INSECT ABUNDANCE AND FOOD INTAKE BY *Agama mwanzae* IN SERENGETI NATIONAL PARK, TANZANIA

BY

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ABSTRACT

The kopjes of Serengeti National Park, can be considered to be an understudied ecosystem although harbours a diverse distinct flora and fauna; even basic information such as knowledge about the food of *Agama mwanzae* is unknown. Thus, the study involved the investigation of the spatial and seasonal variation of insect abundance and agama food intake in the grass plain kopjes of Serengeti National Park. The insects were sampled by pitfall, sweep net and tray traps monthly within one year. A total of 58 175 individuals from 16 orders were collected. The most common orders were Hymenoptera (30.19%), Hemiptera (19.50%), Orthoptera (18.10%), Diptera (10.60%), Coleoptera (9.20%), Arachnida (4.40%), Dictyoptera (2.70%), Lepidoptera (2.50%), and Isoptera (1.90%). Insect abundance was higher during the wet period as compared to the dry season and Gol kopjes attained the highest insect abundance followed by Simba and lastly Barafu kopjes. A total of 2350 insect food items were identified from 120 agama lizard specimens whereby 1597 were found during the wet season and 750 in the dry season. The majority of the diet consisted of the Hymenoptera (47.03%), Isoptera (29.78%), Coleoptera (18.29%), and Orthoptera (2.63%). In addition to insects, *A. mwanzae* fed on plant materials. Insects comprised the majority of food items during the wet period when this prey was most common. During the dry season plant material was the dominant food type to agama lizards because of scarcity of insect food. It was found that there was statistical significant difference in agama food intake between seasons and locations. Due to the increase of destruction of agama lizard habitats the management authorities should ensure that the land management practices should not damage these fragile habitats.

DECLARATION

I JOHN THOMAS MCHETTO do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

_____ _____

John Thomas Mchetto **Date**
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The above declaration confirmed

_____ _____

Prof. S.L.S. Maganga **Date**
(Supervisor)

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LIST OF ACRONYMS

FZS	-	Frankfurt Zoological Society
HSD	-	Honestly Significantly Different test
SQRT	-	Square Root Transformation
SBP	-	Serengeti Biodiversity Programme
SNP	-	Serengeti National Park
SPSS	-	Statistical Package for Social Sciences
TAWIRI	-	Tanzania Wildlife Research Institute
TPRI	-	Tropical Pesticides Research Institute

CHAPTER ONE

INTRODUCTION

1.1 Background

Serengeti National Park (NP) in Tanzania, East Africa, is part of the larger Serengeti-Mara ecosystem, which is defined by annual movements of migratory herds of wildebeest (*Connochaetes taurinus*), zebra (*Equus burchellii*) and eland (*Taurotragus oryx*) (Pennycuick, 1975; Sinclair & Norton-Griffiths, 1979). Also the Serengeti is renowned for its agama lizard populations. Kreulin (1975) reported five species of agama lizard such as *Agama agama, Agama cyanogaster, Agama hispida, Agama planiceps mwanzae,* and *Agama caudospinosa.* However, Howell *et al.* (2002) found only three species of agama lizards occurring in Serengeti NP. The agama lizard species include Flat-Headed Agama (*Agama mwanzae*), Tropical Spiny Agama (*Agama armata*) and Red-Headed Rock Agama (*Agama agama*).

In Serengeti NP, agama lizards are mostly found in the woodland and grassland kopjes, formed by pre-Cambrian orogenic events that created the African Shield (Sinclair, 1995; Porembski *et al*., 1996). Kopjes are unique habitat types because they host diverse plant and animal communities (TANAPA, 1997). Although kopjes cover a small proportion of the park area, they provide resources that are uncommon in the Serengeti landscape and are known to host diverse, yet poorly documented, biotic communities (Tragger & Mistry, 2003) including agama lizards. Agama lizards are primarily insectivorous, however have been known to eat small mammals, small reptiles, and plant materials such as flowers, grasses, and fruits (Anibaldi *et al*., 1998). Many studies have shown that insect abundance was related to rainfall patterns. Similarly, insect abundance decreases when rainfall decrease (Sinclair, 1978; Pinheiro *et al*., 2007). In general, therefore, most types of insects are scarce during the dry season. Diet is a key component of an organism's natural history

and essential for implementing effective conservation and management strategies (Bury, 2006; McCallum & McCallum, 2006).

Agama lizards are very important in an ecosystem by feeding on different varieties of insects and plant materials and inturn being eaten by other living organisms such as hawks. They are regarded as frugivorous and seed dispersers (Herrera, 2002) as well as insectivorous animals. Feeding on plant materials reduces pests of plant (Gupta, 1982) and other insect species of economic importance. The dead bodies and faecal materials provide important nutrients for the food chain to continue. Due to their mode of living and beauty of their habitats add attraction to tourism therefore development of tourist industry and therefore more foreign currency to the country.

The differences in seasons and therefore variation in insect abundance and agama food availability, have lead to major impacts in agama populations. During the wet season when food is abundant agama lizards can have a wider chance of selecting many and different types of food than during the dry season when food is scarce. On the whole, it is not clearly known if there is food limitation for agamas during the dry seasons.

1.2 Problem statement and Justification

The Serengeti kopjes in the plains and woodlands habitats accommodate several agama populations, but no information is available about their feeding ecology, and it is not clearly known, whether food limitation occurs in the dry seasons. This study therefore aims to investigate seasonal and spatial variation of insect abundance and food intake by agama lizards between Simba, Gol and Barafu kopjes in the Serengeti NP. The kopjes are more easily accessible compared to the woodland kojes because they are found in open grass plains where the study can be easily conducted.

The scientific information generated by this study will assist the park management in monitoring the agama lizard populations, which can decrease unnoticeably if appropriate management practices are not taken. Moreover, the information will increase awareness for their conservation status, as very little attention is paid to reptiles. The information will improve our understanding of the factors underlying the diversity and abundance of agama lizards and will be useful for biodiversity conservation in the Serengeti NP.

1.3 Objectives of the Study

1.3.1 General objective

The general objective was to investigate insect abundance and food intake by agama lizards in selected grass plain kopjes of Serengeti NP.

1.3.2 Specific objectives

The specific objectives of this study were:

(i) To determine variation in the abundance of insects and agama food intake between Simba, Gol and Barafu kopjes.

(ii) To determine variation in the abundance of insects and agama food intake between wet and dry seasons.

1.4 Research Hypotheses

The research was guided by the following hypothesis:

H_0. There is no significant variation in seasonal abundance of insects and agama food intake among Simba, Gol and Barafu kopjes.

CHAPTER TWO

LITERATURE REVIEW

2.1 General Information

2.1.1 Agama lizards

The family Agamidae is composed of 35 genera and over 3 900 species, found in Africa, Asia and Australia continents. Agamas originally lived in forest and bush across Africa, but have since adapted to live in villages and compounds where their habitat has been cleared. If caught out in the open, agamas are able to run quickly on their hind legs to reach shelter. In Africa, the genus *Agama* is composed of at least 31 species (Manthey & Schuster, 1996). Eight agama lizard species occur in East Africa whereby three are endemic. The lizard species include red-headed rock agama (*Agama agama*), tropical spiny agama (*Agama armata*), elmenteita rock agama (*Agama caudospinosa*), montane rock agama (*Agama montana*), mwanza flat-headed agama (*Agama mwanzae*), Somali painted agama (*Agama persimilis*), ruppell`s agama (*Agama rupelli*) and black-necked tree agama (*Agama cyanogaster*). In Serengeti NP, Howell *et al.* (2002) found only three agama lizard species; *Agama mwanzae, Agama agama* and, *Agama armata*.

Agama mwanzae also called flat-headed rock agama. In the past it was regarded as a subspecies of the Namibian flat agama known as *Agama planiceps* but now recognized as a full distinct species (Howell *et al*., 2002). The agama lizard distribution ranges from Masai Mara south-west through the Serengeti to south of Lake Victoria shore across to eastern Rwanda and Burundi; south into southern Tabora district. Like other agama lizards, *Agama mwanzae* is a diurnal, insectivorous and oviparous lizard. In Serengeti NP, *Agama mwanzae* inhabits rocky outcrops that are scattered in the woodland and grass plains where they have an impact on other organisms as predators and prey. Like any other lizards, the

A. mwanzae have dry scaly skin, four legs, clawed feet, a long detachable tail and external ear opening (**http://www.eduscapes.com/nature/lizard/index1.htm**).

Mature dominant agama males have bright orange and blue coloring and may have a red face (Plate 1). Subordinate males or any that have recently been frightened will have a dull brown color. At night, all males turn to a dark shade of brown. Males differ from females as often being brightly coloured with large body size [http://en.wikipedia.org/wiki/ Agama_(lizard)].

Plate 1: Male *Agama mwanzae* lizard

Agamas are active during the day, often found scampering around to snatch up their favorite foods. They can tolerate high temperatures than most reptiles, but in the afternoon when temperatures reach around 38°C (100°F) they will settle into the shade and wait for it to cool [http://en.wikipedia.org/wiki/Agama_(lizard)]. Males have frequent fighting to defend their territories which involve a lot of bobbing and weaving in an attempt to scare each other. Many older males have broken tails as a result of such fights. Females may sometimes chase and fight each other.

Most agamas are polygamous. Males may hold six or more females in their territories for breeding. During courtship, the male bobs his head to impress the female. Occasionally, females may initiate courtship by offering their hindquarters to the male and then running until he is able to catch up. The breeding season is typically March-May with eggs being laid in June-September during the season after the rains. Females may lay 2-20 eggs per clutch and may lay several times a year depending with food availability. Incubation is 1.5-4.5 months depending on species. [http://en.wikipedia.org/wiki/Agama_(lizard)].

2.1.2 Insects

Insects are animals belonging to the phylum Arthropoda meaning "jointed feet". Other Arthropods include crustaceans (crabs, lobsters, barnacles, and their allies) and chelicerates (spiders, scorpions, and their allies), and several less diverse and lesser known animal groups (Martin & Wetzer, 2002). The insect body is usually recognizable as being divided into three regions: the head, the thorax (composed of three segments, each of which bears one pair of appendages), and the abdomen. The eyes are large, paired, and compound, and there is often an additional pair or trio of "simple" eyes on the centre of the head. There is only one pair of antennae. Some insects, such as crickets and grasshoppers, develop slowly and gradually, with only small changes during each moult (called hemimetabolous insects),

whereas others, such as butterflies and moths, change drastically during a moult (and are called holometabolous insects). Insects are almost exclusively terrestrial, although many species are aquatic or have an aquatic stage in their life cycle. Common examples of insects include flies, beetles (the most numerous kind of creature on earth in terms of numbers of species), butterflies, crickets, grasshoppers, cockroaches, ants, bees, wasps, dragonflies, termites, and many more. Insects are found in nearly every habitat on earth and are involved with everything from pollination of important agricultural plants to the spreading of deadly diseases (Martin & Wetzer, 2002). Today, insects are by far the most successful group of animals on the planet.

2.1.3 Kopjes or inselbergs as agama habitat

Kopje (pronounced "copy") is an Afrikaans name for the clusters of large granite rocks or inselbergs or rock outcrops which are found in many of the parks in Tanzania, but which are particularly a feature in the Serengeti. Turner & Watson (1965) describe kopjes as rock outcrops littered with crevices and sheltered caves which promote condensation of dew, reduce water loss and increase water retention on the kopje. The milder temperature, humidity changes in the interior rock crevices and fire-resistant thickets growing at the kopje base generate abiotic conditions different from those of the grassland, which may explain the distinct ecological community characterized by dense woody vegetation. Because of these conditions agama prefer to live in these kopjes.

The Serengeti NP harbours one of these rock outcrop communities. They consist of several clustered granitic–gneissic boulders that originate from Precambrian orogenic events (Porembski *et al*., 1996) and most of them have rounded shapes due to weathering, and protrude like “islands” from the surrounding plains to an elevation of up to 30 m (Hay, 1976).

The study of kopjes has provided numerous insights into the composition and ecology of isolated communities. For many species, kopjes function as terrestrial islands within a surrounding habitat matrix, and thus form study subjects for theories pertaining to island biogeography, as well as the biology of fragmented habitats (Porembski & Barthlott, 2000). Previous research of kopjes has described systems with distinct species compositions, often supporting rare or even endemic species (Poelchau & Mistry, 2006).

2.2 Agama Lizard Food

Many agama feed on insects and other small animals, although some species are partly herbivorous. Their incisor-like front teeth are designed for quick cutting and chewing prey. They may also eat grass, berries, seeds and even the eggs of smaller lizards (Anibaldi *et al.*, 1998; Arttatrana *et al.*, 2007).

Stomach contents of the garden agama lizard (*Calotes versicolor)* revealed a diet of mainly ants, although it also ate other small invertebrates and plants (Diong *et al.*, 1994; Kalita, 2000). The garden agama lizard occasionally preys on small birds and nestlings, frogs, geckos, and small snakes (Sharma, 1999). The fan-throated agama lizard (*Sitana ponticerianaa*) stomach contents revealed that the lizard is primarily insectivorous (Arttatrana *et al*., 2007). The Hymenoptera represented the most important food item in terms of total numbers, followed by Lepidoptera and Isoptera. During the summer months, the lizard ate termites, ants and occasionally crickets, gastropods and plant material. Also, small stones, sand particles, fragments of mollusk shell, and an unidentifiable amorphous substance were found in the stomachs. Ants (Formicidae), termites (Isoptera), and crickets (Gryllidae) were the major food items in rainy season. Caterpillar larvae, ants, crickets and beetles represented the major dietary components in winter (Arttatrana *et al*., 2007). In

summer, lizards fed on termites, ants and occasionally crickets, gastropods and plants (Diong, 1994).

Dietary niche breadth also varies within species from time to time and from place to place as the composition of diets change with opportunistic feeding in response to fluctuating prey abundances and availabilities. Some species specialize on scorpions, ants, termites, vertebrates, and/or on plants, whereas other species on each continent are much more generalized, eating an extremely wide variety of food categories, for example, in the diets of climbing lizard species, Hemiptera-Homoptera and mantids-phasmids as well as various flying insects (wasps, diptera and lepidoptera) tend to be better represented than other terrestrial species (Arttatrana *et al*., 2007).

2.3 Agama Lizard Food Analysis

Lizard foods can be analyzed by examining stomach contents, stomach and intestinal contents, fecal pellet contents, by stomach flushing or by actual observation of foraging (Heideman, 2002). The first two methods appear most commonly used. The examination of stomach contents alone provides a more accurate assessment of lizard diets than examination of the entire alimentary canal (Floyd & Jenssen, 1984). According to Floyd & Jenssen (1984), digestion tends to remove soft bodied food items, which are usually large, from the lower part of the alimentary canal so that small bodied food items predominate in the hindgut, leading to an underestimation of large bodied prey if contents of the entire alimentary canal are used. Schoener (1989), however, refuted this argument by showing that in general there is a non significant decrease in both prey species diversity and size from fore to hind gut. Schoener (1989) further contended that an analysis of the entire gut not only eliminates the possibility of larger food items being underestimated but in fact increases sample size.

2.4 Seasonal Variation of Insect Abundance

Pinheiro *et al*. (2007) examined the temporal distribution of insect abundance in the savanna-like vegetation in Brazil. The results showed that the orders were Coleoptera (26.00%), Hymenoptera (23.00%), Diptera (20.50%), Isoptera (20.00%), Homoptera (4.00%), Lepidoptera (4.00%), Orthoptera (1.50%) and Hemiptera (1.00%). The abundance of Diptera, Homoptera, Lepidoptera and Orthoptera was randomly distributed over time. Isoptera peaked in the first half of the wet season, Coleoptera and Hemiptera in the second half of the wet season and Hymenoptera in each season and therefore, concluded that there were no obvious trends that might help explain the abundance patterns observed. In Uganda, West Africa and in Serengeti plains Sinclair (1978), found a large increase of insect numbers with the onset of the rains. Moreover, tropical insectivore lizards often have breeding cycles which coincide with the rainy season of their respective regions (Dunham, 1982; Fuentes & Campusano, 1985). This information suggests that food limitation in the dry season might influence timing of reproductive patterns in tropical lizards.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The study was carried out in the south-east area of Serengeti NP which is situated between 2º30'-2º50'S and 34º50'-36º10'E. The area is bordered by Ngorongoro Conservation Area to the south, south east and east, Seronera woodlands to the north, Loliondo Game Controlled Area to the north east and Naabi Hill to the south west.

The study area encompassed a plain which is essentially treeless with a gently undulating topography, a few temporary rivers and three groups of kopjes located distantly from one another (Fig. 1). The three groups of kopjes include Simba, Gol and Barafu within long, intermediate and short grass plains, respectively (Norton-Griffiths *et al*., 1975; Sinclair, 1978).

Simba kopjes are a group of kopjes found on the western side of the study area. East Simba and west Simba kopjes are separed by a main road passing from Naabi Hill to Seronera. Grass in this area can grow up to more than a meter and that is why is known as long grass plain. The plain in Simba kopjes is covered by cotton soil that makes difficult to pass through during the wet period. The Gol kopjes are found on the south and central part of the study area, the area with the largest number of kopjes and it lies within the intermediate and short grass. Intermediate and short grasses are found in the western and eastern sides respectively. The soil in this area (and Barafu) is friable and porous and is composed of volcanish derived from crater highlands. This is the area in the study area that is mostly visited by the migration of ungulates. Barafu kopjes are found on the eastern side of the

study area with very short grass. Barafu kopjes are the area reported to receive the least amount of rainfall (Norton-Griffiths *et al*., 1975), the one with fewest number of kopjes.

The kopjes are very special because the migration of animals (wildebeest, zebra, eland, and Thomson and grant gazelles) spends most of their time during the wet period grazing on the grass plains. Other wild animals such as lion, cheetah, hyaena and many other migratory birds are also found associated with the wildebeest migration. The agama lizards can also be seen very well in large numbers basking and chasing each other on the kopjes. The area is highly visited by tourists because of its accessibility and the high concentration of animals.

3.1.2 Soils

The soils in the west, central and northern parts of Serengeti NP, in the upper parts of the drainage systems are sandy loams, while in the lower part they are heavy clays (Anderson & Talbot, 1965). The soils in the eastern part of the park are composed of volcanic ash derived from the crater highlands, friable and porous and do not hold rain water long, punctuated by granite outcroppings known as kopjes formed as the result of volcanic activity. Kopjes are composed of granitic gneisses and quartzite formed by pre-Cambrian orogenic events (Sinclair, 1995; Porembski *et al.*, 1996). Tectonic rifting, deep weathering and erosion of volcanic sediment have exposed kopjes throughout the Great Rift Valley of East Africa (Sinclair, 1995).

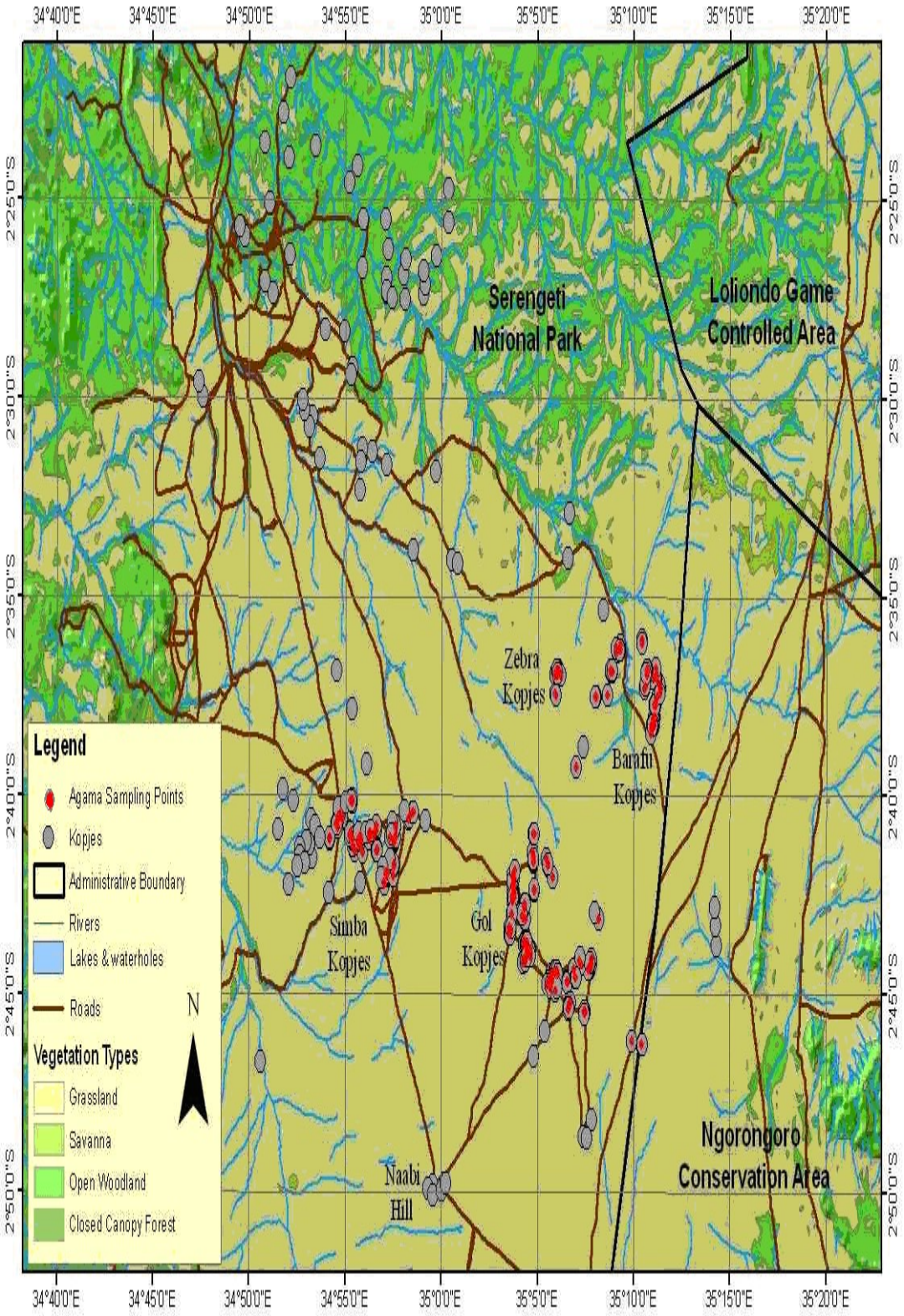

Figure 1: The study area showing Barafu, Gol and Simba kopjes in the Serengeti NP

3.1.3 Climate and vegetation types

Altitudes in the Serengeti range from 920 to 1850 meters with temperature varying from 30º Celsius in the day to 15º Celsius at night and the mean daily temperatures remain around 15º to 25º Celsius throughout the year (Sinclair, 1978). Although the climate is usually warm and dry, rainfall is seasonal and highly variable both in time and space. There are two major seasons, wet season from November to May, and dry season from June to October (Norton-Griffiths *et al*., 1975). Rainfall distribution is bimodal with short rains from November through December. Grass remains green unless there has been a complete failure of the first rains and long rains start from March to May (Sinclair, 1995). The average annual rainfall ranges from 600 mm per year on the south-east plains to about 1100 mm per year in the north (Pennycuick, 1975).

Serengeti NP comprises a mosaic of grassland, wooded grassland, bushland and forest habitats and they are generally distributed along a rainfall gradient with local variation according to edaphic and topographic features. Associated with these gradients are changes of vegetation from the open grasslands of the Serengeti plains to the woodlands of the central and northern parts of the region. Nearly two thirds of the park is bush or woodland (Sinclair, 1995). The south east plains in which this study was conducted, usually receives 350–500 mm $year^{-1}$ and is composed of treeless plains dominated by grass, few trees and shrubs on the kopjes. Grass in Simba kopjes can grow up to 100 cm tall whereas in Gol and Barafu kopjes grass sward stands only 15 cm high. Common grass types found in the study area include *Kyllinga nervosa*, *Sporobolus icoclades*, *Andropogon greenwayi*, *Pennisetum mezianum* and *Themeda trianda* (Braun, 1973). The grasses are alkaline-tolerant and there are many small dicots.

Generally the flora in the kopjes is different from that of surrounding plains. Kopjes are rich in herbs, bushes and trees such as the candelabra euphorbia (*Euphorbia candelabrum*), aloes (*Aloe volkensii* and *Aloe macrosiphon*), fig trees (*Ficus glumosa, Ficus thonningii* and *Ficus ingens*) and wild sisal (*Sansevieria ehrenbergiana*) (Hoeck, 1975).

3.2 Sampling Design

The study area is comprised of more than 280 kopjes of different shapes and sizes (SBP, 2002). Based on this range, kopjes for agama and insect trapping were sampled following three criteria; visibility from vegetation cover (on a scale of 1 for most easily visible, 2 for moderate and 3 for the least visible), height (on a scale of 1 for kopjes less than 5 m in height, 2 for kopjes between 5 and 10 m in height and 3 for kopjes more than 10 m in height), and kopje length (on a scale between 1 for kopjes less than 10 m, 2 for kopjes between 10 and 30 m in length, and 3 for kopjes greater than 30 m in length). The Global Positioning System (GPS) coordinates and waypoint numbers were noted on the data sheet for all kopjes that are easily and moderately visible with a height and length of scale one.

3.3 Techniques for Data Collection

Data were collected from primary and secondary sources.

3.3.1 Primary data collection

The study involved reconnaissance and field survey. Reconnaissance survey was conducted in order to check the research area and a field survey involved a combination of techniques including collecting of insects and agama gut contents.

3.3.1.1 Insect abundance

From each of the three locations, a total of 10 kopjes were used for insect trapping. Insect abundance was sampled in each kopje on monthly basis by the use of four aluminium trays

(28 cm diameter) and four pitfall traps, i.e. beer mug (8.7 cm diameter). The inside of the tray trap was painted yellow to attract insects and then placed on a flat surface with 10% methanol and two to three drops of soap to reduce surface tension. The same method was applied to pitfall traps, which were then buried into the ground. Trays and pitfall traps were left for 24 hours.

Captured insects were collected, labeled and preserved in methylated spirit. In each kopje, forty sweeps were taken with a sweep net (36 cm diameter net of 1.5 mm mesh) and insects captured were placed in a plastic bag and labeled. Three to five drops of ethyl acetate to the piece of cotton wool were used to kill the insects in a plastic bag. Insects from each kopje were then separated out from the vegetation debris, identified to order level, counted, and weighed and data entered into an excel data sheet. Sweep net sampling was taken in the mornings, after the grass has dried and before noon in order to minimize variation due to weather or diurnal rhythms of insects (Lowman, 2006).

3.3.1.2 Agama stomach contents

Agama lizards were trapped from each of the three groups of kopjes during the two seasons. A mist-net 1.5 m wide and 8 m long was laid down on the kopje to trap agama lizards. Trapping was conducted in the morning before noon following an assumption that the agamas generally feed more during this period and digestion is not yet advanced. Once caught, the lizards were euthanized with 0.1 ml of euthapent solution to prevent further breakdown of the stomach contents, labeled and placed in containers with 10% formalin (Arttatrana *et al*., 2007). In the laboratory, the stomachs were dissected out using surgical scissors and forceps and the contents washed with clean water, then left to dry for 72 hours at room temperature. The dry weight of each sample was taken after every 24 hours and this led to three dry weights in which the third weight was taken as a final dry weight of

the sample. Dried pieces of food items both undigested and partially digested were placed in microscope slides and held in place with cellophane tape and then examined using a Nikon Stereomicroscope with 10 – 25x magnification (Serdar & Mehmet, 2001).

Although insects were identified mainly on the basis of head capsules and trophic apparatus, other identifiable body parts such as elytra and appendages were also used. Larvae were counted and identified to order. Plant matter (leaves, seeds, fruits, stems, flowers) were also recorded and identified to family and species level. The frequency of each food item in samples was calculated for both dry and wet seasons. This was done by counting the number of insects in each order and expressed them in terms of percentage of the total number examined from the agama stomachs. The orders with high percentages were then found to be the most preferred food for agama lizards.

However, there were some difficulties in identifying some plant and animal remains from gut contents. Some of the gut contents were completely digested where others were broken into small particles unable to be identified. The study area was not accessible during the rainy period but when accessible the insect catch was very low because of tray and pit chemical dilution.

3.3.2 Secondary data collection

Secondary data were collected from other research findings and experiences from different case studies related to this work. The collection was through literature search of activity reports on programmes such as Serengeti Biodiversity Programme (SBP), Tanzania Wildlife Research Institute (TAWIRI), journals and visiting websites to form an overview. Data on insect abundance and agama gut contents from January to September 2008 were obtained from SBP.

3.4 Data Analysis

Several methods were used to analyse data. Descriptive and quantitative analysis were employed to meet the objectives and the hypotheses of the study. For descriptive analysis the use of means, percentage, cross tabulation were employed to describe the characteristics and trends of some of data and information. Statistical Package for Social Sciences (SPSS) was used to manage survey data to obtain statistics required for interpretation. Inferential statistical analysis by the use of General Linear Model-univariate ANOVAs in SPSS was used to analyze the data and Tukey Honestly Significant Difference (HSD) test for multiple comparisons of means were used to examine variation among locations and between seasons at 5% probability level.

A two way ANOVA between groups of variance was conducted to explore the impact of seasons (dry and wet season) and place (Barafu, Gol and Simba kopjes) on levels of insect dry weight abundance and agama food intake. Since the distribution of the data (insect dry weights and food intake) was found to be heavily skewed transformations by square root (SQRT) was employed to remedy the situation. The multiple comparisons for insect dry weights were not performed because there was neither a significant main effect no interaction effect in overall analysis of variance test.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Insect Abundance

4.1.1 Insects variation between seasons and locations

Monthly insect abundance (in terms of total number) and their percentages in decreasing order was as follows (Table 1 and Appendix 1): August 6169 (10.60%), May 5954 (10.20%), January 5678 (9.76%), April 5426 (9.30%), February 5135 (8.80%), July 5068 (8.70%), March 5035 (8.65%), December 4641 (7.98%), June 4 265 (7.30%), September 4120 (7.10%), October 3690 (6.30%) and November 2993 (2.14%).

Table 1: Monthly number of insects and percentages collected in 2008

Month	Total	Percentage
January	5678	9.76
February	5135	8.80
March	5035	8.65
April	5426	9.30
May	5954	10.20
June	4265	7.30
July	5068	8.70
August	6169	10.60
September	4120	7.10
October	3690	6.30
November	2993	2.14
December	4641	7.98

Hymenoptera 17 563 (30.19%) represented the highest order in terms of numbers and percentage (Table 2). Other Orders of insects (including other arthropods) were as follows: Hemiptera 11 324 (19.50%), Orthoptera 10 508 (18.10%), Diptera 6143 (10.60%), Coleoptera 5332 (9.20%), Arachnida 2528 (4.40%), Dictyoptera 1574 (2.70%), Lepidoptera 1431 (2.50%), Isoptera 1121 (1.90%), Dermaptera 449 (0.80%), Phasmida 165 (0.28%), Diplopoda 16 (0.03%), Odonata 8 (0.01%), Chilopoda 6 (0.01%), Neuroptera 5 (0.01%) and Thysanoptera 2 (0.01%).

Table 2: Orders of insects trapped in the study area

Order	Total	Percent
Arachnida*	2528	4.35
Chilipoda*	6	0.01
Coleoptera	5332	9.17
Dermaptera	449	0.77
Dictyoptera	1574	2.71
Diplopoda*	16	0.03
Diptera	6143	10.56
Hemiptera	11 324	19.46
Hymenoptera	17 563	30.19
Isoptera	1121	1.93
Lepidoptera	1431	2.46
Neuroptera	5	0.01
Odonata	8	0.01
Orthoptera	10 508	18.06
Phasmida	165	0.28
Thysanoptera	2	0.01
Total	**58 175**	**100.00**

*Arthropods that are not insects

According to the results (Appendix 1), insect numbers differ significantly with respect to seasons and locations as high numbers were observed during the wet period. Orders such as Coleoptera (beetles) and Diptera (flies) were higher in number during the wet period (April and May). The Orthoptera (crickets, grasshoppers and katydids) were highest in February (1751) followed by January (1692), March (973), July (903), April (817), May (774), December (697), June (658), October (626), September (611), August (553) and November (453). The Hymenoptera (ants, bees and wasps) were highest in August (3003) followed by December (1919), March (1814), April (1597), June (1337), September (1298), November (1298), January (1221), October (1094), May (1074), February (1007) and July (952). Most orders of insects showed to increase from the short rains in November through the heavy rains to June. Other orders of insects were found to be more or less the same in number during both seasons and their highest peaks being observed in the dry period. The Hemiptera (bugs) were found in two peaks, one in the wet period in May and

the second one in the dry period in July. Large number of bugs was encountered immediately after the rainy season and they were still found even in the dry season though in small numbers. Hymenoptera (ants, bees and wasps) and Isoptera (termites) were found almost all the year round and their highest peaks were in the dry season.

The total numbers of insects within the twelve months were compared by the use of One Way Analysis of Variance (ANOVA). The results showed that there was a significant difference in abundance of insects between the twelve months ($F = 3.08$ and $p = 0.05$) (Table 3).

Table 3: ANOVA for comparing insect numbers within 12 months

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	81 278.517	2	40 639.258	3.08	0.05
Within Groups	4 712 949.083	357	13 201.538		
Total	**4 794 227.600**	**359**			

4.1.2 Insect abundance and dry weights variations with respect to locations

A total of 58 175 individual insects yielded about 1888.10 g of insect dry weights and the weights showed to differ significantly within and between locations and also between seasons (Table 4 & Fig. 2). Among the three locations 764.68 g (40.50%) was represented in Gol kopjes, whereas, 656.71 g (34.80%) in Simba kopjes and 466.71 g (24.70%) in Brafu kopjes. Hymenoptera, Diptera, Isoptera, and Arachnida (Spiders) were the highest in Simba kopjes while Coleoptera, Dictyoptera, Hemiptera, and Orthoptera being the highest in Gol kopjes and only Lepidoptera in Brafu kopjes. Insect abundance was highest represented in Simba kopjes with 21 553 (37.00%) followed by Gol kopjes with 19 654 (33.80%) and Barafu kopjes with 16 968 (29.20%).

Insect abundance not directly related to dry weights as the case shown in Simba kopjes. Simba kopjes were the highly most represented compared to Gol and Barafu kopjes interms of insects abundance. However, when the insects were left to dry and weighed the Gol kopjes were highest represented with 764.68 g (40.50%) followed by Simba kopjes 656.71 g (34.80) and Barafu kopjes 466.71 g (24.70%). The high dry weights in Gol kopjes could be due to body masses of Coleoptera (beetles), Dictyoptera (cockroaches) and Orthoptera (grasshoppers and crickets) which weighed higher than Diptera (flies), Hymenoptera (ants), Isoptera (termites) and Arachnida (spiders) found in Simba kopjes. Likewise, only butterflies were recorded highest in Barafu kopjes and yet weighed least. Other reasons that have resulted into differences of insect abundance and insect dry weights between kopjes could be explained in terms of differences in vegetation cover, soi, differences in size and shapes of kopjes and rainfall patterns among Simba, Gol and Barafu kopjes. The highest insect dry weights in Gol kopjes as compared to Simba and Barafu kopjes could be due to the fact that the Gol kopjes lie within the intermediate and short grass plains. Each of these grass plains harbours several plant species in which a large number of insect species (plant feeders) could be found. Because of high diversity of plant species, some would persist longer even during the dry period and therefore high insect dry weights. The Simba kopjes being dominated by the long grass could be harbouring fewer plant species but more insect species than the short grass in Barafu kopjes. The long grass can live long enough even during the onset of dry period. The soils in Barafu and eastern side of Gol are friable and porous and do not hold rain water long (Porembski *et al*., 1996), they become dry immediately after rainfall has decreased which ultimately result into lower insect abundance and dry weights.

Table 4: Monthly insect dry weights in the Serengeti NP in 2008

Kopje	Barafu		Gol		Simba			
Month	Insect abund	Insect weight (g)	Insect abund	Insect weight (g)	Insect abund	Insect weight (g)	Total insect abund	Total insect weight
January	1971	44.06	1780	66.06	1927	50.64	5678	160.76
February	1683	75.33	1680	78.68	1772	70.00	5135	224.01
March	1626	72.12	1465	67.62	1944	85.44	5035	225.18
April	1482	43.48	2053	142.00	1891	58.44	5426	243.92
May	1629	40.60	2399	100.46	1927	48.78	5955	189.84
June	1523	41.57	1232	36.85	1510	28.32	4265	106.74
July	1051	35.01	2338	77.80	1679	52.63	5068	165.44
August	1288	21.60	1553	48.88	3328	91.38	6169	161.86
September	918	18.66	1521	43.58	1681	51.28	4120	113.52
October	1128	29.57	1286	30.24	1276	40.28	3690	100.09
November	795	15.90	655	16.01	1543	46.44	2993	78.35
December	1874	28.82	1692	56.50	1075	33.08	4641	118.40
Total	**16 968**	**466.71**	**19 654**	**764.68**	**21 553**	**656.71**	**58 175**	**1888.10**
Percent	**29.20**	**24.70**	**33.80**	**40.50**	**37.00**	**34.80**	**100**	**100.00**

According to the monthly insect dry weights two peaks were evident (Fig. 2). One peak was from February to May which was the wet season and the other peak in July and August. Similar findings have been reported by Dingle & Khamala (1972), Sinclair (1978), Van Sluys *et al.* (2004) and Pinheiro *et al.* (2007) who have indicated that in areas with two rain seasons (as the case in Serengeti NP) insect abundance increases with an incresase in rainfall and therefore creating two peaks corresponding to the two seasons.

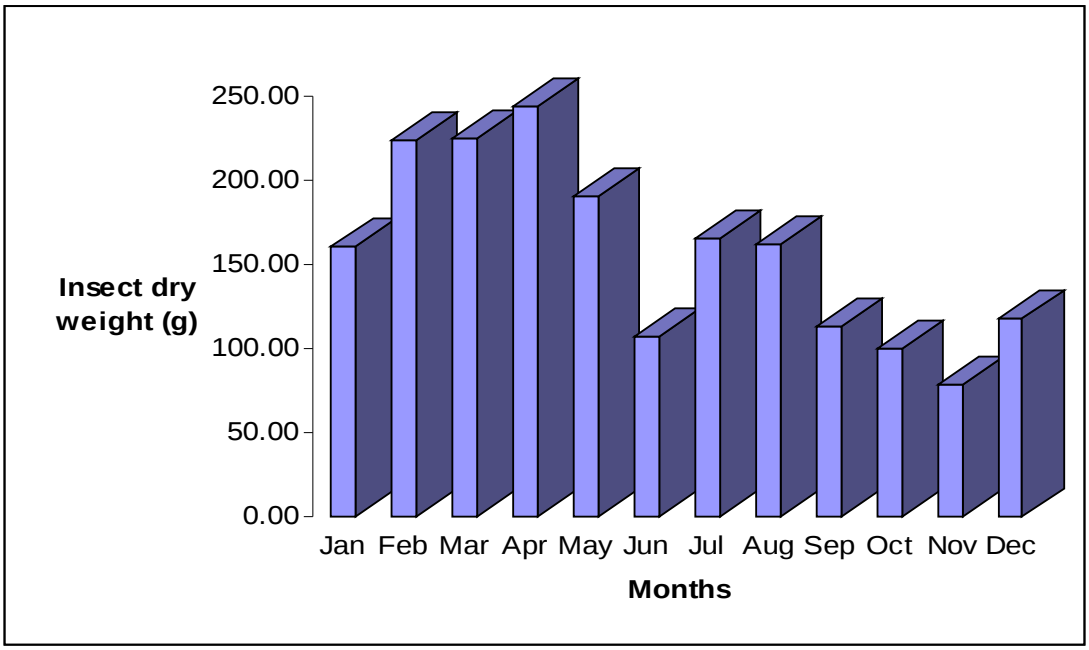

Figure 2: Seasonal variation of insect dry weights in the Serengeti NP in 2008

The insect dry weights in Gol kopjes were highest in April (142.00 g) and followed by May (100.46 g), February (78.68 g), July (77.80 g), January (66.06 g), and December (56.50 g) (Fig. 3) as compared to Barafu and Simba kopjes. Likewise, the insect dry weights in Simba kopjes were highest in August (91.38 g) followed by March (85.44 g), September (51.28 g), November (46.44 g) and October (40.28 g) as compared to Barafu and Gol kopjes within the same months. Among the three places, Gol kopjes had the highest insect dry weights during the wet season (December through May) while the insect dry weights in Simba kopjes were highest during the dry period (August). Generally, the insect dry weights in Barafu, Gol and Simba kopjes were higher during the wet season than in the dry season.

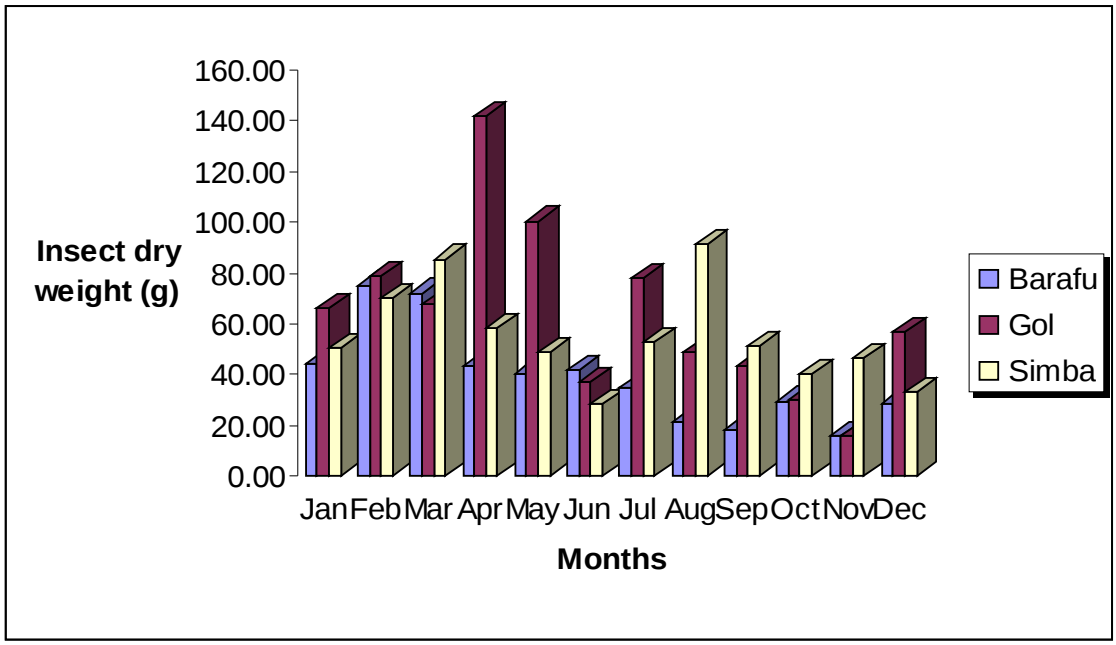

Figure 3: Comparison of insect dry weights between months and kopjes in the Serengeti NP in 2008

4.1.3 Comparison for insect dry weights between kopjes and seasons

The ANOVA showed that there was no significant main effect for kopjes [F (2, 30) = 3.13, p = 0.06] and seasons [F (1, 30) = 0.5, p = 0.5] (Appendix 2). This means that there was no significant statistical difference in scores for Simba, Gol and Barafu kopjes. Likewise, the difference between the seasons was not statistically significant, i.e. wet and dry seasons did not differ significantly in terms of insect dry weight scores. The interaction effect [F (2, 30) = 0.33, p = 0.7] also showed that there was no significant difference in the effect of kopjes (Barafu, Gol and Simba kopjes) on insect dry weights for both dry and wet seasons. The increase of insects from November to January coincided with the increase in rainfall, as did subsequent increase between March and May. Similarly, insect abundance decreased from June to August when rainfall decreased.

In most years rains started in November and insects peaked in December and January, but in some years this does not happen, heavy rains may start in October producing an insect peak in November (Sinclair, 1978). Similar results have been reported by Pinheiro *et al.* (2007) in Brazil. Orders such as Diptera, Hemiptera and Orthoptera were distributed over time whereas Isoptera peaked up in the first half of the wet season. Coleoptera peaked up in the second half of the wet season, whereby the dung bettles seemed to correlate with the annual migration of large herds of ungulates (Sinclair & Byrom, 2006). Hymenoptera was observed to peak in each season.

The small number of insects and their weights in Barafu kopjes might be due to two reasons: First, it might be due to the fact that during the dry period, the number of insects decreases because there is no food for them (plant materials for the plant feeders which comprise the largest group of all insects). Secondly, some of the sampling points were burnt during the dry period which ultimately killed vegetation and insects in the area.

4.2 Agama Intake of Food Items

4.2.1 Agama food intake between seasons and kopjes

The analysis was based on 120 animal specimens. Of the 120 dissected digestive guts, all except two were either full or partially full of food. The stomach and proximal end of the intestine contained more identifiable prey than the distal end of the intestine and the rectum. Based on the analysis of stomach contents (Appendix 3), invertebrates and plants were the major and minor food sources, respectively. Other non-food materials, such as small stones, and sand grains possibly ingested during prey capture, were also present. Similar findings have been reported by Diong *et al*. (1994), Kalita (2000), Serdar & Mehmet (2001), Heideman (2002) and Arttatrana *et al*. (2007). Although a large number of

prey fragments were found in dissected guts, most of them were digested to such an extent that they were unidentifiable. The stomach contents are presented in Table 5 and Appendix 3 according to prey groups (their taxonomic orders, number of food items, and their percentages).

Table 5: Agama insect food items and their percentages in the Serengeti NP in 2008

Order	Food items	Percentage
Arachnida	4	0.17
Coleoptera	430	18.32
Dictyoptera	4	0.17
Diptera	2	0.09
Hemiptera	21	0.89
Hymenoptera	1105	47.08
Isoptera	700	29.83
Lepidoptera	19	0.81
Orthoptera	62	2.64
Total	**2347**	**100.00**

Of the 2347 insect food items, the number and their percentages for each order were as follows: Hymenoptera 1105 (47.08%), Isoptera 700 (29.83%), Coleoptera 430 (18.32%), Orthoptera 62 (2.64%), Hemiptera 21 (0.89%), Lepidoptera 19 (0.81%), Arachnida 4 (0.17%), Dictyoptera 4 (0.17%), and Diptera 2 (0.09%). The most commonly observed food items included: Ants 951 (40.47%), termites 700 (29.79%), dung beetles 342 (14.55%), wasps 88 (3.74%), leaf beetles 79 (3.36%), bees 66 (2.81%), and grasshoppers 62 (2.64%). This suggests that *Agama mwanzae* feeds heavily on ants, termites and beetles whereas grasshoppers, spiders, cockroaches, flies, bugs, butterflies and moths were occasionally taken. The agama lizards feed heavily on ants, termites and beetles because were found higher in abundance, enriched with proteins and more palatable as compared to other groups of arthropods.

Of the 2347 insect food items, 1597 were found during the wet season and 750 in the dry season (Table 6). The total number of insect food items and their percentages for each of the two seasons are as follows: Gol kopjes 801 (50.10%), Simba kopjes 606 (37.90%) and Barafu kopjes 192 (12.00%) for the wet season and Gol kopjes 338 (45.00%), Simba kopjes 247 (32.90%) and Barafu kopjes 166 (22.10%) for the dry period.

Table 6: Total seasonal insect intake by *Agama mwanzae* in the study area

Season	Insect food	Barafu	Gol	Simba	Total
Dry season	Number of insects	166	337	247	750
	Percent	22.10	45.00	32.90	100.00
Wet season	Number of insects	191	801	605	1597
	Percent	12.00	50.10	37.90	100.00

This suggests that most invertebrates were taken during the wet season which is about 68.04% of all insects and only 31.96% consumed during the dry period and this is because during the rainy period the insect abundance is higher as compared to dry period. The study by Warner *et al*. (2007) examined the relationship of food abundance with reproductive output in a lizard (*Amphibolurus muricatus*; Agamidae) and found that in habitats with scarcity of food, females may invest more energy into individual clutches rather than producing multiple clutches. On the other hand, in years or habitats with an abundance of food, females will produce more clutches per season. In other words tropical lizards have breeding cycles which coincide with the rainy season of their respective regions. The study by Majid (2008) examined the seasonal changes in the concentrations of Na and K ions in the blood of *Agama nupta* and found that the lizards did not have access to free water and acquired all their required water from their diet of insects. Therefore, during the scarcity of insects (summer period) the lizards experienced hypernatraemia (a high serum sodium level caused by inability to drink water which can result to seizures

and death) and hyperkalaemia (an abnormally high amount of potassium in the blood caused by lack of access to free water) due to chronic dehydration.

The three major orders Hymenoptera and Coleoptera were highly encountered in the gut contents of agama lizards in Gol kopjes (Fig. 4). The Hymenoptera and Isoptera were higher during the wet period while Coleoptera was the only highest agama insect food found in the dry period particularly in Gol. The Isoptera was the second major order of agama insect food in the study area and found mostly in Simba kopjes during the wet period. Stomach contents therefore revealed that *Agama mwanzae* is primarily insectivorous. Hymenoptera represented the most important food item in terms of both total numbers of food items and the number of stomachs examined, followed by Isoptera and Coleoptera with other less prevalent arthropod orders (Fig. 4).

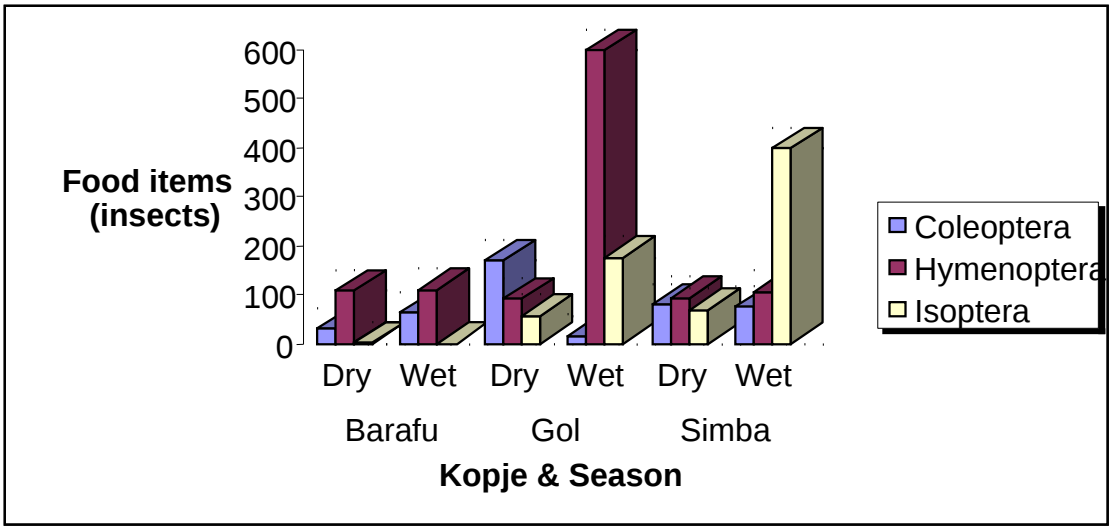

Figure 4: Seasonal variations of major agama insect food in the three kopjes in the Serengeti NP

All these findings suggest that *Agama mwanzae* is an opportunist feeder preying on a diverse insect food items. This situation is related to the type of habitat they live in and the abundance of prey species in the vicinity.

Of the 2347 insect food items that were found in agama stomach contents the Gol kopjes were the highest represented (Table 6) with 1138 (48.49%), followed by Simba kopjes with 852 (36.30%) and Barafu kopjes with 357 (15.21%) insect food items. The reasons for the differences of insect food items between kopjes could be caused by differences in plant cover, soils and rainfall patterns between kopjes. Apart from the invertebrate prey, it was observed that *Agama mwanzae* feeds on plant material as well. Most of agama specimens in Barafu kopjes, especially males had a large amount of plant materials and two specimens, a male and a female were observed with plant materials only. Most of the identified materials were leaves, stems, flowers, fruits and seeds of monocot and dicot plants. Leaves constituted a large amount of all plant materials identified. The identified plant parts (Table 7) were from the following families in decreasing order of frequency of occurrence: Commelinaceae (40.13%), Zygophullaceae (19.59%), Papilionaceae (15.07%), Moraceae (10.33%), Poaceae/ Graminae (8.38%), Capparaceae (3.21%), Vitaceae (2.16%).

Table 7: Species and family names of identified plant materials

No.	Species name	Family name	% of occurrence
1.	*Commelina africana*	Commelinaceae	40.13
2.	*Indigofera arecta*	Papilionaceae	15.07
3.	*Mearua triphylla*	Capparaceae	3.21
4.	*Cyphostemma adenocaule*	Vitaceae	2.16
5.	*Ficus natalensis*	Moraceae	10.33
6.	Unknown	Graminae/ Poaceae	8.38
7.	*Rynchosia minima*	Papilionaceae	1.13

9.	*Tribulus terrestris*	Zygophullaceae	19.59

Agama mwanzae also feed on plant materials in both seasons but most of the plant materials were taken during the dry period and the largest amount were found in Barafu lizards (Table 8). About 19 (25.00%) agama lizards observed in Barafu kopjes during the dry period had higher amount of plant materials as compared to 13 (17.11%) in the same area during the wet season. In Gol, 11 (14.47%) of the agama lizards had plant materials during the dry period and 9 (11.84%) in the wet period whereas in Simba 16 (21.05%) of the lizards were found with plant materials during the dry period as compared to 8 (10.53%) during the wet season. Among the 120 specimens dissected, 12 insect larvae were found in four specimens and one agama lizard had nothing in its stomach. Moreover, 45 endoparasites (round worms) were observed in Barafu agama lizards, particularly during the dry period.

Table 8: Total agama food intake (g) between seasons and places

Place	Season	Insect food (g)	Lizards with insect food	Plant food (g)	Lizards with plant food
Barafu	Dry	0.90	20	1.40	19
	Wet	3.10	20	0.80	13
Gol	Dry	2.20	20	0.30	11
	Wet	3.00	20	0.30	9
Simba	Dry	0.40	20	1.00	16
	Wet	2.20	20	0.10	8

The presence of worms may suggest that during the dry period in Barafu kopjes the lizards feed on the ground where the grass is very short and then become infested with worms. Other findings by Adeoye & Ogunbanwo (2007) examined the helminth parasites of the lizard *Agama agama*, reported that the lizards serve as transport and reservoir to several protozoan and helminth parasites and they were mostly found during the dry period and the prevalence of infection was higher in adult male lizards. However, the lack of information

on most parasites in African lizards prevents us to better understand the relationship between these parasites and their hosts.

4.2.2 Insect and plant food items variations

As shown in the insect dry weights, the agama food items showed to vary among kopjes and between seasons (Fig. 5). A higher amount of insect food was taken during the wet season than during the dry season in all areas but this was vice versa for plant materials whereby a larger amount was taken during the dry period. In Gol kopjes the amount of plant materials taken during the dry period was more or less equal in amount to that of wet season.

The seasonal variations in insect abundance have led to variations in insect and plant food items as insect food becomes higher in abundance during the wet period and scarce in the dry period. In other words, when invertebrate (arthropods) food becomes more abundant, plant materials are less taken by agama lizards but when invertebrate (arthropods) food becomes less abundant, more plant materials are taken.

Agama food intake varied greatly between kopjes (Table 8). The agama lizards in Gol kopjes represented a highest amount of insect food 5.2 g and the lowest amount of plant food items 0.60 g among the three groups of kopjes.The agama lizards in Barafu kopjes constituted the second highest with insect food 4.0 g and also the highest with plant food items 2.20 g. In Barafu kopjes agama lizards found with plant food items comprised of 32 of the total 40 (80%) examined. This means that most of agama lizards in Barafu fed largely on plant materials as insect food being scarce. On the other hand the agama lizards in Simba kopjes have shown to represent the lowest insect food 2.60 g with 1.10 g plant food items in which 60% of the agama lizards had plant materials. The reasons for the

differences in agama food intake between kopjes could be due to differences in vegetation cover that support different varieties of insect food, soil which allow plants to grow in and

therefore insects, differences in size and shape of kopjes and rainfall patterns in the study area.

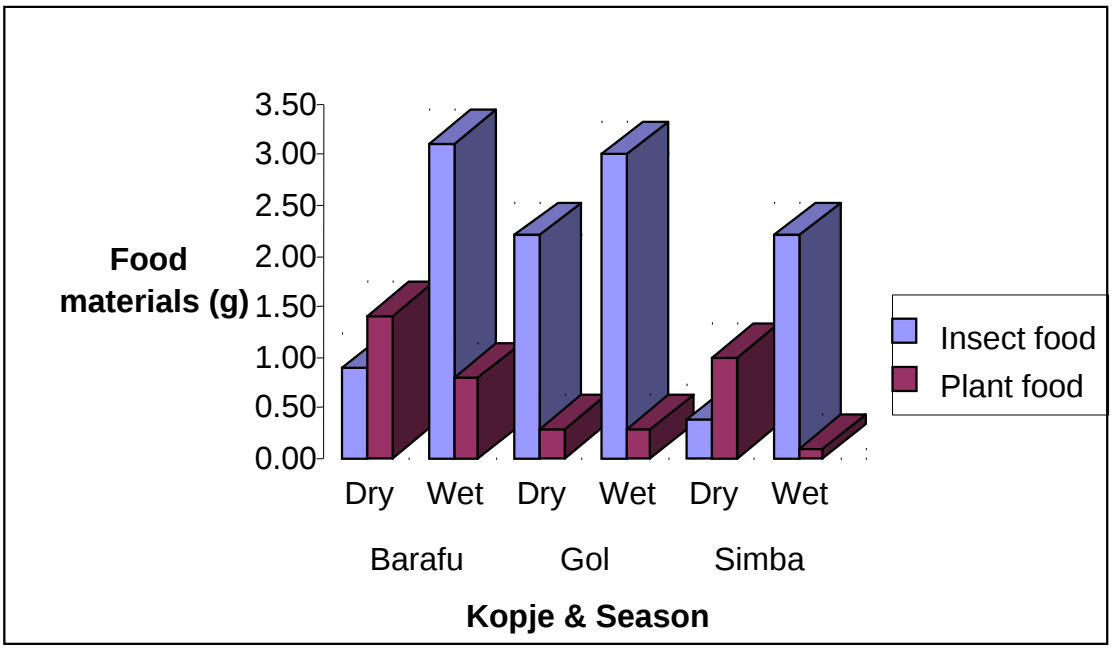

Figure 5: Comparison between agama insect food and plant food items in the three kopjes in the Serengeti NP

4.2.3 Comparison for insect and plant food items

The ANOVA showed that there was a statistically significant main effect for place [$F(2,14) = 4.35$, $p = 0.02$] and season [$F(1,114) = 6.45$, $p = 0.01$] (Appendix 4). This means that all the three places (Barafu, Gol and Simba kopjes) and the two seasons (dry and wet) differ significantly to each other in terms of agama food intake. Multiple comparisons indicated that the food intake in Barafu kopjes and Gol kopjes was significantly different from the food intake in Simba kopjes, but the food intake in Barafu kopjes did not differ significantly from Gol kopjes (Appendix 5). The interaction effect [$F(2, 114) = 0.17$, $p = 0.85$] was not statistically significant

meaning that there was no significant difference in the effect of places on agama food intake for dry and wet seasons.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

During both seasons (dry and wet) 16 orders of arthropods were found in which the first nine orders were the most abundant. The orders include; Hymenoptera, Hemiptera, Orthoptera, Diptera, Coleoptera, Arachnida, Dictyoptera, Lepidoptera, Isoptera, Dermaptera, Phasmida, Diplopoda, Odonata, Chilopoda, Neuroptera and Thysanoptera. The results showed that there was significant variation in the abundance of insects among the 12 months whereby the wet period had higher insect abundance than the dry period. Likewise, the monthly insect dry weights showed two peaks, one during the wet period (i.e. December through May) and the other peak in August. The two peaks indicate that insects (arthropods) increase in abundance with the increase in rainfall. Gol kopjes had the largest insect dry weights (including other arthropods) followed by Simba and Barafu kopjes.

The agama lizards (*Agama mwanzae*) were found to feed on insects (including other arthropods) and plant materials, although the two differed with respect to seasons. Eight orders of insects (including Arachnids) were found in the agama stomachs; Hymenoptera, Isoptera, Coleoptera, Orthoptera, Hemiptera, Lepidoptera, Arachnida, Dictyoptera and Diptera. Out of 2347 insect food items, 1597 (68.04%) were found during the wet period and 750 (32.95%) were found in the dry period. The most observed orders include Hymenoptera, Isoptera, Coleoptera and Orthoptera whereby ants represented the most food item during the wet season and termites being the second major insect food and the first

major in the dry period. Other preferred insect food included beetles and grasshoppers. Apart from insects (Arthropods), plant materials were also taken in large amount in both seasons. The plant materials that were observed include; leaves flowers, stems, fruits and seeds of monocots and dicots. As in insect food, the lizards were specific to certain species of plant materials that are available in their areas. Seven species of plant materials were identified as being eaten by the agama lizards which indicate that more other species are taken. The plant species include; *Commelina africana, Indigofera arecta, Mearua tryphylla, Cyphostemma adenocaule, Ficus natalensis, Rynchosia minima* and *Tribulus terrestris.* More plant materials were taken during the dry period as compared to the wet season which seemed to be a vice versa with the insect food. The agama lizards in Barafu kopjes were observed with the highest amount of plant materials followed by Gol and Simba kopjes. Generally, the food intake in Barafu and Gol kopjes was shown to vary significantly from that of Simba kopjes. Due to these variations of food intake, i.e. more insect food during the wet period than during the dry period and more plant food during the dry period, it can be concluded that agama lizards feed on plant materials in both seasons, but more during the dry period because of scarcity of insect food.

5.2 Recommendations

Due to the fact that agama lizards depend on insects (including arthropods) and plant materials as food for their survival and since there is an increase in destruction of their habitats (e.g. construction of lodges, tented camps, camp sites and tourist tracks, wild fires), the park management should ensure that these areas are highly conserved. It is important to ensure that their land management practices should not impact insect communities or plant distribution during critical times of the year, when these organisms are in low abundance. The vegetation is depended upon by insects that are plant feeders

which in turn both provide important food materials to agama lizards during the critical times of the year and therefore should be well preserved.

Agama lizards as other animals contribute very much in the ecosystem; provide food to other animals like birds of prey and poisonous snakes, they feed on harmful insects, their droppings (faeces) provide nutrients for vegetation, yet the lizards are less studied. What was found is very little, since there are so many other areas that are not known, including; their movement patterns, reproduction, growth and diseases. It is important therefore for more studies to be conducted in order to know their ecology.

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APPENDICES

Appendix 1: Monthly insect variation in Barafu, Gol and Simba kopjes in the Serengeti NP in 2008

	SAMPING TIME (MONTHS)											
Order	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Arac*	261	318	244	233	201	185	124	163	205	197	173	224
Chil*	1	0	2	1	0	2	0	0	0	0	0	0
Cole	779	522	471	784	694	320	528	0	387	363	171	313
Derm	6	7	1	0	2	2	1	430	0	0	0	0
Dict	271	140	242	71	50	222	161	137	122	77	33	48
Dipl*	3	1	6	3	1	1	0	0	0	0	1	0
Dipt	588	506	411	1005	928	422	235	416	312	488	292	540
Hemi	683	685	684	816	2099	1050	1964	1087	1006	572	333	345
Hyme	1221	1007	1814	1597	1074	1337	952	3003	1298	1094	1247	1919
Isop	70	126	80	16	79	18	117	280	95	25	167	48
Lepi	97	64	80	59	41	33	68	86	60	243	116	484
Neur	1	1	1	1	1	0	0	0	0	0	0	0
Odon	1	0	1	1	0	0	4	0	1	0	0	0
Orth	1692	1751	973	817	774	658	903	553	611	626	453	697
Phas	4	7	25	22	9	15	11	14	23	5	7	23
Thys	0	0	0	0	2	0	0	0	0	0	0	0
Total	5678	5135	5035	5426	5955	4265	5068	6169	4120	3690	2993	4641
Percent	9.76	8.83	8.65	9.33	10.24	7.33	8.71	10.60	7.08	6.34	5.14	7.98

Code	**Order**
Arac*	Arachnida
Chil*	Chilopoda
Cole	Coleoptera
Derm	Dermaptera
Dict	Dictyoptera
Dipl*	Diplopoda
Dipt	Diptera
Hemi	Hemiptera
Hyme	Hymenoptera
Isop	Isoptera
Lepi	Lepidoptera
Neur	Neuroptera
Odon	Odonata
Orth	Orthoptera
Phas	Phasmida
Thys	Thysanoptera

*Arthropods that are not insects

Appendix 2: Tests of between effects of kopjes and seasons for insect dry weights in the Serengeti NP in 2008

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	20.843(a)	5	4.169	1.430	0.242	0.192
Intercept	1746.638	1	1746.638	599.091	0.000	0.952
Kopjes	18.234	2	9.117	3.127	0.058	0.173
Season	1.371	1	1.371	0.470	0.498	0.015
Kopjes * Season	1.930	2	0.965	0.331	0.721	0.022
Error	87.464	30	2.915			
Total	1888.110	36				
Corrected Total	108.307	35				

$R^2 = 0.192$ (Adjusted $R^2 = 0.058$)

Appendix 3: **Agama insect food items in three kopjes for the wet and dry season in the Serengeti NP in 2008**

Food items		Barafu				Gol				Simba			
		Dry		Wet		Dry		Wet		Dry		Wet	
Order		**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**
Arac*		0	0.00	1	0.04	1	0.04	1	0.04	0	0.00	0	0.00
		0	0.00	0	0.00	0	0.00	0	0.00	1	0.04	0	0.00
	Total	**0**	**0.00**	**1**	**0.04**	**1**	**0.04**	**1**	**0.04**	**1**	**0.04**	**0**	**0.00**
Cole		3	0.13	50	2.13	149	6.34	16	0.68	60	2.55	64	2.72
		27	1.15	4	0.17	20	0.85	0	0.00	17	0.72	11	0.47
		0	0.00	8	0.34	0	0.00	0	0.00	1	0.04	0	0.00
	Total	**30**	**1.28**	**62**	**2.64**	**169**	**7.19**	**16**	**0.68**	**78**	**3.31**	**75**	**3.19**
Dict		2	0.08	2	0.08	0	0.00	1	0.04	2	0.08	0	0.00
	Total	**2**	**0.08**	**2**	**0.08**	**0**	**0.00**	**1**	**0.04**	**2**	**0.08**	**0**	**0.00**
Dipt		0	0.00	0	0.00	0	0.00	2	0.08	0	0.00	0	0.00
	Total	**0**	**0.00**	**0**	**0.00**	**0**	**0.00**	**2**	**0.08**	**0**	**0.00**	**0**	**0.00**
Hemi		0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.04
		11	0.47	2	0.08	2	0.08	5	0.21	0	0.00	0	0.00
	Total	**11**	**0.47**		**0.08**	**2**	**0.08**	**5**	**0.21**	**0**	**0.00**	**1**	**0.04**
Hyme		93	3.96	89	3.78	66	2.81	512	21.78	91	3.87	100	4.25
		6	0.26	0	0.00	6	0.26	52	2.21	0	0.00	2	0.08
		8	0.34	20	0.85	19	0.81	35	1.49	2	0.08	4	0.17
	Total	**107**	**4.56**	**109**	**4.64**	**91**	**3.88**	**599**	**25.49**	**93**	**3.96**	**106**	**4.50**
Isop		1	0.04	0	0.00	56	2.38	175	7.45	69	2.94	399	16.97
	Total	**1**	**0.04**	**0**	**0.00**	**56**	**2.38**	**175**	**7.45**	**69**	**2.94**	**399**	**16.97**
Lepi		0	0.00	0	0.00	0	0.00	0	0.00	1	0.04	0	0.00
		0	0.00	4	0.17	4	0.17	2	0.08	0	0.00	5	0.21
		0	0.00	0	0.00	1	0.04	0	0.00	0	0.00	2	0.08
	Total	**0**	**0.00**	**4**	**0.17**	**5**	**0.21**	**2**	**0.08**	**1**	**0.04**	**7**	**0.29**
Orth		15	0.64	12	0.51	14	0.59	0	0.00	3	0.13	18	0.76
	Total		**0.64**	**192**	**0.51**	**338**	**0.59**	**801**	**0.00**	**247**	**0.13**	**606**	**0.76**
	Total	**166**	**7.03**		**8.16**		**14.38**		**34.06**		**10.49**		**25.75**

Code	Order
Arac*	Arachnida
Cole	Coleoptera
Dict	Dictyoptera
Dipt	Diptera
Hemi	Hemiptera
Hyme	Hymenoptera
Isop	Isoptera
Lepi	Lepidoptera
Orth	Orthoptera

*Arthropods that are not insects

Appendix 4: Tests of between effects of kopjes and seasons for agama food intake in the Serengeti NP in 2008

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	0.283(a)	5	0.057	3.098	0.012	0.120
Intercept	12.165	1	12.165	664.800	0.000	0.854
Kopjes	0.159	2	0.080	4.353	0.015	0.071
Season	0.118	1	0.118	6.445	0.012	0.054
Kopjes* Season	0.006	2	0.003	0.169	0.845	0.003
Error	2.086	114	0.018			
Total	14.535	120				
Corrected Total	2.370	119				

$R^2 = 0.120$ (Adjusted $R^2 = 0.081$)

Appendix 5: Multiple comparisons for agama food intake in the Serengeti NP

Tukey's HSD

(I) Place	(J) place	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Barafu	Gol	-0.0015	0.03025	0.999	-0.0733	0.0704
	Simba	0.0765(*)	0.03025	0.034	0.0047	0.1484
Gol	Barafu	0.0015	0.03025	0.999	-0.0704	0.0733
	Simba	0.0780(*)	0.03025	0.030	0.0062	0.1499
Simba	Barafu	-0.0765(*)	0.03025	0.034	-0.1484	-0.0047
	Gol	-0.0780(*)	0.03025	0.030	-0.1499	-0.0062

Based on observed means.

* The mean difference is significant at the 0.05 level.