi-natural areas

10.1 Wetlands	10.1.1 Rivers
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	10.1.2 Streams 10.1.3 Marshes and vleis 10.1.4 Channalized rivers and streams
10.2 Grasslands	10.2.1 Sandy grasslands 10.2.2 Rocky grasslands 10.2.3 Clayey grasslands
10.3 Sparse Woodlands	10.3.1 Dominated by trees 10.3.2 Dominated by shrubs

11. Biotope of disposal sites and ditches

11.1 Household disposal sites
11.2 Industrial disposal sites
11.3 Gravel ditches

12. Biotope of waste grounds

12.1 Annual and biennial communities
12.2 Perennial communities
12.3 Green channels

13. Biotope of special land-use types

13.1 Military areas
13.2 Schools
13.3 Agricultural college
13.4 Institutional open space

Appendix 3

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Figure 1: The data sheet