ECOLOGICAL EFFECTS OF THE INVASIVE HOUSE SPARROW (*PASSER DOMESTICUS*) ON SYMPATRIC NATIVE SPARROWS IN THREE URBAN AREAS IN KENYA

By

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(Reg. No. I56/65624/2010)

Thesis submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Biology of Conservation of the University of Nairobi.

June, 2014

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university

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DEDICATION

To God almighty for having strengthened and enabled me pursue this study, my family especially my wife Naomi, my son Emmanuel, daughters Joy, Euphrecia and Purity, my mother Bernadette, and to my late father Jackson Imboma. They have all inspired me and always been a mirror to my life.

ACKNOWLEDGEMENT

This study could not have been successful without the generous and kind support from my academic supervisors and advisors, Professor Nathan Gichuki and Dr. Evans Mwangi, both of School of Biological Sciences, University of Nairobi, who took their precious time to discuss and offer all the guidance needed. They offered a wealth of support and encouragement during all the processes of proposal development to implementation.

I am very much grateful to Domick Chesire and Vincent Otieno (interns at National Museums of Kenya, Ornithology Section) for their dedicated support during data collection in Nakuru. My sincere gratitude goes to Nicodemus Nalianya (technical staff) and Colins Ogugu for their generous support in data collection in Mombasa. My sincere thanks also go to Gail, Doug and Ted Cheesemans for suggestions and advice during proposal development and taking time to read through the thesis. I express my sincere gratitude to Dr. Gabor Lovei for his great advices especially on choice of field methods and encouragement.

I express my great appreciation to John Tanui, the Manager at KCC factory in Nakuru and rest of staff members who gave us permission and great support while carrying out this research on their premises. I am grateful to Dr. Kiahi for allowing us to carry out surveys on the Kabete Vet Labs farm. He was quite supportive with logistics on the ground in identifying sites for experiments.

My sincere appreciation goes to Dr. Ronald Mulwa, Dr. Muchai Muchane, (Head of Zoology Department) and Dr. Peter Njoroge, (Head, Ornithology Section, National Museums of Kenya) for their generous support and continuous encouragement.

My sincere gratitude goes to the all staff members and interns at the ornithology section for their continuous support and encouragement. I express my greatest thanks to Joseph Mwangi (Tropical Biology Association) for his advice, criticism and support during data analysis.

ABSTRACT

House sparrow is one of the world's most successful avian invasive species. It has colonized many urban environments in central Europe, Central Asia and Africa. It was accidentally introduced to Kenya in Mombasa in 1950 and has since spread inland to major cities and minor towns. The factors contributing to the rapid spread of the species and quick establishment in inland urban areas are not well understood. The purpose of this study was to investigate the ecological effects of the invasive house sparrow on the native sympatric sparrows in three cities (Mombasa, Nairobi and Nakuru) in Kenya. The specific objectives of this study were to determine the relative abundance of the House Sparrow and the native sympatric sparrows in Mombasa, Nairobi and Nakuru, determine the morphological and behavioural traits that facilitates its dispersal and colonization in the three urban environments, identify the competitive interactions between the invasive house sparrow and native sympatric sparrows, and to establish how different human settlement structures and social economic activities influence the spread and settlement of the House Sparrow. Three transects (1800 meters each) were laid in different habitats inhabited by humans. Points counts were carried out on each transect to investigate sparrow abundance, avian species diversity and richness. Feeding experiments were used to test for competition and food preferences between house sparrow and native species. Mist nets were used to capture sparrows to test morphometric differences in body sizes among sparrow populations in the cities of study. A sample of 20 adult house sparrows was measured for wing, tarsus, weight and head at each study site. Nesting experiments were carried out using nest boxes to investigate competition for nesting sites and nest selection between the invasive sparrow and the native sympatric species. The results indicated that house sparrows coexisted with native sparrows as well as other bird species in all the three urban areas studied. A total of 2990 individual birds, belonging to 72 species of 28 families were recorded in the three sites during the point counts established along the baseline transects. There were 890 House Sparrows, representing 30% of the total number of birds observed. There was a significance difference in species abundance among the study sites (P= 0.052). The differences in feeding guilds among the three sites were not significant (P=0.064). Mombasa had the highest number of house sparrows with the least species diversity and richness (21 species), while Nakuru had the least number of house sparrows (n= 96) but with the highest bird species diversity and richness (n= 48 species). The native grey-headed sparrow was the most common associate of house sparrow in nesting and feeding areas. The wing length of house sparrows in the three study sites differed significantly ($F_{0.05,\ 2,\ 87,}$ 3.477, = 0.035), with birds in Mombasa having shorter wings compared to those in Nairobi and Nakuru. This study has established that house sparrows competed with native sympatric sparrows for grain food and nest sites, but there was no sufficient evidence that the invasive sparrows had displaced the native sparrows or significantly changed the community structure of urban avifauna.

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CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 Background

The study of invasive biology provides key insight into biology of conservation and change in species ecology and ecosystems over time (Sakai, 2001). Invasive species contribute towards many ecological upsets in ecosystem characters, such as offsetting the food chain, hence weakening the ecosystem services, functions and community stability (Thomas 2002). The introduction of non-native populations can lead to the competitive exclusion (displacement) of native populations (Hulex1999). They take time to learn and adapt to new habitats and environments. This enables them to establish a viable population before expanding their range into the ecosystem. The invasion process can cause substantial evolutionary shifts in traits that influence the invader's dispersal rate and its ability to establish new populations (Shine, 2011). Such can affect a given ecosystem through ecological association with native environment. The most likely to be affected are the native sympatric species, whose populations may be upset or be altered by competition for available ecological resources (Aikio *et al*, 2010). However, contrary to negative impacts, such introductions could be of an added advantage to native ecosystem, enriching biodiversity by filling empty niches (Herbold and Moyle, 1986). People have a long history of moving animals and plants around the globe either deliberately or inadvertently. Understanding the various factors, which promote the success of different invasive species and how these could be affecting natural ecosystems, can highlight the possible threats and impacts of the invasive

species on native species. These will provide practical measures and sound management steps when finding ecological solutions to the problem of invasive species.

1.2 Literature review

1.2.1 Invasion theory

Human movement across the world has been accompanied by increasing numbers of invasion of non- native invasive species to many parts of the world, where they were not previously found. Human role in spread of non-native species can be either deliberate (intentional), while others are non- intentional or as consequences of human movement (Dyke, 2008). Invasive species are a major threat to our environment because they can change habitats and alter ecosystem function and ecosystem services. They crowd out or replace native species. Numerous species of plants and animals have invaded natural areas resulting in vast range extensions and displacement of local species (Spellerberg 1998).

There are various routes or pathways through which alien invasive species can enter into new environments. (Veitch and Clout 2009) identified three main categories. These are; (a) some species spread naturally or passively by water or wind. During heavy rains especially during *El-nino* storms, lakes and rivers flood and heavy run-offs carry different aquatic and terrestrial life forms including both native and exotic fish species from artificial ponds and terrestrial environments to different wetlands. While some can crawl, others like birds fly across boundaries into new environments. (b) However, some species are deliberately introduced as new genetic stocks, biological control agents, hunting agents, pets, or through ornamental trade. In most cases, such species are introduced legally or illegally through smuggling into a new area. (c) Other species are accidentally introduced especially on travel vessels during trade, mainly ships moving across continental waters.

Species invasion is an ecological and an evolutionary process. Such a process might lead to speciation to new species or extinction of the original species. Never the less, they offer opportunities to study the impact of micro evolutionary forces on introduced populations. New behaviour is acquired due to genetic changes or cultural learning and the rate of morphological and physiological evolution can be estimated since the time of introduction is usually known (Diamond 1986, Lewin 1987). The study of exotic birds has had particularly long history and has come to represent a fascinating intersection between the study of biological invasions, avian conservation biology, and basic principles of ecology and evolution (Blackburn *et al*, 2009). Invasive non-native species have been involved in the extinction of 68 out of the 135 bird species lost in the world globally over the last 500 years, (Birdlife international, 2012).

The house sparrow is ideal for the study of invasions because its introduction and spread are still quite recent and because of its rapid movement across East Africa. It is also likely to provide a complete cycle of the diffusion process. Even though the House Sparrow was deliberately introduced to North America from Europe (Moulton *et al*, 2010), and in Southern Africa in 1900, it accidentally arrived in Mombasa on commercial boats or ships (Zimmerman, 1996). This study seeks to establish the ecological effects of invasive House Sparrow (*Passer domesticus)* on the sympatric native sparrows in the urban environments in Kenya. There are two native sparrows closely associated with the House Sparrows in Kenya: the Grey-headed Sparrow (*Passer griseus)* and the Kenya Rufous Sparrow (*Passer rufocinctus)*.

1.2.2 Global Invasion history of house sparrow

The House Sparrow originated in Europe and much of Asia and spread to the Middle East, Mediterranean region and North Africa. It spread along with the spread of agriculture and human settlement to most of Eurasia and parts of North Africa. Since the mid-nineteenth century, it has

reached most of the world, not only due to chiefly deliberate introductions, but also through natural dispersal and ship-borne travel. The house sparrows are known to breed throughout Europe except in the islands in the west and northern Asia, including Japan, China and Indonesia (Snow and Perrins, 1998; Clement *et al*, 1993).

The house sparrow and the Eurasian Tree Sparrow (*Passer montanus*) were both first introduced to North America from Europe in the mid 1800s. The introduction was meant to provide biological control of invertebrate pests and also to provide new Americans with a reminder of their former homeland in Europe (Sibley, 2001). They were also meant to control the population of canker worms, but in half a century they were considered pests because of their destructive tendencies towards plants in developed areas and their consumption of food staples, such as wheat and corn, as well as their ability to carry disease (Pierson and Hauk 2008). Its intentional or accidental introductions in many regions, including parts of Australia, Africa, and the Americas, make it the most widely distributed wild bird.

It was first introduced to North America in the Brooklyn, New York area from Europe. This was in 1851 with the initial introduction of 16 birds (Moulton *et al*, 2010), and again in 1852, in San Francisco in 1871, 1872, and in Salt Lake City in 1873 and 1874 (Moss, 2007). After managing the pests of farm crops, they later became invasive. The introduction was such a success that house sparrow populations soon exploded. Now, they can be found almost anywhere in Canada, the United States, and Mexico.

House Sparrow has a pioneering nature due to its ability to adapt to different environmental conditions. It is spread to six of the seven continents of the world and therefore one of the most common and wide spread song birds in the world. It has been known to have negative ecological impacts on native species in the invaded areas in North America, but little information exists on

the species in sub-Saharan Africa. Invasive house sparrows have had significant impacts on bird communities in urban areas, (Johnson and Violette, 2012).

In agricultural areas of USA, house sparrows compete with native birds for limited nesting cavities and may affect local populations. They destroy eggs, harass and even kill native Eastern Bluebirds (*Sialia sialis)* and other cavity nesting natives (Sibley 2001). After evicting their competitors, the house sparrows take over nesting sites. They also prefer to nest in manmade structures, such as eaves or walls of buildings, street lights, and nest boxes instead of natural nesting sites, such as holes in trees, due to its abundance and lack of fear towards humans. They compete for nesting sites, especially with other secondary cavity nesters (Newton, 1998).

1.2.3 Invasion and colonization of house sparrow in Sub-Saharan Africa

The breeding habitats of the house sparrow are not well studied in Africa (Fry and Keith 2004). Since its arrival to the continent during the last century, the house sparrow has evolved into different forms, primarily because of overlaps in their distribution ranges and hybridization. There are two races of the house sparrow. European sub-species, the *Passer domesticus domesticus* and the Asian *Passer domesticus indicus* from Asian continent. The introduction to South Africa involved the two sub- species. As a result, there was a genetically diverse founder population established a long the coastal belt of South Africa. Originally, the species was introduced into Durban in 1893 and 1897 from Europe (Mackworth and Grant 1963). Further introduction in South Africa was at the Cape Province in 1914 (Mackworth and Grant 1963). The Asian Passser domesticus indicus was later introduced to the coast of Kwazulu - Natal in the late 19^{th} century (Msimanga 2001). The invasion was characterized by an initial period of slow spread for about 50 years after introduction followed by rapid expansion and occupation of most of the sub-region in the next 15 years. It now occurs virtually throughout South Africa except in

Kalahari Desert, northwestern Namibia, the sand dunes of southern Namib Desert, and wilderness areas of Botswana (Clement and Davis 1993). In the East and North Eastern Africa, The Asian race, Passer domesticus indicus was introduced to the port of Khartoum through Nile, Mogadishu, Zanzibar and Mombasa(Lewis and Pomeroy 1989).

The house sparrow and house crow in Mombasa have their origin in Zanzibar Island. The Zanzibar birds were introduced from Bombay in India around 1900 (Brown and Britton 1980). The House Sparrow was introduced to Kenya through merchant ships docking in Mombasa in the 1950s. It remained in the old town. In 1979 to 1982 it spread inland from Mombasa Island to Moi International Airport, Mariakani to Voi (about 200 km) from Mombasa along Mombasa Nairobi highway, becoming common in Mombasa 1983. The sparrows settled at Voi, where repeated breeding took place. First record from Mtito Andei, some 100km further inland (westwards), along Mombasa Nairobi highway was in 1983 (Lewis and Pomeroy 1989). They were first reported in Nairobi in 1992. In October 1993, house sparrow was recorded and reported along Magadi Road at the Magadi Supermarket as a first record for the area (Kenya Birds 1994). The species established itself in the municipality, occupying modified habitats amongst human settlements. Since then, the species has spread to other parts of Kenya (Figure 1.1)

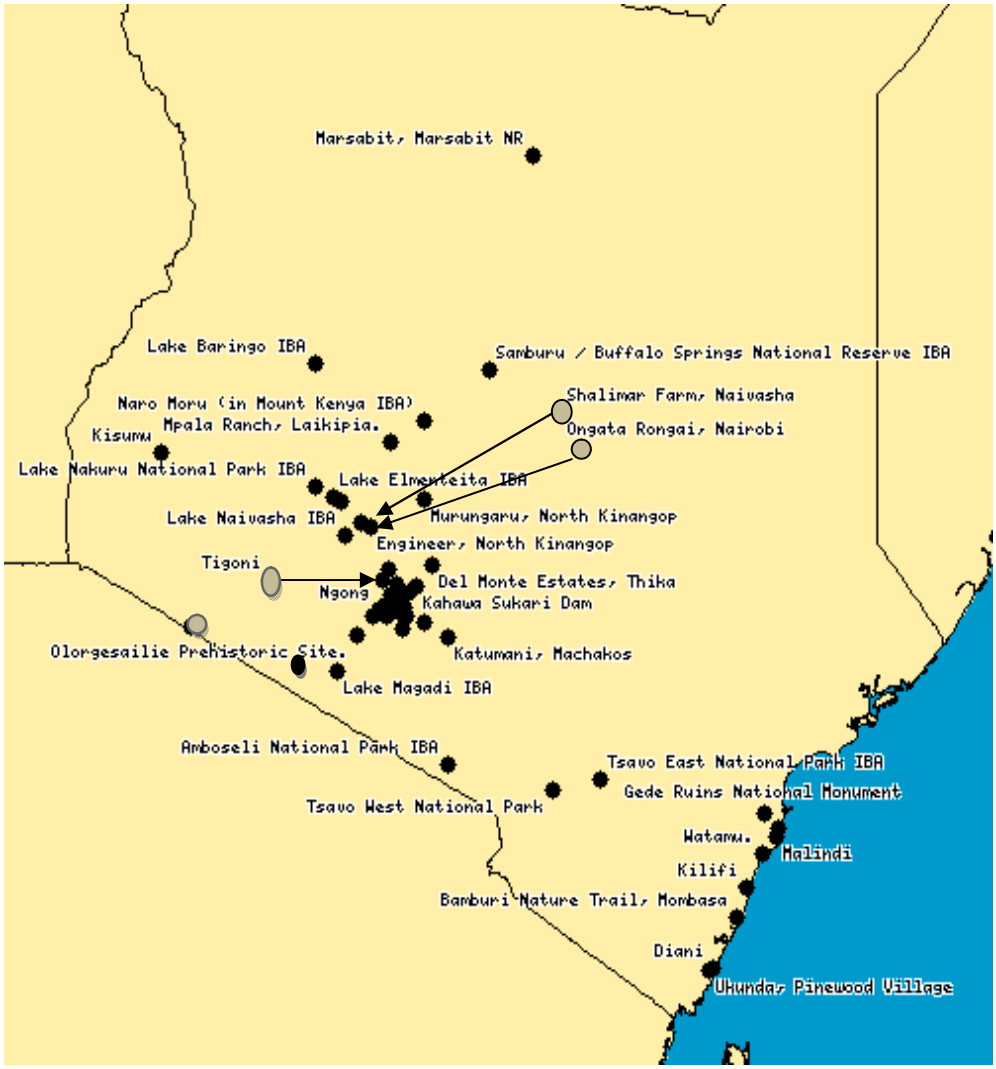

Figure1.1: Distribution of House Sparrow records in Kenya during the period between 1996 to 2010. (Kenya Bird finder 2011).

The distribution House Sparrow in Kenya was derived from sighting records during the last 14 years (Nature Kenya and National Museums of Kenya, 2011). The data was extrapolated to establish the trend in range expansion of the species across the country since 1950s. It is clear that the birds have been moving northwest with high concentrations in Nairobi and Nakuru cities. The current distribution, west and north of Nairobi, reflects only 19 years (1992 to 2011) of colonization.

According to (Zimmerman *et al* 1996), it was not until 1992 that the species arrived in Nairobi about 350 kilometers northwest of Mombasa. The sparrows have been dispersing northwards and westwards to urban centers along the along Mombasa-Kisumu highway. By the year 2008, the species had established itself in western Kenya and eastern Uganda.

Information from bird watching records (Kenya Birdfinder, National Museums of Kenya and Nature Kenya 2011) shows that house sparrows had by the year 2010 already invaded wildlife protected areas of Maasai Mara and Samburu National Reserves. They are found at major tourist hotels in Mara such as the Serena Lodge, Sarova Hotel and the buildings at the main gates. After managing to reach the mainland away from Mombasa, the species spread quite fast across the country. It took six years for it to move from Nairobi to Nakuru, less than 200 kilometers away, while it took 46 years to spread from Mombasa to Nairobi, about 480 kilometers way.

This pattern of dispersal shows that there is time taken during the dispersal and colonization in house sparrow. There are four species of sparrows native to Kenya. These are Somali Sparrow (*Passer castanopterus Blyth)*, Chestnut Sparrow (*Passer eminibey Hartloub)*, Grey-headed Sparrow (*Passer griseus Vieollot)* and the Kenya Rufous Sparrow (*Passer rufocictus).* The later three are the main focus of this study, with much emphasis on the invasive house sparrow and the grey-headed sparrow

1.3 Study species

1.3.1The Rufous sparrow *Passer rufocinctus*

Two sub-species occur in east Africa Passer rufocinctus rufocinctus is endemic to the highlands of Kenya and northern east of Tanzania breeds in a more natural habitat. The Passer rufocinctus shelleyi is spread from northern east of Uganda to north west Kenya and south Sudan (Pomeroy and Lewis 1989, Stevenson *et al* 2002). In Kenya *P. r. rufocinctus* is found in the Rift Valley and in the highlands of Eldoret and Maralal. *Shelleyi* is found along the Uganda It inhabits bushlands, wooded vegetations and near human inhabitations, mostly within the highlands. Their nests are constructed in the wild. The grey-headed sparrow, like the invasive house sparrow constructs their nests in human residential houses. It is sometimes termed as African house sparrow because it nests in residential houses.

1.3.2 Grey-headed Sparrow *Passer griseus* (Vielott)

There are five races of the grey-headed sparrows. These are the Parrot-billed sparrow (*Passeer gongoensis),* the nominate race (*Passer griseus*), the Swainson's sparrow (*Passer griseus swainsonii*), the Swahili sparrow (*Passer suahelicus)* and the race Southern grey-headed sparrow (*Passer moambicus*), which is now known as *Passer diffuses.* All the races are regarded as allopatric species in a single super species (Britton, 1980). These races appear similar in appearance but are very different in range and distribution (Stevenson, 2002). Habitat requirements vary from race to race.

1.3.2 a. *Passer gongoensis*

This is the largest of all the races. It is regarded as a separate species. It has a distinct thick black bill like the parrot bill. It is darker in general plumage, with uniform dark grey on the underparts. Unlike other races, it has no white on the throat(Zimmerman 1999). It inhabits more drier or semi-arid habitats, with bushes and thickets. It range is in east of the Rift Valley, north to Lake Turkana, south to north eastern Tanzania and on the Kenyan coast. The nominate race *P. griseus* and the *P. gongoensis* are thought to be ecologically distinct in central Kenya, where they meet without integrating (Britton, 1980)

1.3.2 b. *Passer griseus*

This is the nominate race. It has rufous-brown back contrasting with the grey nape and crown. Has a conspicuous white throat, light-grey breast contrasting with whitish belly. It is confined to the highlands and moist plateaus west of the Rift Valley. It prefers higher rainfall areas(Brown, 1980).

1.3.2 c. *Passer suahelicus*

The Swahili sparrow has grey-brown nape. It more closer to the nominate race, but more dark-grey on the belly. This race is endemic to interior Tanzania and south to south-west Kenya.

1.3.2 d. *Passer swainsonii*

This race is similar to gongoensis but has a much smaller beak with rufous upper tail coverts. Has a white throat with dark grey head and underparts. This is the northern race that reaches north Kenya at Moyale. It is common in town and the surrounding foothills of the Ethiopian

highlands. It is thought to intergrades with the *p. gongoensis* in Turkana and Marsabit districts (Britton, 1980, Zimmerman, 1999)

1.4 Problem statement

House Sparrows affect the natural dynamics of bird communities in a number of ways. They become the most abundant and dominant species, consequently replacing some native species. This may thus affect the total number of species in the community. They have significant effects on native bird communities in urban and agricultural areas (Johnson and Violette, 2012). This may threaten native species richness and diversity in the invaded habitats. The study of the ecology of the house sparrow as an invasive species, especially in Kenya, is significant for understanding its impacts on native avian communities and its future management.

1.5 Objectives:

1. To determine the relative abundance of the House Sparrow and the native sympatric sparrows in Mombasa, Nairobi and Nakuru.
2. To determine morphological and behavioural traits that facilitates dispersal and colonization by the House Sparrow in the three urban environments.
3. Identify the competitive interactions between the invasive house sparrow and native sympatric sparrows.
4. To establish how different human settlement structures and social economic activities influence the spread and settlement of the House Sparrow.

1.6 Research questions

1. What is the relative abundance of the House Sparrow in relation to the two sympatric sparrows in urban environments in Kenya?
2. What are the morphological and behavioral traits that support dispersal and colonization by the House Sparrow in their new environments?
3. What are some of the competitive interactions involving both the invasive house sparrow and the native sympatric species?
4. How do human activities and densities affect the dispersal and colonization by house sparrow?'

1.7 Hypothesis

The ability of the House Sparrow to adapt to different environmental situations and compete for the available resources with the native avifauna will impact negatively on the sympatric native sparrows in urban environments in Kenya.

CHAPTER TWO: STUDY AREA, MATERIALS AND METHODS

2.1 Location and description of the study area

This study was carried out in three major urban cities in Kenya; Nairobi, Mombasa and Nakuru. The three are quite different both geographically and in age (when they were established as cities). They are of different elevations, as well as different human settlements types and densities. The house sparrow invasion occurs in human modified environments. Different cities established at different times have different human settlement types. These may have different effects on the invasion and colonization by invasive species.

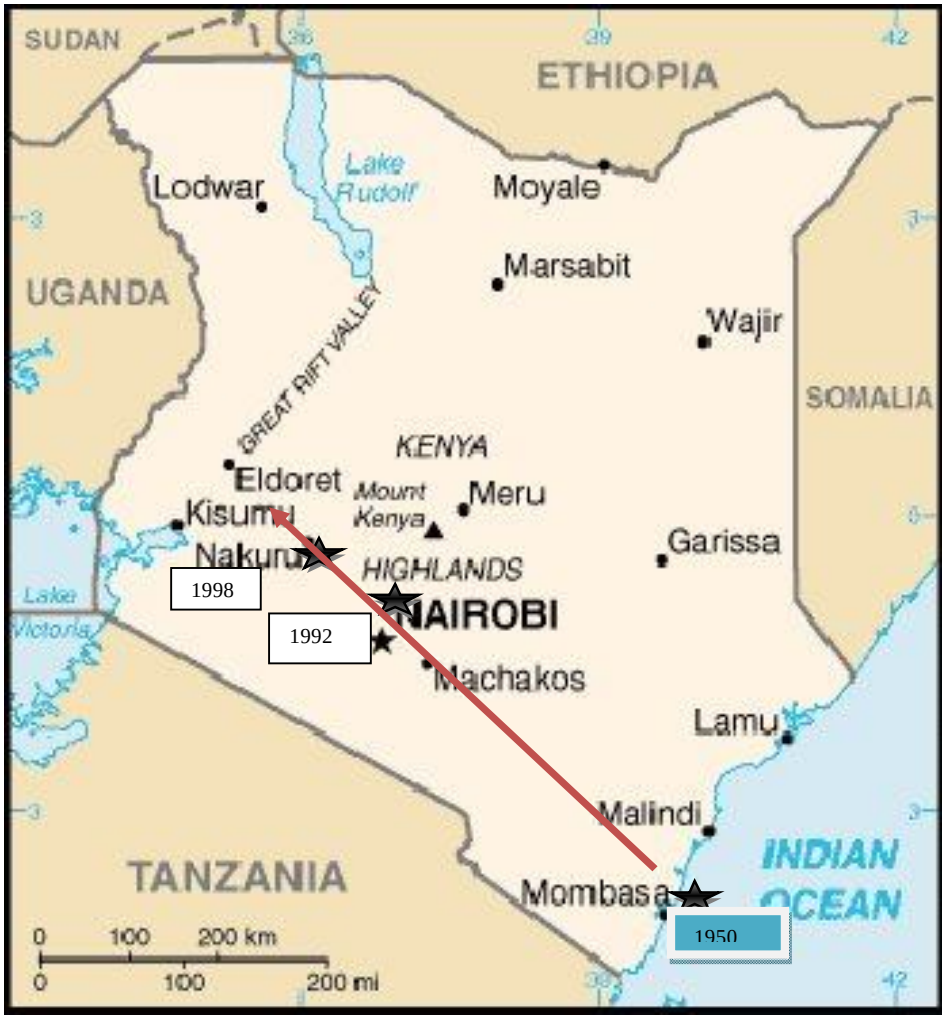

Figure 3.1 Map of Kenya showing location of study sites (stars), arrows showing the direction of House Sparrow dispersal from coast towards western Kenya and the year of firsts records of House Sparrows at the site.

2.1.1 Mombasa city

Mombasa is located within 01˚17'S, 36˚49' E. It borders the Indian Ocean to the East and South East. The city has an area of 218.9 Km², with human population estimate of approximately 939,370 (census 2009). Has a variation of temperature ranging from a minimum of 20˚ C. to a maximum of 32˚ C. with an elevation of 50 meters above the sea level. It is approximately 450 kilometers from Mombasa to Nairobi. Mombasa is Kenya's oldest city, having been established as early as 12th century. It was an important centre for the trade in spices, gold, and ivory. Its trade links reached as far as India and China. It is for this reason that the House Sparrows first arrived in this city in 1950 (Zimmerman *et al*, 1996). The species was accidentally introduced on ship-borne travels. It has since successfully colonized and dispersed along the coastal towns and inland to main towns along the Mombasa - Kampala highway. Mombasa has unique habitats that support a variety of both flora and fauna. Some key sites are the Haller Park and the Shimba Hills National Park some 33km from Mombasa town. Some 111 species of have been recorded within the Shimba Hills National Park (Bennun and Njoroge, 1999). A total of 116 bird species have been recorded ate the Haller Park, some of which have been introduced to the nature trail.

2.1.2 Nairobi city

Nairobi city has an area of 695.1 Km², located within 01˚17'S, 36˚49' E. It has a human population estimate of about 3.2 million people (Kenya Census 2009). Nairobi has an altitude of 1795 meters above the sea level. Temperature ranges from 10˚ C to 24˚ C. It took close to 45 years for the House sparrow to fully colonize the coastal region before it started moving inland. Its first record in Nairobi was in 1992.

Nairobi city and its environs support a richer diversity of avifauna. A total of 613 species has been recorded. Of these, 18 species are globally threatened (Avibase, 2004). This is attributed to a variety of different habitat types in different ecosystems. They include the Nairobi National Park, the Nairobi Arboretum, the botanical gardens at the National Museums of Kenya, highlands pockets of forests in Langata and Karen area and Karura Forest among others. The house sparrow has colonized mostly varied habitats associated with human settlements. They include human residential areas including high human densities like slums, organized estates, central business areas/district (CBD) and industrial areas.

2.1.3 Nakuru city

Nakuru **(**0˚22'N, 36˚05' E) city is found in south eastern part of Rift Valley Province. It is the capital of the province. It covers an area of 7496.5 Km². Nakuru has a varied temperature ranging between 12˚C and 26˚ C. It is the 3rd largest city that begun in 1900 by the arrival of Kenya Uganda Railway from Nairobi. It later attained township in 1904. Has a population estimate of 1.6 million inhabitants (Kenya census 2009). Nakuru city is located within an ecotone between low human density of agriculture to natural shrubland, to industrial, commercial business with high human densities with unstructured settlements or slums. In general the study site comprised of different habitats with different anthropogenic activities and infrastructure. Low human density areas had well organized infrastructure such as permanent residential housing, road network, few shops and kiosks, and proper waste management. Areas with high human densities had irregular semi permanent infrastructure, many retail, small shops and many dumping sites.

The Lake Nakuru, the soda lake together with other habitats and different ecosystem types provide both feeding and breeding sites for different species of birds. Close to 450 species of

birds have been recorded just within the national park, of which five species are globally threatened. According to unpublished data (Kenya Birdfinder, 2011), the House Sparrow arrived in Nakuru in the Rift Valley in 199, and now dispersing and colonizing different human inhabited areas.

Study species

Plate 2.1 Male and female invasive house sparrows

Plate 2.2 Two native Grey-headed sparrows on bread on breakfast table

Plate 2.3.Native Grey-headed sparrow nesting in a roof of house

2.2 Materials and methods

2.2.1 Field observations and counts of sparrows

This study was conducted through field observations and experiments. The three study sites selected (Mombasa, Nairobi and Nakuru) represented the sequence of house sparrow colonization and dispersal from Mombasa in 1950 to Nakuru in 1998. In each study site, four habitat types coinciding with different human densities, their activities and settlement systems were selected. The habitats were categorized into index one to four. Index one represented study areas with the lowest human density. These were planned residential areas with gardens and some bushes in their compounds. They also had very few human inhabitants. Such areas had no food kiosks or small retail shops. Domestic solid waste was collected every morning to dumping sites located some distance way. Index four representing the highest human density areas with unplanned and congested settlements. They included slum areas with poor solid waste management. Index ii represented central business district (CBD) where there are infrastructures set for business, offices learning institutions. They in most cases don't provide boarding or sleeping facility for most of dwellers apart from hotels.

Index iii represents residential areas in urban settings where middle income residents stay. Unlike index I, they may have some kiosks and shops with structured plans. They are usually not overpopulated.

During point counts, 1800 meters transect was established in each of the each study site. Bird observations and counts were carried out between 8.00 am – 11:00 am each day. A point was established at an interval of 200 meters along a given transect. Birds were observed within a radius of 50 meters at every point over a period of five minutes. All bird species and their numbers seen and heard were recorded at each point. Careful species identification was made using 8 x 50 Swift pair of binoculars and a suitable field guide (Birds of Kenya and Northern Tanzania). Both species and the number of individuals per species were recorded to reflect species richness, evenness and abundance on each site.

2.2.2 Mist netting

To investigate morphological traits that might aid dispersal and colonization, house sparrows were captured in the three study sites and some morphormetric measurements taken. Four standard mist nets (18 meters long and three meters wide) were used to capture the sparrows. Nets were opened at 6:00 am when birds were more active, moving and feeding, and at 11:00 am when bird activities slowed down.

For each individual bird captured, four different measurements were taken: wing length, tarsus length using a stop rule, head to bill using Vanier caliper, and body mass using weighing balance. The purpose of these measurements was to establish whether there were any differences in morphometrics in sparrow populations among the three study sites. The rationale here was that the sparrows in Mombasa had been there for 60 years while the

populations in Nairobi and Nakuru had been there for less than 16 years. In order to avoid taking data from the same individual birds more than once, each bird captured was marked with a metal ring on one tarsus. A combination of three different plastic colour rings was placed on the other tarsus for individual recognition in the field observations. Metal rings had a unique number for each individual bird captured. Colour rings of unique colour codes (combinations) for each bird were later used for individual identification of the birds in field during behaviour observations, particularly feeding and breeding behaviour of the birds.

2.2.3 Determination of competitive interactions through feeding experiments

Cafeteria feeding experiments were used to study competition in food as an important resource shared among the invasive house sparrow, the native sympatric sparrows and other native species. During the experiment, five different food types were offered to birds. These were maize, rice, red finger millet, green millet and sorghum. These were feeds found common in cereal boards, milling industries, on the open markets, and homes in the three study sites. These feeds were assumed to be crucial to the survival of the house sparrows. The feeds were spread on the ground 15 meters apart in a cafeteria system. Observations of birds feeding at different feed types were made from 7:00 am to 11:00 am per day for a period of 14 days. Bird species feeding on different feeds and their numbers and frequency of visit to a particular feed were observed and recorded. Also observed was how much time individuals spent on each type of feed. Aggression behavior between and within species was also recorded.

2.2.4 Nest boxes

Experiments on breeding behaviour were carried out by use of wooden nest boxes. The nest boxes with a small entrance of 32 mm were used to allow only smaller birds(size of sparrows) to enter and exclude larger birds like starlings and raptors form entering the nests. This was to avoid nest robbing by starlings and predation of nestlings and eggs by birds of prey. Female sparrows accepted coarse nests built by males but lined them with soft nesting material before they laid eggs. The nests were put at different heights and on different structures and environment. Ten nest boxes were used, of which five were placed at close distance of five meters between each nest. They were put on a wall of buildings, six meters high. The other five were placed 15 meters apart, each at a height of 12 meters. They were laid on different structures (two on wall of a building and three in an open environment, on an electric pole, and two on two live Cyprus trees). Nests were observed 11 hours every day from 07:00 hours – 17:00 hours every day for 30 days. This was from the period of nest construction, egg laying to hatching till the chicks fledged. Nest material used by birds during nest lining were observed and recorded. 'Nest contents such as number of eggs and chicks were checked every morning before the daily actual monitoring begun, and at the end of the day. After hatching, daily chick feeding activities were recorded. They included observations of food material fed to the chicks by adult birds. The frequency of feeding the young by both parents was recorded. Aggression behaviour by other birds at the nest was also observed and recorded.

2.2.5 Influence of human activities

To determine how human activities affect House sparrow distribution and dispersal, point counts were laid in different human settlements. Human density was taken as a measure or an index of one to four, with highest density represented by four and lowest represented by one. They varied from low human density areas (areas with formal and well organized estates (Kileleshwa in Nairobi) to areas with informal settlements with high human densities (slums). Areas with high human population densities had informal and unstructured, mostly, temporary settlements. They were characterized by congested infrastructure, no proper solid waste management, congested shops and food kiosks. Low human density estates had no waste dumping sites since solid wastes was regularly picked by trucks and carried away. Such areas had proper housing plans with some live fences and gardens in the compounds.

2.3 Data analysis

All data collected were entered into an excel spreadsheet. Statistical Programme SPSS was used to run statistical analysis.

2.3.1 Abundance of house sparrow and bird diversity

Bird diversity in the three study sites was calculated using Shannon Diversity Index of the diversity index H**,** (Zar 1996**);** $H = \sum - (P_i * \ln P_i)$.Where H = the Shannon diversity index, P_i = proportion of a species relative to the total number of species present. This was used to determine the relative abundance of the house sparrows and the sympatric species in the study sites. S = numbers of species encountered in the three study sites. $\sum$ = total sum of individuals from species 1 to species S. This was used to determine the diversity and abundance of species among the avian community in the three urban environments.

2.3.2 Morphometrics

ANOVA was used to compare differences in house sparrow biometrics in the three study sites. Four different measurements; wing length, mass, head and tarsus length were used to compare size differences in alien sparrows across the study sites.

2.3.3 Bird species richness

Pearson's Chi-square test was used to determine the independence of occurrence of house sparrows and the sympatric sparrows in different human environments/habitats (different human densities and human activities), and how this affected the entire native species richness and bird community. The total number of species encountered was divided by the number of points (point counts). The distribution values were used as expected frequencies for the purpose of calculating the Chi- square (x^2) values.

2.3.4 Breeding and feeding observations

Feeding experiments were used to measure competition in food as a resource shared among the invasive house sparrow and the native species, including the native sympatric sparrows. Five common feeds in the study sites were used. These included rice, maize, sorghum, finger millet, dry and crushed maize seeds and bulrush millet. Different bird activities were recorded during bahavoural observations and were categorized as nest building, foraging (feeding in adults and adults feeding young). The number of individuals per given activity per species and site were tested for differences between the invasive and the sympatric sparrows using Kruskal – Wallis test.

Chi- square was also used to determine feeding frequencies among different bird species and food preference by different birds. This was used to establish any competition for certain feeds among birds.

2.3.5 Feeding guilds

One way analysis of variance (ANOVA) was used to compare birds in different study sites using different feeding guilds. This was based on feeding modes (frugivore, granivores, insectivores, nectivores and carnivores) of different bird species among the three sites.

CHAPTER THREE: RESULTS

3.1 General bird communities

The invasive house sparrow and the house crow comprised 55% of the entire avian population. The native avian community comprised of 70 species, an equivalent of 45% of the total number of birds. Mombasa had the highest recorded numbers of individual birds, where record of 1556 individuals belonging to 21 species was observed. Out of those 614 (39%) of the population were house sparrows and 751(46%) were house crows. Other avian species (19 species) in Mombasa were represented by only 15% (n= 291) of the entire community.

Nairobi and Nakuru had the least numbers of individual birds (n=719 and n=711 respectively), but with most species recorded. Nakuru had the most species (n=48) followed by Nairobi (n=37) (Table 4.1).

3.2 Taxonomic diversity of the bird community

During the study period, 2990 individual birds, belonging to 72 species of 28 families were encountered during the point counts (Table 4.1). Two urban non-native species, House Sparrow (*Passer domesticus*) and House Crow (*Corvus splendid*) had overall 890 (30%) and 751 (25%) observations respectively, of all birds observed in all the three sites. However, the crow was observed only Mombasa. There was a significant difference in species richness. ($F_{2,}$ 422= 2.00, p=0.033) and number of individuals (F_2, 244 = 16.11, P = 0.000)

Table 3.1 General bird communities in the Mombasa, Nairobi and Nakuru

Study Sites	No. of Individuals	No. of Species	No. of genera	No. of families
Mombasa	1556	21	14	13
Nairobi	711	37	31	27
Nakuru	719	48	36	23

3.3 Bird species richness and diversity

Species diversity differed significantly among different habitats ($F_{2, 443}$ =1.796, p= 0.052), and among the three urban areas. Number of species and species diversity is shown in (table 4.2). Shannon-index of diversity ranged from 0.68 in Momsasa to 2.34 in Nairobi and 3.18 in Nakuru in terms of other avian communities they supported. Mombasa had the lowest species diversity, where the Industrial Area recorded the least (0.68) while Nyali Estate had the most (1.72). Nakuru had the highest species diversity, where Kiamunyi Estate had the highest diversity (3.18), while the Nakuru CBD had the least (1.68). In Nairobi, Kileleshwa Estate had the highest species diversity (2.77), while Nairobi CBD had the least (1.75)

Table 3.2 Species richness and diversity in different cities affected by invasive sparrows

City	Site	Number of species	Species diversity
Mombasa	CBD	4	0.70
	Industrial Area	5	0.68
	Kiembeni Estate	5	1.07
	Nyali Estate	7	1.72
Nairobi	CBD	7	1.75
	Kangemi	15	1.90
	Uthiru	20	2.34
	Kileleshwa	24	2.77
Nakuru	CBD	14	1.68
	Industrial Area	27	2.71
	Muslim Estate	20	2.35
	Kiamunyi Estate	30	3.18

3.4 Feeding guilds

The 72 species encountered during the point counts were grouped in six groups of feeding guilds based on the feeding modes and type of feeds that the birds preferred. Insectivores had the highest species number observed (35 species containing 445 individuals). Omnivores (mixed or catholic feeders) were second (18 species), but with highest individuals (n= 1521) observed. Granivores (grain feeders) had 16 species, with second highest number of individuals (n=965). Nectivores (sunbirds or nectar feeding, four species with 21 individuals) and carnivores (birds of prey or meat eating, 3 species of 5 individuals) were the least

observed. The feeding guilds differed significantly among the three study sites ($F_{0.05, 2,}$ 412, 1.893 P=0.038). The number of feeding guilds increased with distance away from Mombasa to mainland. Mombasa had the least with only three (granivores, insectivore and omnivore). Nakuru and Nairobi had all the six guilds present with but with granivores and insectivores dominating. All the CBDs in the three study sites had equal number of feeding guilds, each having four. The three study sites were dominated by the omnivores followed by the granivores. Carnivores and nectivores were the least observed. They were common in Nakuru and Nairobi. Nakuru had the highest number of insectivores observed.

Table 3.3 Total percentage of feeding guilds in study areas

Guilds	**Mombasa**	**Nairobi**	**Nakuru**
Carnivores	0.0	1.5	0.75
Nectivores	0.0	5.5	2.80
Frugivores	7.0	4.0	7.80
Granivore	35.0	40.0	35.65
Insectivore	17.0	18.0	32.0
Omnivore	41.0	31.0	21.0
	100	100	100

3.5 Relative abundance and densities

The house sparrow was the most abundant and common species in Mombasa, where they had the highest population recorded. They were common in Nairobi, which had the second highest population. Least population was observed in Nakuru. Even though the Indian house crow was only recorded in Mombasa, it was rated overall second most abundant among all birds recorded in all the three sites after the house sparrow (Table 4.5). Two sympatric native sparrows; the Grey-headed Sparrow (*Passer griseus*) and Rufous Sparrow (*Passer rufocintus*) were observed only in Nairobi and Nakuru but not in Mombasa. The Grey-headed

sparrow had (n=52) individuals observed, representing 1.7% of total bird population while the Rufous sparrow (n=49) of individuals representing (1.6%). Mombasa had the least record of the native Pied crow *Curvus albus* (sympatric to house crow), with only two individuals recorded at one site (Kiembeni).

Both invasive species (House Sparrow and House Crow) were the most abundant and dominant species (55%) of the entire avian population in these urban areas. In all the three sites, a total of 890 house sparrows were observed, out of which n= 613 (69%), were observed in Mombasa, n= 184 (20.61%) in Nairobi and n= 92 (10.37) in Nakuru.

Table 3.4 Densities of invasive species and the native sympatric sparrows.

City	Site	Hs Sparrow	Grey-headed sparrow	Ruf. Sparrow	HS crow
Mombasa	CBD	27.08	0	0	78.82
	Industrial Area	35.38	0	0	64.13
	Kiembeni Estate	61.11	0	0	28.39
	Nyali Estate	46.3	0	0	17.36
Nairobi	CBD	40.52	0	1.05	0
	Kangemi	42.02	5.31	7.21	0
	Uthiru	17.52	1.66	5.80	0
	Kileleshwa	4.8	5.50	10.41	0
Nakuru	CBD	4.5	0	0	0
	Industrial Area	11.5	2.12	8.66	0
	Muslim Estate	37.40	7.60	2.99	0
	Kiamunyi	4.8	5.50	10.41	0

Table3.5. The abundance Invasive and sympatric species in the three study sites.

Species	Nakuru	Nairobi	Mombasa
House Sparrow(invasive species)	92	184	751
Grey-headed Sparrow (native sp.)	40	12	0
Rufous Sparrow (native sp.)	17	32	0
House Crown (invasive sp.)	0	0	890
Pied Crow (native sp.)	24	74	3

3.6 Sparrow distribution across the study cities

The House Sparrow population decreased with distance away from the coast towards mainland. Of the total number of all the house sparrows found in the three study sites, Mombasa had 68%, followed by Nairobi with 20% and Nakuru 12%. Nairobi and Nakuru had both the native sympatric sparrows (Grey-headed and Kenya Rufous Sparrow), while none was observed in Mombasa.

Only Mombasa had an additional invasive species, the House Crow *Corvus splendens*. (Figure 4.1). The crows are much larger in size compared to Sparrows. Their density and abundance in Mombasa was much higher compared to the House Sparrows.

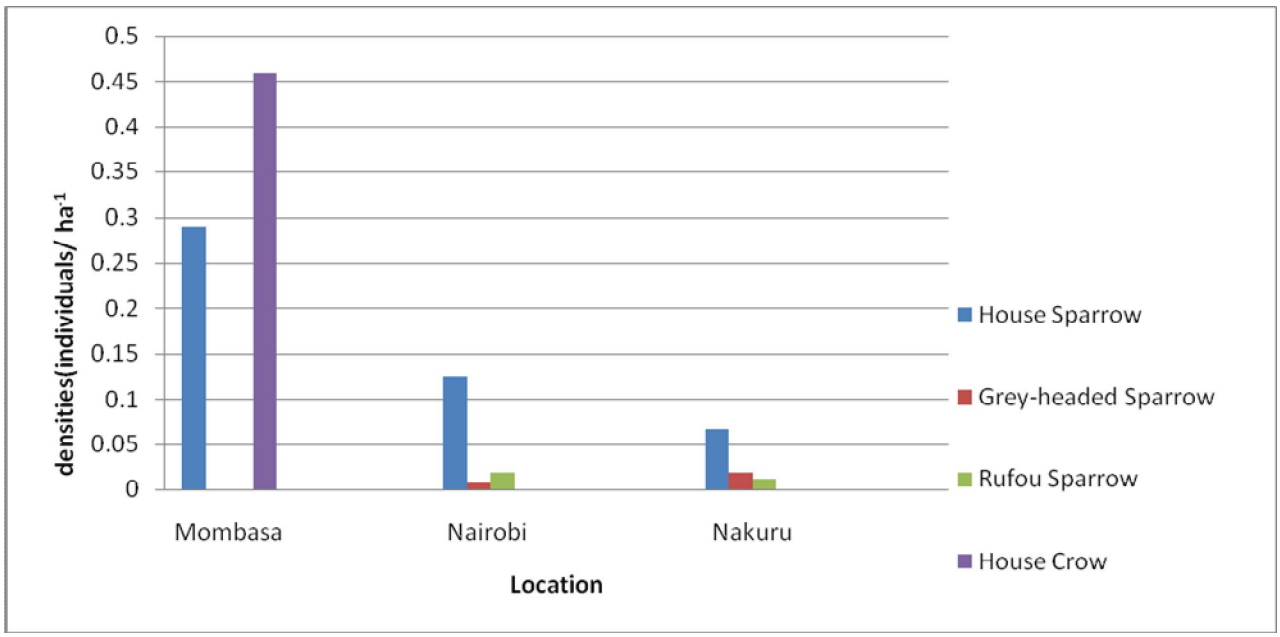

Figure 3.1 Densities of both sympatric and invasive sparrows in three study sites differed significantly

3.7 Morphological traits

To establish any morphological traits that may aid dispersal of invasive house sparrows in the three study sites (Mombasa, Nairobi and Nakuru). Four morphometric measurements were taken from 20 adult house sparrows captured at each site. They include are mass, wing length, head to beak length and tarsus length (Table 4.6).

Tabe 3.6 (Mean ± SE) Morphometric measurements in House Sparrows in different cities.

Morphometric	n	Mean	F	P
Wing (mm)	20	74.88±1.50	3.477	0.035
Tarsus (mm)	20	23.32±0.35	1.223	0.299
Mass (gms)	20	21.06±0.14	1.123	0.330

There was a significant difference in wing length of house sparrow among the three cities, ($F_{2, 87,}$ 1.223, P = 0.035). Sparrows in Nairobi had the longest wing length (75.57± 2.3 mm.), followed by Nakuru (75.03 mm). The House sparrows population in Mombasa had the shortest (74.04 mm) wing length.

There was no significant differences in head to beak length (F_2, 26, = 4.087, P >0.05) and the tarsus length among the sparrows in the three sites ($F_{0.05, 2, 87,}$ 1.22, P>0.05), though birds in Mombasa had the least weight, and therefore smaller than birds in Nakuru and Nairobi.

There was no significant differences in the body mass ($F_{2, 0.05, 2, 84}$, 1.223, P= 0.330) and the tarsus length the invasive sparrow populations among the three study sites

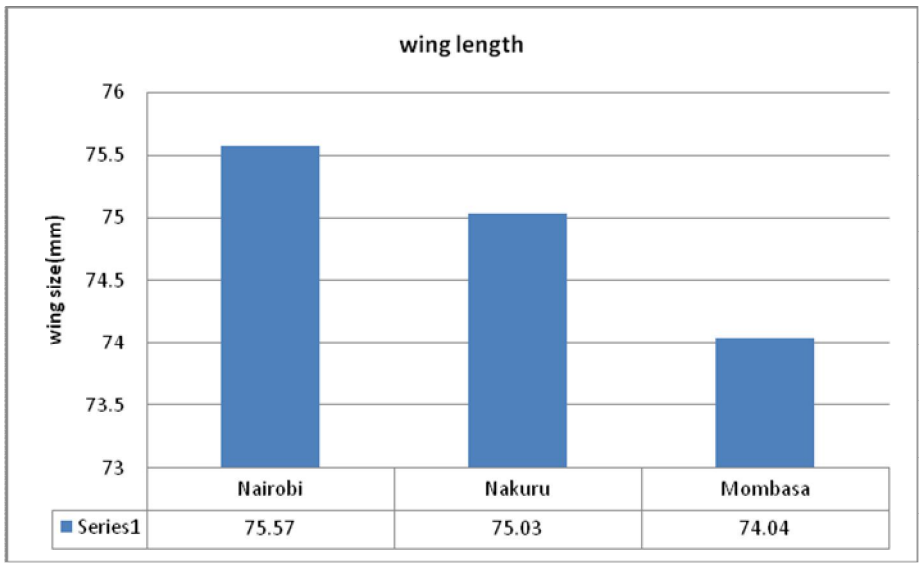

Figure 3.2. Mean wing length of House Sparrows in Nairobi, Nakuru and Mombasa

3.8 Competitive feeding interaction among sparrows

Bird feeders attracted eight seed-eater species, of which two were native sympatric sparrows and the invasive house sparrow. There was a significance difference in food preference

among all the 13 species observed. (D=85, p>0.05). However there was no significant difference in food preference between the invasive house sparrow and the native grey-headed sparrow (D=37, p>0.05).

Of the total six feeds provided to test for competition, only three were preferred and selected by the two native sympatric species (maize, rice and green millet). Two out of the three food choices (rice and crushed maize) were preferred by the invasive house sparrow which had a higher preference for rice (71%), followed at a distance by crushed maize (29%). In addition to rice and maize, the two native sympatric species had a third choice of food, the green millet (Table 4.7). Both Grey-headed and House sparrow had higher preference for rice while Rufous sparrow had a higher preference for maize (62.5%). The choice of maize by house sparrow was quite low compared to the sympatric species, with Grey-headed sparrow bearing the greatest preference, followed by the Rufous sparrow (Table 4.8). The house sparrow fed the nestlings exclusively on arthropods whereas the native grey- sparrows fed their nestlings 40% on rice four days before fledging. The difference in food choice between the native sparrows and invasive species house sparrow was a significant (x^2= 7.049, df = 1, p =0.008).

Table 3.7 Utilization of food patches by invasive house sparrow and native grey-headed sparrow

Bird Species	Maize	Rice	Finger Millet	Sorghum	Bulrush millet
House Sparrow					
No. of Birds	2	7	0	0	0
Feeding frequency (min)	12	18	0	0	0
Grey-headed Sparrow					
Number of birds	5	7	3	0	0
Feeding frequency (min)	23	26	9	0	0
Feeding duration (min)	42	35	20	0	0

Table 3.8 Relative Frequency of food choices by the House sparrow and the sympatric species

Species	Rice	Maize	Green millet	Total
House sparrow	71.0	29.0	0.0	100
Grey-headed sparrow	47.4	38.6	14.0	100
Rufous sparrow	29.2	62.5	8.3	100

3.9 Competitive breeding interactions among sparrows

Both the invasive House Sparrow and the native Grey-headed Sparrow had much closer association compared to the Rufous Sparrow, which is also native. Both species accepted and nested in the nest boxes provided for breeding experiments, while the Rufous Sparrow nested in the purely uncontrolled natural habitat. Five nest boxes that were placed together, at an interval of five meters apart were all occupied by both invasive House Sparrow and native Grey-headed Sparrow. Only one nest was occupied by the invasive house sparrow, while four were occupied b the native sparrows.

A pair of house sparrows occupied one nest, where they laid two eggs. There was increased aggression between the house sparrow and the grey-headed sparrows at the nest boxes though they were placed five meters apart. The female house sparrows abandoned the nest earlier following aggression from the native grey-headed sparrows. The male house sparrow restricted displacement for a short while but abandoned later after 2-3 days of tending the nest without a female.

The native sparrows occupied one nest which they cushioned ready to lay eggs but always protected extra nests from being occupied by the invasive house sparrow. The male grey-headed sparrows often attacked the invasive house sparrow at the entrance to the nest. The other five nest boxes placed at an interval of 15 meters apart were also occupied. Two of the five (one for invasive house sparrow and another for native grey-headed sparrow) were successful. Birds laid eggs, incubated, and eggs hatched successfully. The house sparrows eggs ranged between six and five eggs per nest, out of which four eggs hatched. The grey-headed sparrow laid three eggs and two eggs hatched. Mortality of nestlings was heavy in invasive sparrow nests but not in native sparrow nests. Few days to fledgling the adult house sparrows stopped feeding the nestlings because the nest was infested by lice. They stayed at the entrance with food material without entering the nest. The louse infested nestlings eventually succumbed to death.

Nesting of invasive house sparrow and native grey headed sparrows in artificial nest boxes

Plate 4.1. A: A male House Sparrow patched on a nets box with food material on beak. The female was in the nest. Both the male and female fed the young in turns.

Plate 4.1 B. Male and female Grey-headed Sparrow, on the nest and while female is at the nest entrance. She stayed in the nest much longer than the male during the first week of hatching.

Nesting of invasive house sparrow in artificial nest boxes

Plate 4.2 A: Female House and the male (Nest B) nesting in a sound block wall on a building in Nairobi (National Museums of Kenya).

3.10 Human influence

Human densities were categorized into index i to iv. Index i represented sites with low human density and iv represents high human density. Human plays key role in introduction

and spread of alien invasive species. There number of sparrows varied significantly along the population gradient (i– iv) among the study sites in Mombasa. There was a significant difference or variation in number of sparrows along the human population density gradients in Mombasa ($F_{3, 14}$, 4.689, $p < 0.01$), where sparrow invasion begun and established some 50 years ago. The site with low human population density (index i), Nyali Estate, had much lower sparrow population too, compared with the areas with higher human population density (iv), such as the industrial Area, which equally had higher invasive sparrows. However, there was no significant difference in sparrow population along the human population densities in Nairobi and Nakuru (P= 0.223 and P= 0.321) respectively (Table 4.9). The number of House Sparrows varied significantly along human population density gradient (i-iv) in Mombasa but not in Nairobi. However, low population density areas had even much lower sparrow population (Table 4.9).

Though areas with low human population had low sparrow population densities in Nairobi and Nakuru, there was no correlation between sparrow density and human densities across the study sites. Kileleshwa in Nairobi had the least number of house sparrows (index i, n=7), but shared same number of bird species with Uthiru (n=23). In Nakuru, Kiamunyi Estate (index I) had no house sparrow but had the highest number of bird species (n=30). The distribution of House Sparrows differed significantly among the low human habitat categories.

Table 3.9 Impact of human density on House Sparrow numbers

City	Site	Human Density index	Number of House Sparrows.
Mombasa	Nyali Estate	i	88
	CBD	ii	124
	Kiembeni Estate	iii	208
	Industrial Area	iv	234
Nairobi	Kileleshwa	i	17
	Uthiru	ii	52
	CBD	iii	87
	Kangemi	iv	68
Nakuru	Kiamunyi	i	10
	Industrial Area	ii	37
	CBD	iii	17
	Muslim	iv	57

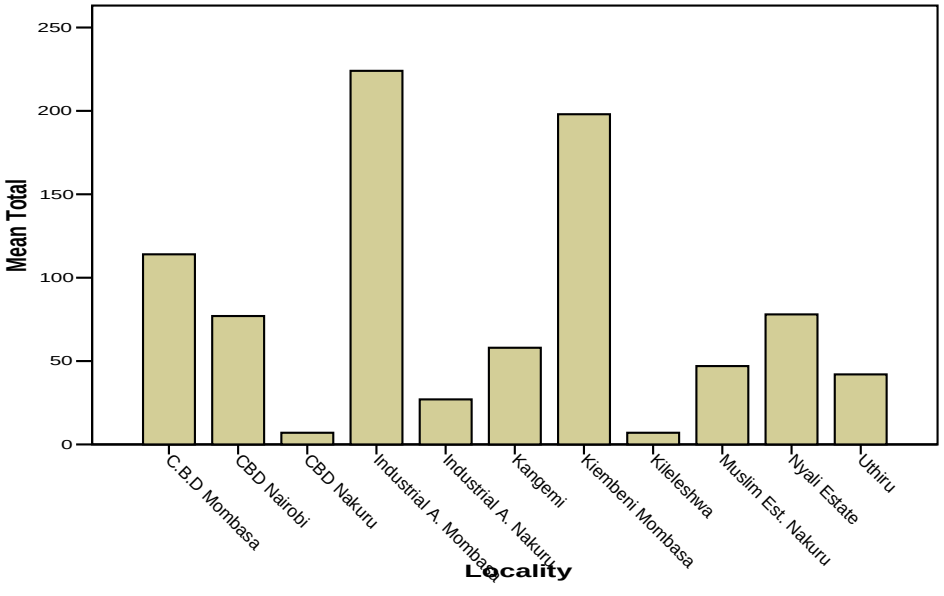

Figure 3.3. Local distribution of house sparrows, with wider distribution in Mombasa and least distribution in the inland house sparrows (Nairobi and Nakuru).

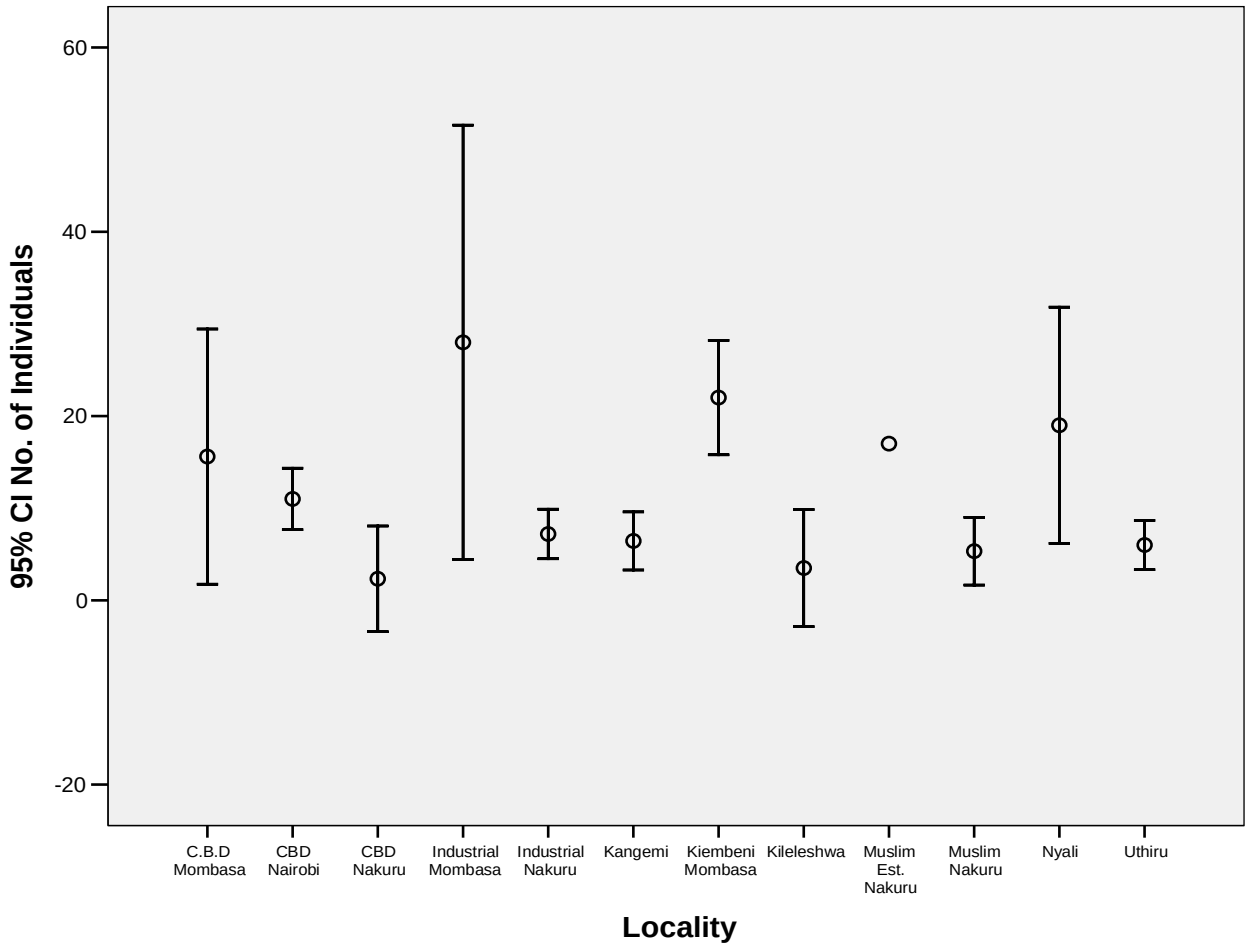

Figure 4.4 Abundance of House Sparrows along different human settlement types. The mean number of sparrows is shown with 95% confidence of intervals in equivalent settlement types in the three cities studied.

House sparrows were well distributed in Mombasa regardless of differences in human densities (index I –iv). Nairobi and Nakuru however registered higher invasive sparrow population in higher human densities.

CHAPTER FOUR: DISCUSSION, CONCLUSION AND RECOMMENDATIONS

4.1 Bird community and relative abundance of house sparrow

Species composition and abundance within an ecosystem change largely due to the interaction between species that regulate such interactions (Veitch, 2009). Invaders that comprise a larger portion of the biomass at a given trophic level may measurably alter the ecosystem structure and function, (Dukes and Mooney, 2004). The house sparrows shared their invaded habitats with quite a number of native species, including native sympatric sparrows in urban environment in Kenya. (Lewis and Pomeroy, 1989) shows that the parrot-billed race of grey-headed sparrow was well distributed from Mombasa towards central, western and northern Kenya. All these sites have confirmed breeding records. During the same time, the invasive house sparrow was only recorded on at Old town in Mombasa and Voi. This study reveals grey-headed sparrow is rare in areas sampled in Mombasa at present. This could be attributed to increased population of the invasive house sparrow and probably the house crow. It is therefore evident that the invasive house sparrows had a negative ecological impact on both the sympatric native species and the entire native bird communities. The difference in species richness, abundance, diversity and feeding guilds are attributed to differences in abundance, dominance and population pressure from the invasive species over the native species.

The house sparrows were more abundant and dominant in Mombasa where they first colonized before dispersing inland. Here they have outcompeted and displaced the native

sympatric sparrows. Mombasa was therefore the most affected site with reduced number of native bird families, species richness and even feeding guilds.

The house crow population seems also to have surpassed that of the house sparrow in Mombasa. The competition from house crows may have contributed to house sparrow dispersal from the coast to mainland. Sites with higher numbers of crows had low population of house sparrows, whereas sites with higher numbers of sparrows had low population of the house crows. Apparently, house sparrows avoided the larger predatory house crows in Mombasa.

5.2 Bird species richness and diversity

Invasive species alter evolutionary pathway of native species through competitive exclusion, niche displacement, hybridization, introgression, predation and ultimately extinction (Mooney *et al*, 2003, Simberloff and Holle, 1999). A number of studies have shown that there are higher bird densities in urban areas than in natural areas, with bird diversity decreasing. Urban avian communities are dominated by a few species (Huhtalo and Jarvinen, 1977; Bland, 1979).

Huhtalo and Jarvinen (1977) found that in the cities of Tornio and Helsinki in Finland, there were eight species and three species respectively that were dominant. This study shows that sites with higher populations of invasive species correlates with low numbers of native species and bird communities. The three study sites deferred greatly in population sizes of the invasive house sparrow. They also differed in native species richness and diversity. Mombasa, which had the highest population of invasive species, dominated by the house sparrow and house crow had both the lowest native species diversity and richness. It is also the original site, where the house sparrow pioneered in 1950. High species diversity and

richness were realized in both Nairobi and Nakuru, with both sites having least population density of the invasive house sparrow. This was attributed to increased competition between the invasive and the native bird species. The native sympatric species were the most affected Areas where the invasive species have colonized and naturalized themselves for long had native sympatric species displaced completely. Time lag following invasion also appeared to determine dominance and abundance in invasive species. It also determined the rate of displacement of the native species. Mombasa where alien species had colonized for more than 65 years had the least native species richness and diversity compared to Nairobi and Nakuru. Both the native sparrows were present in Nakuru and Nairobi.

4.3 Some factors that enhances sparrow dispersal and colonization

Biotic and abiotic factors may influence avian adaptation and success by way of modification of behavioural and physiological changes. Such changes enable affected communities or population stay put and adjust to the changed conditions by means of phenotypic plasticity without altering their genetic constitution (Gienapp, et al 2007). Assessments of the effect of environmental factors on morphological variation in house sparrows in North America indicate that selection for optimal size tends to be most intense during winter months. That is, body size variation tends to be affected more by minimum temperatures (Johnston and Fleischer 1981, Lowther1977 and Rising 1972).

Increase in size has been associated with latitudinal environmental changes. In this study, we examined morphological variation in relation to environmental factors within and between localities in urban environments in Kenya. This was to investigate local differentiation in sparrow populations as a measure of local dispersal and adaptation of the invasive sparrow.

There were clear differences in wing length between the sparrow population in Mombasa and those in Nairobi and Nakuru. The coastal sparrow found in Mombasa had smaller wing length compared to the inland Nairobi and Nakuru populations. This was attributed to adaptation to longer distance of movement and dispersal. The inland sparrows in Nairobi and Nakuru would be of same population. They had much longer wing, probably due to the adaptation for long distance movement and dispersal compared coastal founder population which was more sedentary. The inland sparrows are more likely to be the same population due to much closer distance of less than 200 km in between Nairobi and Nakuru compared to Mombasa which is approximately 450 km from Nairobi. There is much less settlements along the Mombasa – Nairobi highway, especially Mombasa to Muitito Andei, between Voi and Tsavo National Park, where there are hardly human settlements, hence sparrows could hardly stop. This suggests that sparrows were less adapted to occupy natural niches away from human settlement. This could have triggered the enlarged wing length in the dispersing population.

Studies have shown that continued spread of an established population of an invasive species often occurs because of excellent adaptations for dispersal. Invasive species may therefore evolve both during their initial establishment and during subsequent range expansion. This would be in response to selection pressures generated by the novel environment (Sakai *et al*, 2001). Individual phenotypic characteristics have been associated with the dispersal ability and distance travelled by invasive species (Jensen *et al*, 2007). Differences in physical measurements or sizes of the sparrows might as well be as a result of the difference in populations that are separated in time and space, creating two distinct sub populations (the coastal and inland sub population). Skjelseth, *et al*, (2007) established that longer wing

length in house sparrows are associated with longer dispersal distance. Yong (1994) established that flight morphology affects aerodynamic performance. House sparrows have been localized to the coastal region for close to 65 years. Increased wing length is therefore attributed partly to morphological adaptation to new (space and flight), which seem to have enhanced further dispersal and colonization. Evolutionary changes in physiological traits can be important for determining distribution and abundance of species in natural communities. Such changes have been observed in invasive species colonizing new habitats and can be instrumental during the invasion processes (Reznick and Ghalambor, 2011).

There was an increase in mass of inland sparrows compared to the coastal sparrows. This is attributed to less intra-species competition between the inland invasive sparrows. Smaller body size in founder population, especially during establishment and colonization of invasive species is attributed to higher rate of population growth and higher carrying capacity (Lawton & Brown 1986). This might have facilitated the fast population growth of house sparrows at the source or entry point at the Kenyan coast. This would later establish a much larger and viable population that would later out-compete the native sympatric sparrows. In addition to Small size (mass), the head (head to beak) length in coastal sparrows was smaller compared to larger inland sparrows.

Therefore, a southward decrease in overall body size was predicted for the region. Variation in local temperature and humidity conditions in Zimbabwe and South Africa have been known to affect length of extremities, the populations in arid localities would have longer tarsi than those in the more humid sites, (Musimanga, 2001). This can be attributed to an adaptation to new feeds and also more food resource in new environment in inland sparrows.

Competition from the second invasive species (the house crow) might have resulted to reduced food resource, hence reduced body size. This means competition between two invasive species for limited food resource at the coast compared to less competition inland, hence more food for inland invading sparrow population. Sparrows inland had therefore a much reduced competition in their new environment compared to their initial site of colonization at the coast.

There might have been increased competition within the invasive sparrows as well as sympatric. Interspecies competition between the invasive species (the house crows and house sparrows) might also have triggered the dispersal of house sparrows inland. Lack of competition within the invasive sparrow might have provided more food resource in the newly invaded areas (Nairobi and Nakuru). The sparrows were also testing and leaning new feeds in their new environment without much competition. At the coast, house sparrow population was much higher in areas where the house crow population was lower.

4.4 Feeding behaviour and sparrow invasion

Resource competition is one potential behavioral mechanism by which invasive species can impact on native species, but detecting this competition can be difficult due to the interactions that variable environmental conditions can have on species behavior (Peck, *et al*, 2014). There was much closer association in food preference between the invasive house sparrow and the native grey-headed sparrow. These two species were found along the Nairobi Nakuru highway and in the industrial areas, where they fed on spilled cereals from the transport trucks. Both species preferred the same food type during feeding experiments,

but in different ratios and frequency of visits on different feeding patches. This is an indication of niche overlap, which might aggravate interspecific competition. It would be expected that the invasive species would explore more food variety than the native sympatric species. Food preference could be closely connected to flexibility of a species to adapt to different feeds.

The ability to develop new behaviors should facilitate the use of novel food resources and hence increase its survival in the new environment (Sol *et al*, 2011). A population or species that readily tastes new foods or adopts novel foraging strategies could be more pre-adapted to survive and reproduce in a novel environment than a more specialized (population) that persists with the behaviors of its area of origin, (Lynn and Lisa 2005). The house sparrow appeared to have had a narrow niche breadth by specializing on two types of food. In the experimental trials, they showed a higher preference for rice, then later a second choice of maize, while the native sparrows had three food choices. The invasive sparrow could still be learning new types of feeds in the new environment by taking on maize as second option in Nakuru. In Nairobi and Nakuru, house sparrows also were seen to frequent areas around retail cereal shops where they flew in the shops particularly chose to feed on rice. The shops sold rice and other cereals like maize, finger-millet and ground nuts.

Learning to adapt to new conditions in new environment is therefore a key factor in invasive species dispersal, naturalization and colonization of new environment. This shows flexibility in learning behaviour in the invasive house sparrow in new environment, showing novelty behaviour in invasive species. This could be one reason as to why it took close to 65 years for the invasive house sparrow to spread inland close to 500 kilometers. Rice is a common meal among the coastal people of Kenya compared to maize and its associated products.

Since the house sparrow had colonized the coastal region in 1950, they could have become familiar with rice for long.

Nakuru is a farming region of the Rift Valley and versed in agriculture. Maize is a common cereal in the region and readily available on farms as well as commercial and retail cereal outlets. The ability of the house sparrow to exploit new food resource indicates that the sparrows have an innovative novel behaviour of learning and exploring for new feeds with time. They are also quite selective and would prefer picking on one feed at a time during the processes of learning and adapting new environment.

There was some aggression behaviour observed between the native grey-headed sparrow and invasive house sparrow, where house sparrow was seen chased by the native sympatric sparrow from feeding points and also at breeding sites. The house sparrow is much smaller body size compared to the native grey- headed sparrow and therefore overpowered and chased away.

4.5. Breeding behaviour and sparrow invasion

Though both the native grey-headed sparrow and the invasive house sparrow bred in human manipulated infrastructure or buildings, the choice of nesting sites greatly differed between the two species. The house sparrow preferred higher human density sites while the grey-headed sparrows preferred sparsely or less human density sites. The grey-headed sparrow was very selective in choosing the infrastructure type on which to nest, the direction from wind and sun, and the site. For example during the nesting experiment, the native sparrow chose the nest boxes put on live trees and on the electric poles in an open environment. They also preferred their nest being raised between 10-12 meters high from the ground. The

invasive house sparrows preferred nesting in the nest boxes on human infrastructure (ware houses, cereal sores, milk factory). They were not very selective in terms of the height above the ground. They had a larger clutch size of (5-6 eggs) per nest, compared to the native sympatric sparrows with three eggs. This could easily lead to low population in native species. Studies have shown that low population size especially in native species results to increased susceptibility to genetic assimilation and native species displacement (Huxel, 1999).

It has been shown that range expansion in birds is related to dispersal ability. This is where high rate of population increase in invasive species is a result of large clutch size and production of several clutches per season. This enables the invasive species to compete for limited resources and habitat with native species, (O'Connor 1986).

Juvenile mortality was so high in the invasive house Sparrows. This was associated to nest infestation from lice observed inside nest boxes a few days before fledging of the juveniles. It was difficult for the parents to enter the nest and feed the young due to the infestation. Juvenile mortality was therefore due to starvation rather than the direct impact of infestation. However, studies have shown that invasive species are released from enemies and that they occupy empty niches, (Theoharides and Dukes, 2007). Enemies may include diseases, parasites and competitors which might affect their different stages of development. Already the invasive sparrows have parasites, which help in checking on their population growth.

Early nest abandonment was also observed in house sparrow close to the sympatric native sparrows. This was attributed to continuous aggression behaviour from the native grey-headed sparrows attacking the invasive house sparrow. The male house sparrow is quite persistent to aggression but the female easily gave up and in this case she abandoned both

persistent male and nest. The male could not carry out incubation and feed the young independently. He also abandons the nest and the un-hatched eggs two to three days after the departure of the female out that the femal. The female quickly gets to a different nest with a different male and can breed. Breeding in invasive house sparrows is a shared responsibility between the males and females. This involves nest building, feeding young, removing the fecal material of the nestlings from the nest and guarding the nestlings against predation.

Blue-eared Glossy Starling (*Lamprotornis chalybaetus)* raided both the house sparrow and the grey-headed sparrows at the nest. The starling is twice as large in size as the sparrows. They persistently attempted to enter and raid the sparrow nests but failed due to the small size of the entrance into the nest box. The starling was interested in robbing the nesting material from the sparrow nests.

4.6 Human influence activities in relation to spread and colonization of House Sparrows

Human influence is the major course of present plant and animal invasion. This is due to human introduction of alien invasive species to non native environment or offering means through which they can be introduced and expand their new ranges or territories. This study has established that both the native grey-headed sparrow and invasive house sparrow have a close human affinity especially during breeding. However the native sparrow has not depended on human for its entire survival compared to the invasive alien house sparrow. The invasive sparrows depend entirely on human for its survival. They nest in any opening in the roofs of buildings in human residential houses, cities, towns, shopping centers, gas stations, kiosks and cereal manufacturing industries. They feed on spilled food in kiosks, restaurants, dumping sites, gas stations and on roads along the highways. They also feed or rob directly especially rice from retail whole sale cereal shops in cities and sub-urban areas. Small flocks

were observed searching for seeds hay bale stores in Nairobi. House Sparrow densities and abundance were much higher in areas with higher human densities. Natural habitats in such areas were highly fragmented leading to loss of important ecosystems that support native biodiversity. This was seen to open a special niche to dispersal and spread of invasive house sparrows. Areas with low human densities recorded lower invasive sparrow population with higher native avian species diversity and richness. This could be attributed to the complexity of habitats resulting from natural and manmade (gardens) habitats with varied vegetation types. This provided a coherent and richer avian community structure. Such areas provided microhabitats leading to different ecosystems with different ecosystem services. This can lead to an elaborate ecosystem functions such as food chains and food webs. Habitat fragmentation in high human density sites provides an open niche for invasive species which accelerates further lose of native species through competition and predation. These are areas with higher population of invasive sparrows.

Filing gas stations were identified to provide both breeding and feeding sites for invasive sparrows along the Mombasa Malaba highway. The Sparrows roosts and breed in the roofs of shades and the cafeterias at the gas fueling stations. These have provided stopovers for feeding, breeding and dispersal sites for invading species. Food spillages from travelers at gas stations are fed on by the sparrows. There are shopping malls and cafeterias at present gas filling stations. These infrastructures provide both feeding and breeding sites for invasive house sparrows. Road transport seems to have enhanced invasive sparrow distribution and dispersal from Mombasa inland. Trucks and lories transport cereals along the Mombasa highway. Maize and rice spilled from the trucks especially on speed pumps along the highways supplement feeds for sparrows.

4.7 Solid Waste management

Informal settlements in urban and peri-urban centers due poverty and unstable income have resulted to influx of human population and continuous loss of habitat, (Chamberlain *et al* 2007). This is because people with minimal to poor income prefer to settle in such settlements because they are affordable. There are poor services in terms of solid waste management, sewer treatment, water drainage systems, and poor road networks, lack of clean water and health facilities among others. These areas are prone to increased industrialization and open damping sites of mostly domestic solid waste. Pollution and lose of natural habitat can cause an abnormal population growth of some species (especially native) leading to ecosystem disturbance and biodiversity reduction. On the other hand it favours alien invasive species. House Sparrow arrived in Nairobi in 1992 and spread quickly on the garbage sites (Zimmerman et al 1996). Dumping sites were identified as potential feeding sites for the house sparrow across the study areas. This is where domestic wastes, especially kitchen remains are deposited. Continuous human population increase in urban and peri urban centers is detrimental due to loss of natural habitats that support variety of native bird species. This affects interaction in natural ecosystems and ecosystem services as well as natural coexistence of different species. This has aided the increase in naturalization and dispersal of invasive species, which hastens the further loss of sympatric species due to competition for limited resources.

4.8 Predation in house sparrow

Woodlands and gardens provided cover for three species of raptors; African Harrier Hawk (*Polyporoides typus*), Great Sparrow Hawk (*Accipiter melanoleucus)* and Peregrine Falcon (*Falco peregrines*). The three are predators specialized in bird hunting especially on passerines. The Great Sparrow Hawk and African Harrier Hawks were observed Nairobi and Nakuru. They were associated with woody habitats. These are areas with large trees, suitable for nesting raptors. The African Harrier hawk preferred nestlings of the invasive sparrows from the rooftops of houses before the young birds fletched. Once it pursued a prey, it went to the branches of big trees and fed. It was also observed walk on the roof tops of houses in search of nests. This could be attributed to change in behaviour in these predators due to the presence and of the house sparrows, which have become an easy target prey. It is specialized in raiding and robbing nests of wood cavity nesting passerines. It has a double-jointed knee flexible to attain nestlings and eggs from nest and crevices. The Peregrine Falcon preferred patching on roofs of tall buildings in the CBD. This was attributed to their prey type, the swifts and feral pigeons. Peregrine pursue prey in flight, hence easy to catch swifts in the air, unlike house sparrows, which more concealed and camouflaged ground feeders.

4.9. Conclusion and recommendations

4.9.1 Conclusion

The study established that the native Grey-headed sparrow is a close associate to the invasive House sparrow in both feeding and breeding sites. The higher species richness and diversity was correlated to low abundance in invasive sparrows, while increased abundance in invasive species negatively affected native species richness and diversity. This agrees with other studies, where invasive house sparrows have been known to have significant negative impacts on native bird communities, especially in the urban areas, (Johnson and Violett, 2012). Higher abundance of invasive sparrows also affected the sympatric native sparrows, whereby they were outcompeted and displaced. The current spreading of the house sparrow across different altitudinal levels across the country is most likely to affect other avian communities resulting to detrimental changes in the entire biodiversity and the ecosystems within the major cities and smaller towns in urban environment in Kenya.

Ability to adapt to new and different environmental conditions and varied altitudinal gradients has enabled house sparrow to establish and easily colonize different urban environments in Kenya. Invasive house sparrows have the ability to acquire quantitative and social traits which enriches and enhance their ability to adapt to different environmental conditions in new environments. This enables the species to become a better competitor with native species as well as to acquire the efficiency in dispersal and colonization. The house sparrow has developed a variety of traits and characteristics that enhance this adaptability. Sparrows in newly invaded areas had increased wing length, body size (mass) head-bill size. They are also able to learn and adapt to different environmental challenges. This novelty behaviour enabled them to quickly learn and adapt to new feeds in new environment.

Invasive sparrows had increased clutch size, hence increased brood size compared to the native sparrows. Enlarged clutch size enabled the invasive sparrow to have a larger population size compared to the native sparrows. House sparrow raises twice the brood size of the native sympatric grey-headed sparrow. This led to increases competition for food resource between the invasive sparrows and the native sympatric species. However, they were not very selective in where they set their nest.

Due to their affinity to human inhabited areas, and the ability to survive in wider altitude range (from sea level to foot of on Mount Kenya), the house sparrow survive in wide range of habitats. As the urban centers continue to expand every year, there is an in increase in human population as well. This leads to fragmentation of urban natural habitat. This will continue to open wider niches for invasive species as it narrows the niche for native species. The house sparrow will therefore continue to spread and disperse in Kenya.

The present continuous growth in infrastructure (road networks, highway bridges, rural electrification, discoveries and mass extraction of natural resources such as gas and oil in Kenya will continue to threaten the natural ecosystems. This will provide and enhanced range expansion for invasive sparrows. They provide means for invasion dispersal as well as sites for feeding and breeding hence naturalization. The population will soon realize fast increase in near future in urban centers as well as wildlife protected areas such as national parks game reserves and sanctuaries.

4.9.2 Recommendation for research

- The association of two invasive species (the house crow and house sparrow) in the urban environment at the Kenyan coast and their ecological interaction is not clear. We recommend that further studies to be carried out to determine their relationship in terms of space and food. Food and space may also affect the dispersal and colonization of the two alien species. This may also affect the distribution of the native avian community.
- There are four races of the native grey-headed sparrow. It is not clear which races will be the most vulnerable following the present dispersal and colonization of the invasive house sparrow, and therefore need for further investigation.
- Predation and house sparrow infestation with parasites was evident during this study. We recommend further studies to investigate mortality at different stages (nestlings to adult) of development and how this affects reproductive success. Also to find out is the causes of the mortality.
- Breeding seasons in House Sparrows are not well known in East Africa, the fact that it is latest in invasion. We recommend studies to investigate the breeding seasons of the species.

4.9.3. Recommendation for invasive species management.

There is need for further ecological studies and monitoring to be carried out on the effects of the invasive House Crow on the general avian community on the Kenyan Coast. The absence of the native Pied Crow larger part of the urban environment in Mombasa is an alarming ecological and niche breakdown. The invasive House Crow has just started expanding its range from the coast to inland. This calls for speedy measures in controlling and managing the species, since its impacts have already been felt.

Invasive species management especially the House Sparrow and House Crow calls for synergetic approach from different stake holders. They include the County governments, the Kenya Wildlife Service (KWS), the National Museums of Kenya (NMK), National Environmental Management Authority (NEMA) and higher learning institutions among others. These will come up with the best structured management policies and tools to aid in alien species management.

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Appendix 1. List of Species of birds observed in Mombasa(20 species)

House Crow	*Corvus splendens*
House Sparrow	*Passer domesica*
Cattle Egret	*Bubulugus ibis*
Common bulbul	*Pycnonotus barbatus*
Little Swift	*Apus afinus*
Speckled Mouse bird	*Colius stratus*
Yellow Wagtail	*Motacilla flava*
Village Weaver	*Ploceus cucullatus*
Pied Crow	*Corvus albus*
Common Drongo	*Dicrurus adsimilis*
Red-cheeked Cordon-bleu	*Uraeginthus bengalus*
African Palm Swift	*Cypsiurus parvus*
African Pied Wagtail	*Motacilla aquimp*
Bronze Manikin	*Spermetes cuculatus*
Tambourine Dove	*Turtue tympanistia*
Hadada Ibis	*Bostrychia hagedesh*
Diederik Cuckoo	*Crysococcyx caprius*
White-ramped Swift	*Apus caffer*
Red-cheeked Cordon-bleu	*Uraeginthus bengalus*
Feral Pigeon	*Columba livia*

Appendix 2. Species of birds observed in Nairobi (40 species)

House Sparrow	*Passer domesicus*
Kenya Rufous sparrow	*passer rufocinctus*
Common bulbul	*Pycnonotus barbatus*
Red-chested Cuckoo	*Cuculus solitaries*
Baglafetcht Weaver	*Crithagra sulphurata*
Cape Robin Chat	*Cossypha caffra*
Red-eyed Dove	*Streptopelia semitorquata*
Bronze Sunbird	*Nectarinia kilimensis*
Speckled Mousebird	*Colius stratus*
Red-faced Cisticola	*Cisticola erythrops*
Olive Thrush	*Turdus olivacea*
White-eyed Slaty Flycatcher	*Melanornis fischeri*
Streaky Seedeater	*Melvus migrans*
Black Kite	*Milvus migrants*
Grey-headed Sparrow	*Passer griseus*
Pied Crow	*Corvus albus*

Speke's Weaver	*Ploceus spekei*
Sacred Ibis	*Threskionis aethiopicus*
Speckled Pigeon	*Columba guinea*
Red-eyed Dove	*Streptopelia semitorquata*
White-belied Tit	*Parus albiventris*
Black-backed puffback	*Dryoscopus cubla*
Hunter's Cisticola	*Cisticola hunter*
Hadada Ibis	*Bostrychia hagedesh*
Village Indgobird	*Vidua chalybeate*
Egyptian Goose	*Alopochen aegyptiaca*
African Paradyse Flycatcher	*Terpsiphone viridis*
African pied Wagtail	*Motacilla aquimp*
Common fiscal	*Lanius collaris*
Variable sunbird	*Cynniris venusta*
Cinnamon-chested Bee-eater	*Merops oreobetes*
Red-billed firefinch	*Lagonostica senagala*
Gymnogen (African Harrier Hawk)	*Poyboroides typus*
Rock Martin	*Ptynoprogne fuligula*
Singing cisticola	*Cisticola cantans*
Feral Pigeon	*Columba livia*
Little Swift	*Apus afinus*
Cinnamon-chested Bee-eater	*Merops oreobetes*
Red-billed fire finch	*Lagonostica senagala*
Gymnogen (African Harrier Hawk)	*Poyboroides typus*

Appendix 3. Species of Birds observed in Nakuru City (49 Species)

House Sparrow	*Passer domesicus*
Speckled Pigeon	*Columba guinea*
Little Swift	*Apus afinus*
Superb Starling	*Lamprotornis superbus*
Grey-headed Sparrow	*Passer griseus*
Baglafetcht Weaver	*Ploceus baglafetcht*
Common fiscal	*Lanius collaris*
Red-eyed Dove	*Streptopelia semitorquata*
Speckled Mousebird	*Colius stratus*
Common bulbul	*Pycnonotus barbatus*
Bronze Sunbird	*Nectarinia kilimensis*
African mourning Dove	*Streptopelia decipiens*
Cape Robin Chat	*Cossypha caffra*
Tropical Boubou	*Laniarus aethiopicus*
Pied Crow	*Corvus albus*
Fischer's Lovebird	*Agapornis fischeri*
Red-cheeked Cordon-bleu	*Uraeginthus bengalus*
Yellow Bishop	*Euplectes capensis*
Brimstone Canary	*Crithagra sulphurata*
Streaky Seedeater	*Melanornis fischeri*
Winding cisticola	*Cisticola chiniana*
Plain Martin	*Riparia paludicola*
Hadada Ibis	*Bostrychia hagedesh*
Village Indgobird	*Vidua chalybeate*
Pin-tailed Whydah	*Vidua macroura*
Red-winged Starling	*Onychognathus morio*
Kenya Rufous sparrow	*passer rufocinctus*
Cardinal Woodpecker	*Dendropicos fuscescens*
Cattle Egret	*Bubulugus ibis*
Laughing Dove	*Streptopelia senegalensi*
African Pied wagtail	*Motacilla aquimp*
Kenya Rufous sparrow	*passer rufocinctus*
Northern Anteater Chat	*Myrmecocichla aethiops*
Ruppell's Robin Chat	*Cossypha semirufa*
Tawny-flanked Prinia	*Prinia subflava*
Feral Pigeon	*Columba livia*
Olive Thrush	*Turdus olivacea*

Great Sparrowhawk	*Accipiter melanoleucas*
Nyanza Swift	*Apus niansae*
Common stonechat	*Saxicola torquata*
Red-billed firefinch	*Lagonostica senagala*
Speke's Weaver	*Ploceus spekei*
Grey-backed Camaroptera	*Camaroptera brachyuran*
Rock Martin	*Ptynoprogne fuligula*
African Paradyse Flycatcher	*Terpsiphone viridis*
White-rumped Swift	*Apus caffer*
African Palm Swift	*Cypsiurus parvus*
Scarlet-chested Sunbird	*Chalcomitra senegalensi*
African citril	*Streptopelia semitorquata*

Appendix 4. The abundance of different bird species observed in the three study areas.

House Sparrow	92	184	751
Grey-headed Sparrow	40	12	0
Kenya Rufous Sparrow	17	32	0
House Crow	0	0	890
Pied Crow	24	74	3
Cattle Egret	2	0	21
Hadada Ibis	18	4	2
Sacred Ibis	0	13	0
African Harrier hawk	1	2	0
Great Sparrow hawk	1	0	0
Black Kite	0	54	0
Tambourin Dove	0	0	1
Red-eyed Dove	21	22	0
Laughing Dove	36	0	0
Mourning Dove	4	0	0
Feral Pigeon	6	6	4
Speckled Pigeon	64	14	0
Little swift	150	40	72
Nyanza Swift	15	0	0
African Palm Swift	6	2	12
Plain Martin	8	0	0
Rock Martin	2	3	0
African Paradise flycatcher	1	1	0
African Pied Wagtail	2	2	2
Yellow Wagtail	0	0	1
Cardinal Woodpecker	1	0	0
Cinnamon-chested Bee-eater	0	1	0

Common Bulbul	7	26	4
Common Drongo	0	0	10
Common Fiscal	6	1	0
Black-backed puff back	0	1	0
Red-chested Cuckoo	0	1	0
Diedrick Cuckoo	0	0	1
Fischer's Lovebird	11	0	0
Grey-backed Camaroptera	1	0	0
Speckled Mousebird	24	28	5
Red-winged Starling	2	0	0
Superb Starling	18	0	0
Olive Thrush	1	12	0
Northern Anteater Chat	3	0	0
Ruppell's Robin-chat	1	0	0
Cape Robin	5	4	0
Common Stonechat	4	0	0
Tropical Boubou	8	0	0
Bronze Sunbird	4	12	0
Variable Sunbird	0	4	0
Scatlet -chested Sunbird	2	0	0
Hunter's Cisticola	0	2	0
Singing Cisticola	0	4	0
Red-faced Cisticola	0	2	0
Winding Cisticola	1	0	0
Tawny-flanked Prinia	4	0	0
White-belied Tit	0	1	0
White-eyed Slaty Flycatcher	0	3	0
White-rumped Swift	8	0	1
Speke's Weaver	10	80	0
Village Weaver	0	0	34
Baglafetched Weaver	36	29	2
Black-headed Weaver	0	0	2
Yellow Bishop	4	0	0
Bronze Mannikin	0	0	4
Village Indigobird	5	10	0
Pin-tailed Whydah	17	0	0
Red-billed Firefinch	4	2	0
Red-cheeked Cordon-bleu	2	0	5
African Citril	4	0	0
Streaky Seed-eater	8	15	0
Brimstone Canary	8	0	0
Total number of birds	**719**	**704**	**1827**

Appendix 5 determine significance in food choice between sympatric sparrows

Sparrows.	**Grey. H. Sparrow**	**House Sparrow**	**Rufous Sparrow**
Grey-headed Sparrow	-	0.040	0.338
House Sparrow	0.040	-	0.298
Rufous Sparrow	0.338	0.029	-