DISTRIBUTION, ABUNDANCE, POPULATION RATIOS AND ACOUSTIC BEHAVIOUR OF *CONOCEPHALUS MACULATUS* (ORTHOPTERA: TETTIGONIIDAE) IN KAGERA REGION NORTH-WESTERN TANZANIA

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DECLARATIONS

Declaration by the Candidate

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

Signed ……………………………….. Date …………………..

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Declaration by the Supervisors

We confirm that the work reported in this thesis was carried out by the student under our supervision.

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DEDICATION

To Rubya *Alma Mater* Alumni of all times: to my nieces and nephews; Karen, Gerald, Linus, Yvonna and Alex, and to all others who diligently search the created reality to marvel at the Creator`s wondrous designs.

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ABBREVIATIONS AND ACRONYMS

ARI	Agricultural Research Institute
a.s.l.	above sea level
DRC	Democratic Republic of Congo
GBIF	The Global Biodiversity Infomation Facility
GIS	Geographic Information System
GPS	Global Positioning System
IUCN	International Union for Conservation of Nature
TCCIA	Tanzania Chamber of Commerce Industry and Agriculture
URT	United Republic of Tanzania
s	Seconds (time)
FRD	Federal Research Division of the Library Congress (USA)

ABSTRACT

The longhorn grasshopper, *Conocephalus maculatus* (Le Guillou, 1841), is reported to be distributed over a wide range of grassland habitats in tropical Africa, Asia and Australasia. The species has gained attention in Asia as an important biological control agent of rice pests. In Tanzania, the species has been reported around Mount Kilimanjaro ecosystem with no reliable information in Kagera region, north-western Tanzania. The present study sought to bring to light the distribution, abundance, population ratios and acoustic behaviour, of this tettigoniid in Kagera region. The study was carried out in Bukoba, Karagwe, Kyerwa, Missenyi and Muleba districts at various randomly selected sites including; Maruku, Bugorora and Nshambya. It involved *in-situ* observation of the species for nine months from September 2014 to May 2015. A cross-sectional design was used in this study. Quadrat method, acoustic search, sweep-netting and direct hand-picking were applied in data collection. Distribution pattern was tested using the index of dispersion (I_D). One-way ANOVA with LSD post hoc tests were used to analyse spatial and temporal variations in *C. maculatus* populations. Linear regression and Pearson`s correlation analyses were used to test the relationship of *C. maculatus* distribution, abundance and population ratios with ecological factors, and time of the day with sound signaling. Students` t-tests were used to compare laboratory and field sound characteristics and also to test the significance in population ratios. Results revealed that distribution of this species was of aggregated nature ($z = 3.09$) and it was abundantly present in the area. Results also indicated a male-biased adult sex ratio ($t = 3.473$), a 1:1 nymph sex ratio ($t = 1.107$), and an adult-biased age ratio ($t = 5.578$). Distribution and abundance were positively related to temperature ($r = 0.556$; $p < 0.0001$) and grass vegetation ($r = 0.49$; $p = 0.001$) but inversely related to altitude ($r = -0.611$; $p< 0.0001$), humidity ($r = - 0.341$; $p = 0.012$), herbal vegetation ($r = -0.340$; $p = 0.022$) and shrubs ($r = -0.387$; $p = 0.009$). There were significant differences in abundances between the three sites in the order Nshambya < Maruku < Bugorora ($f = 16.968$; $p < 0.0001$). There were seasonal differences in abundance in the order Short dry < long rains < short rains ($f = 5.591$; $p = 0.005$). Results further revealed that sound signaling in *C. maculatus* was a daylight activity ($r = 0.798$, $p = 0.000$), which varied with environmental conditions. The results provide resourceful ecological information on the species. The study recommends the Tanzanian environmental authorities to enforce comprehensive conservation measures for grasslands which are a preferred habitat of this species.

CHAPTER ONE

INTRODUCTION

1.1 Background

Conocephalus maculatus (Le Guillou, 1841) (Orthoptera: Tettigoniidae), is a longhorn grasshopper of the order Orthoptera, suborder Ensifera, super family Tettigonioidea, family Tettigoniidae and sub-family Conocephalinae, commonly known as the Spotted Meadow Katydid (GBIF, 2013). Orthopterans constitute the most abundant terrestrial group of insects, with consequent biomass depletion, crop damage and shift in plant community structure (Capinera *et al.,* 2004). At the same time, they also play a beneficial role because they are food to many animal taxa including; reptiles, birds, mammals and other arthropods (Antonatos *et al.,* 2014). Members of this order play another important role as bioindicators of habitat quality and variations, ecosystem biodiversity and environmental stress (Nagy *et al.,* 2007; Krämer *et al.,* 2010; Tan *et al.,* 2013). Therefore, a study on any ecological aspect of this order is of paramount importance.

Tettigoniids are widely spread in tropical and subtropical regions of the world (Heller, 1995). They are characterized by their mating songs, long threadlike antennae, an elongated sickle-shaped ovipositor in females, four-segmented tarsi and a tympanum (hearing organ) located on each foreleg. Their counterpart, Acridids or shorthorn grasshoppers, have short, heavy antennae, a short four-valved ovipositor, three-segmented tarsi and tympana at the base of the abdomen (Heinrichs and Barrion, 2004; Rogers, 2016). *C. maculatus* is distinguished from the rest of the genus by the presence of a reddish-brown longitudinal band on the dorsum of head and pronotum, tapering anteriorly (Heinrichs and Barrion, 2004).

Various studies have been carried out on *C. maculatus* worldwide including its taxonomy, morphometry, geographical distribution, behaviour, sound characteristics, economic importance and population dynamics (Hemp and Hemp, 2003; Heinrichs and Barrion, 2004; Hemp *et al.*, 2010; Hemp, 2013; Panhwar *et al.*, 2013; Grant, 2014; Arya *et al.*, 2015). The species is found in grass habitats of the Afro-Asian regions (Bazelet and Naskrecki, 2014). This tettigonid is widely distributed throughout, the Middle East, Southeast Asia and Australasia where it is native to Pakistan, India, Bangladesh, Cambodia, Indonesia, Japan, Korea Malaysia, Philippines and Taiwan (Panhwar *et al*., 2013; Bazelet and Naskrecki, 2014). In Africa, it occurs in many parts of the continent including Cameroon, Congo (Brazaville and DRC), Ghana, Guinea, Libya, Madagascar, Mozambique, Senegal, Sierra Leone, South Africa, Tanzania, Kenya and in Zimbabwe (Biota, 2004; Mahasneh and Katbeh-Badera, 2004; Hemp, 2013; Grant, 2014). In East Africa the species has been reported on Kilimanjaro Mountain and Rufiji Delta in Tanzania and Kakamega forest in Kenya (Sjöstedt, 1909; Biota, 2004).

There has been an increasing interest in this insect species especially in Asia where it has been earmarked as an important biological control of rice pests (Khan, *et al.*, 1991; Litsinger, *et al.*, 2006; Takahashi and Kiritani, 2008). In feeding habit *C. maculatus* is omnivorous, principally a vegetarian, partly carnivorous and cannibalistic at times (Senthilkumar, 2004; Chakraborty *et al.*, 2014). Its main food as a herbivore, includes seeds, flowers and stems of various grass species while as a carnivore, the species preys on eggs and nymphs of moths and sometime feeds on dead insects (Oda and Ishii, 1998; Wason and Pennings, 2008). *C. maculatus* has been identified as a predator of serious rice pests including the striped stem borers, *Chilo suppressalis* and *C. polycrysus* (Lepidoptera: Crambidae), the white stem borer (WSB) *Scirpophaga innotata*, the purple stem borer, *Sesamia inferens* (Lepidoptera: Noctuidae), leaf folders *Cnaphalocrocis medinalis* and *Marasmia* spp. (Lepidoptera: Pyralidae) as well as the apple snail, *Pomacea* *canaliculata* (Gastropoda: Ampullariidae; (Khan *et al.*, 1991; Kraker, 1996; Heinrichs and Barrion, 2004; Litsinger *et al.*, 2006; Takahashi and Kiritani, 2008). It has also been suggested as a potential source of food for humans and animals, and as a bioindicator for climate change (Senthilkumar and Sanjayan 2008; Hanboonsong *et al.*, 2013). Therefore, attempts have been made on mass rearing of this grasshopper for agricultural and food purposes (Senthilkumar, 2006; Senthilkumar and Sanjayan, 2008). The aim of the present study was to establish distribution and abundance, sound characteristics, and population ratios of *C. maculatus* in Kagera region North western Tanzania.

1.2 Problem statement

The studies on *C. maculatus* in Africa have looked into its taxonomy, morphometry, geographical distribution, sound characteristics and its economic importance (Hemp and Hemp, 2003; Heinrichs and Barrion, 2004; Hemp *et al.*, 2010; Hemp, 2013; Grant, 2014). The Eastern African fauna is generally poorly known (Hemp *et al.*, 2010). In Tanzania various taxonomic studies have been carried out and reports have been given on insect taxa mainly from the Eastern Arc Mountain system and the volcanic mountains of Kilimanjaro and Meru in the north due to their high diversity and endemism (Sjöstedt, 1909; Gorochov and Kostia, 1999; McKamey, 1999; Hochkirch, 2001; Behangana *et al.*, 2009; URT, 2014). The eastern arc mountain system is a mountain series that runs from Taita Hills in Kenya, through north Pare hills north east Tanzania, down to Udzungwa mountains, south west Tanzania (Hochkirch, 2001). The only reported Orthopteran from Kagera region so far is *Ruspolia differens* (Serville) (Orthoptera: Copiphorinae) (Matojo and Njau, 2010). Tettigoniids have been studied and reported in various parts of Tanzania including Kagera, Rufiji, and mountain ecosystems such as Usambara Uruguru, Nguru, Kilimanjaro, and Kazimzumbwi hills (Hemp, 2009; Hemp *et al.*, 2010; Matojo and Njau 2010; Hemp, 2013; 2017). Among these places, *C. maculatus* was only recorded at Msala, Rufiji

Delta and around Mt Kilimanjaro (Sjöstedt, 1909; Kevan and Knipper, 1961). Apart from these two places, no reports of this insect have been made in any other part of the country, the fact which makes the knowledge of its distribution and abundance in Tanzania insufficient.

Kagera region contains a high diversity of species, both plants and animals which is little explored (Perking and Bearder, 2004; U.R.T. 2016). The only tettigoniid, and probably the only Orthopteran studied in Kagera region is *R. differens*, a longhorn grasshopper, well known for its nutrition value in the East African Lake Victoria zone (Agea *et al.*, 2008; Matojo and Njau, 2010; Kinyuru *et al.*, 2011; Matojo and Hosea, 2013). An unidentified insect similar to *C. maculatus* was observed at various locations in this region only giving a clue of its presence, distribution and abundance. This study, therefore, sought to bring to light presence, distribution and abundance, population ratios and the acoustic behaviour of *C. maculatus* in Kagera region, north western Tanzania.

1.3 Justification of the study

The lack of researched information about a species in any ecosystem deprives the world of knowledge about the biodiversity of a region and puts the species at risk of vulnerability to extinction especially when its habitat is in proximity with humans. Although *C. maculatus* is known in many parts of the tropical Africa and Asia, reports on its occurrence in Tanzania are so far confined to Kilimanjaro and Msala Rufiji Delta, north and Eastern part of the country. There was no documented information on distribution and abundance of this species in Kagera region although it has been seen in various locations. The documented arthropod biodiversity in Kagera includes butterfly species and *R. differens* only (Perking and Bearder, 2004; Williams, 2008; Matojo and Njau, 2010). Kagera is the region in Tanzania where insects have high ecological and economic values such that knowledge about one more species could unleash new potentials regarding these two aspects. Moreover, the population ratios of *C. maculatus* are least known although they are important in telling about the conservation status of a species. Acoustic study on the other hand gives crucial information about identity, population and behaviour of a species under various conditions. Therefore, this study was conducted in order to document for the first time, distribution pattern, abundance, population ratios and the sound characteristics of *C. maculatus* in Kagera region, north western Tanzania including the factors affecting them.

1.4 Research questions

(i) What is the distribution and abundance of *C. maculatus* in Kagera region Tanzania?

(ii) What are the age and sex ratios of *C. maculatus* found in Kagera region Tanzania?

(iii) What are the factors affecting distribution, abundance and sex and age ratios of *C. maculatus* in Kagera region, Tanzania?

(iv) What is the acoustic behaviour of *C. maculatus* found in Kagera region Tanzania?

1.5 Hypotheses

(i) There are no differences in distribution and abundance of *C. maculatus* between different sites within Kagera region Tanzania.

(ii) There are no differences in population age and sex compositions of *C. maculatus* found in Kagera region, Tanzania.

(iii) There are no factors affecting distribution, abundance and sex and age ratios of *C. maculatus* in Kagera region Tanzania.

(iv) There are no time differences in acoustic behaviour of *C. maculatus* found in Kagera region Tanzania.

1.6 Objectives

1.6.1 General objective

The general objective of this study was to assess of the distribution and abundance *Conocephalus maculatus* in Kagera region North-western Tanzania.

1.6.2 Specific objectives

The specific objectives of this study were:

(i) To evaluate the distribution and abundance of *C. maculatus* in Kagera region Tanzania

(ii) To determine the age and sex ratios of *C. maculatus* found in Kagera region Tanzania

(iii) To establish the factors affecting distribution, abundance and sex and age ratios of *C. maculatus* in Kagera Tanzania

To compare acoustic behaviour of *C. maculatus* under different conditions in Kagera region Tanzania

1.7 Significance of the study

The findings are deemed to provide substantial information on the distribution, abundance and population ratios of *C. maculatus* in Kagera region North-western Tanzania. The information will help in establishing beneficial utilization, control and conservation measure of this insect and other species that use its habitat. This will further add more information on the tettigoniid biodiversity in this region. The finding will also widen the scope of knowledge of sound characteristics of *C. maculatus* for further researches using acoustic signals of organisms.

CHAPTER TWO

LITERATURE REVIEW

2.1 Distribution and abundance

Distribution is the manner in which a biological taxon is spatially arranged. It is regarded as series of local populations across a number of habitat patches and quantified as the proportion of the occupied patches (Kean and Barlow, 2004). It can simply be determined by the presence and/or absence of a species in different parts of a given area (Fergnan *et al.*, 2008). Abundance is the relative representation of a species in a particular ecosystem as opposed to population size which is the actual number of individuals in a population (Collier *et al.*, 2008). Abundance and population size two are highly correlated (Collier *et al.*, 2008). Abundance data are collected by complete enumeration, counting all individuals in a well defined sampling unit (Sileshi, 2007). These counts are interpreted as measures of relative abundances and are used to compare both population size and fluctuations in abundance (Collier *et al.*, 2008). Abundant species are those found in large numbers in a given habitat at agiven time (Vestal, 1913). Distribution and abundance patterns are closely related because together they provide information for the classification of the availability of the species. If distribution is wide and local abundance is high the species is said to be common: it is localized, if distribution is narrow but local abundance is high; it is sparse if distribution is wide but local abundance is low; and scarce, if distribution is narrow, and abundance is low (Kean, 2006). Information on the spatial abundance of the species directly gives information of the spatial distribution pattern of it (Serrezuela and Pinilla, 2015). The knowledge of spatial distribution of insect is a requirement for understanding the biology and ecology of the species and for develoment of an appropriate sampling procedure, (Binns *et al.*, 2000). Distribution also provides the paleological informatin of a species (Simões and Quartau, 2008).

Many invertebrates are more abundant in tropical than temperate regions (Fattorini *et al.*, 2013). Grasshoppers are commonly terrestrial inhabitant occupying wide range of ecosystems, from sea level to high altitudes, healthy and disturbed, natural and anthropogenic (Latchininsky *et al.*, 2011). Researchers have reported *Conocephalus maculatus* as being widely distributed throughout Afro-Asian tropics, the Middle East including; Saudi Arabia, Yemen, United Arab Emirates, and Jordan (Ingrisch 1999; Gwynne, 2001; Mahasneh and Katbeh-Badera, 2004; Massa *et al.*, 2010; Zhou *et al.*, 2010); Southeast Asia, including; Thailand, Singapore, Philippines, Burma, Indonesia and Malaysia (Tan, 2012; Hanboonsong *et al.*, 2013; Tan *et al.*, 2013; Hwang and Yue, 2015); Australia and Australasia including Papua New Guinea (Ingrisch 1999; Panhwar *et al*., 2013; (Bazelet and Naskrecki, 2014). In Eastern Asia it is found in China, Japan, and Korea (Oda and Ishii, 1998, 2001; Ito and Ichikawa, 2003; Zhou *et al.*, 2010; Park *et al.*, 2013). It has been reported in South central Asia in the countries of India (widespread; in Himachal-Chamba, Sirmour and Solan), Pakistan, Sri Lanka, Nepal and Bengal, (Gwynne, 2001; Shishodia and Gupta, 2009; Arya *et al.*, 2015). In Pakistan, it is distributed throughout the country in all cultivated fields, forests, fruit orchards, grapevine, hilly, semi desert and desert areas, trees, shrubs, herbs and grasses (Panhwar *et al*., 2013).

In Africa, it occurs in, Congo (Brazaville and DRC), Guinea, Libya, Mozambique, Senegal, Sierra Leone, and Zimbabwe, then in Ghana, Cameroon and Ivory Coast, Somalia, South Africa Tanzania and in Kenya (Sjöstedt, 1909; Kevan 1950; Baccetti and Abukar, 1987; Ingrisch 1999; Hemp and Hemp, 2003; Biota, 2004; Heinrichs and Barrion, 2004; Bazelet and Naskrecki, 2014).

2.2 Population ratios in grasshoppers

Population ratio is a component of population size and structure studies, which is used to describe the degree of balance between two elements of the population, such as males versus females, that is the sex ratio or children versus women of reproductive age, which is age ratio (Loomis-Price, 2016; Schowalter, 2011). Sex ratio is measured as male to female ratio and includes measurements at birth or hatching, measurements of the whole population and measurements of the reproductive age, normally between 15 to 49 years of age in humans (Loomis-Price, 2016). The best tool to define population status is the operational sex ratio (OSR), which is the ratio of sexually active males to fertilizable females (Gwynne, 1989; Kvarnemo and Simmons, 1999). Where OSR cannot be established, the adult sex ratio (ASR) which is the ratio of all male adults to all female adults, is a better determinant of the rate of population growth (Raven, 2011).

The sex ratio can be 1:1 or skewed towards males which cause sexual competition among males or towards females which brings the opposite effects (Gwynne, 1989). Biased sex ratios are common in birds (Donald, 2007), ungulates (Weaver and Weckerly, 2011), guppies (McKellar *et al.*, 2009), and in reptiles (Grayson *et al.*, 2014). Such biases are also common in insects such as houseflies and monarch butterflies, where they are male biased (Sören *et al.*, 1995; Carrillo, *et al.*, 2011). There are also 1:1 sex ratios among Orthopterans such as the Afrophlaeoba genus (Accridoidea) (Hochkirch, 2001). Some studies have been carried out on sex ratios in tettigoniids (Gwynne, 1985; 1989; 2001; Kvarnemo, 2008; Matojo and Yarro, 2010). There are no directly reported researches on the sex ratio in *C. maculatus*. Few researchers have produced data on male and female numbers, which can somehow serve as source of data for computing sex ratio in *C. maculatus* (Senthilkumar and Sanjawan, 2008; Panhwar *et al.*, 2013). This study sought to establish *in situ* the sex ratio of this katydid to the adult level.

Age ratio in a population indicates the population growth status. Presence of fewer adults and more young individuals indicates an expanding while the presence of fewer young individuals than adults indicates a declining population (Arya *et al.*, 2010). In the Orthopterans, five species of the genus Afrophlaeoba were found to have a 1:1 adult/nymph ratio (Hochkirch, 2001). Age studies in *C. maculatus* have involved a comparison of colour polymorphism whereby adults and nymphs were compared for this trait (Oda and Ishii, 2001). Also the age differences have been looked into under the exposure to environmental conditions (Hemp and Hemp, 2003; Hemp, 2013). In this study, age ratio was meant to provide further information on the population structure of *C. maculatus*.

2.3 Factors affecting distribution, abundance and population ratios of grasshoppers

Studies on the factors affecting distribution and abundance provide vital information on species habitat preferences, which can be used for insect conservation or control (Rodríguez–Pastor, *et al.*, 2012). Studies also play an important role in determing mate choises, sex roles, population structure and the extinction status of a population, (Gwynne,1985). Habitat characteristics determine the distribution pattern and abundance of organisms (Bondarenco, 2000). Both biotic and abiotic factors play a role in determination of distribution and abundance of grasshoppers. Biotic factors include the flora and the fauna, while the abiotic factors include all the physical conditions such as climatic variables, topography and soil (Storch *et al.*, 2003; Craft, 2007; Sim Simões and Quartau, 2008; Fiera and Ulrich, 2012;Wasowicz *et al.*, 2014). Distribution patterns are determined by habitat availability and ecologcal demands (Habel *et al.*, 2015), species richness and specific interactions, which include predation, competition, parasitism and mutualism (Lepŝ and Kindlmann, 1987; Vasconcelos *et al.*, 2011). Also, local rates of increase, dispersal, and extinction, may affect the distribution and relative abundance of a population across habitat patches (Kean and Barlow 2004). Dispersal is normally a result of movement in search for mates, food, breeding sites suitable habitat, avoiding competition and predators (Berggren *et al.*, 2001; Robinson and Hall, 2002). Species will be more abundant in habitats that provide food and shelter with few or no natural enemies (Rodríguez–Pastor, *et al.*, 2012; Mitchell and Power, 2003). In many organisms sex ratio at birth is 1:1, which implies that this is genetically constituted. However, several factors cause this ratio to change including; resource availability, unequal longevity of sexes, sex specific predation, differential diseases, aging and mortality (Gwynne, 1985; Mckeller *et al.*, 2009; Arya *et al.*, 2010; Wehi *et al.*, 2011).

Many grasshoppers prefer vegetation particularly grass, for habitat (Tan, *et al.*, 2013). Thus, vegetation composition and structure determine distribution of grasshoppers (Linkimer, 2012). Species will always be found where host plant are present (Luotto *et al.*, 2001). Grasshoppers feed on a variety of grass types including; natural and cultivated, where they have been notorious pests, desease vectors but also beneficial pest control agents. (Koudamiloro *et al.*, 2014). A study on Orthoptera diversity and relative abundance in the rice field in Tamil Nadu India concluded that distribution and abundance were determined by species, growth stage and management level of grass fields (Kandibane *et al.*, 2004). *Conocephalus maculatus* is known as a grassland dweller (Heinrichs and Barrion 2004; Hemp, 2013; Tan *et al.*, 2013; Bazelet and Naskrecki, 2014). It depends but not solely on grass for food, shelter and oviposition (Scholtz and Holm, 1985; Senthilkumar 2006). As a herbivore, *C. maculatus* normally feeds on pollen, seeds, flowers and stems of various grass species, including; *Hyparrhenia* spp, *Eleusine* spp, fingergrass, *Digitaria adscendens* (H.B.K.) (Graminae) and *Sorghum halepense* (Poaceae) (Oda and Ishii, 1998; Wason and Pennings, 2008). In Jordan, this insect was collected form tall grasses of *Eleusine indica* (Poales: Poaceae) and *Sorghum halepense* (Graminae) (Mahasneh and Katbeh-Badera 2004). In India, it was found feeding both on grasses, particularly *Cynodon dactylon*

(Poales: Poaceae) and *Apluda mutica* (Poales: Poaceae) and tender leaves of herbs. (Arya *et al.*, 2015).

The species has been reported in almost all rice fields in Asia where it feeds mainly on rice pests (Khan, *et al.*, 1991; Kraker, 1996; Litsinger, *et al.*, 2006; Takahashi and Kiritani, 2008). In South Africa, it is distributed to all lowland grassy areas throughout the country, except the arid regions (Bazelet and Naskrecki, 2014). In Tanzania, *C. maculatus* was earlier found in the lush vegetation of coconut plantation at 0 m above sea level, (a.s.l.) wet grassland near Msala, Rufiji Delta (Sjöstedt, 1909). This species has been reported to inhabit the savanna, grasslands dominated by *Hyparrhenia* and ruderal vegetation on Mt Kilimanjaro (Kevan and Knipper, 1961; Hemp and Hemp, 2003; Hemp, 2013).

Presence, distribution and abundance of species correlate with the physical conditions such as temperature, humidity, rainfall, amount of solar radiation, wind speed, patch size, altitude and slope angle (Ingrisch, 1996; Luotto *et al.*, 2001). Tropical invertebrates are more habitat specific than their temperate counterparts (Hodkinson, 2005). Environmental variables can be correlated with spatial distribution of many insect species (Bazelet *et al.*, 2016). *Conocephalus maculatus* is generally said to thrive well in moist conditions and lowland areas with relatively high temperature (Bazelet and Naskrecki, 2014). change in altitudes changes optimum environmental conditions, affecting insect development and survival, leading to substantial changes in species richness, distribution and abundance (Fattorin *et al.*, 2013 (Le Cesne *et al.*,2015). Generally, ambient temperature affects the rate of metabolic activities in organisms (Fattorin *et al.*, 2013). Temperature moisture and humidity are closely correlated to egg incubation period and fecundity in Tettigoniids and thereby shape their population dynamics (Ingrisch, 1996: Gottschalk *et al.*, 2003).

Temperature correlates highly with humidity (Alduchov and Eskridge, 1996; Lawrence, 2005). In the Asian climate large numbers of Orthopterans are found during the rainy season when there is adequate moisture and high temperatures, declining through summer when it is dry and high temperature, to the lowest in winter when temperatures are extremely low (*Arya et al.*, 2010). *Conocephalus maculatus* appears throughout the rainy season in (April – July) with temperature ranging from 24°C and 36.5°C, but persists during dry seasons in wetlands and irrigated rice fields (Kandibane *et al.*, 2004; Mahasneh and Katbeh-Badera 2004; Panhwar *et al.*, 2013; Chakraborty *et al.*, 2014). The species is found at altitudes varying from 147 m a.s.l. in Madurai to 2400 m a.s.l. in Nanda Devi (Kandibane *et al.*, 2004; Arya *et al.*, 2010). A research carried out in India to investigate the impact of climate change revealed that change in climatic factors leads to change in growth and development of *C. maculatus* (Senthilkumar and Sanjayan, 2008).

In West Africa Conocephalus spp were found to prefer the guinea savanna region characterized by bimodal rains (1000 – 1200 mm per annum, separated by a short dry spell and along dry season), and the humid tropical zone characterized by long heavy monomodal rains above 2400 mm per annum (Heinrichs and Barrion, 2004). Surveys in Ivory Coast and Guinea, found highest *Conocephalus* populations in the Guinea savanna climatic zone particularly in the hydromorphic and lowland sites, with the highest incidence in the latter and extremely low populations in the upland sites. *C. maculatus* in particular was found in Ghana, Sierra Leone and Cameroon (Heinrichs and Barrion, 2004). In South Africa, it is distributed to all lowland grassy areas throughout the country, except the arid regions which are extremely dry most of the time (Bazelet and Naskrecki, 2014). In East Africa, the Kilimanjaro ecosystem in Tanzania is divided into various altitudinal zones and *C. maculatus* was reported to prefer the colline (700 – 1100 m a.s.l.) and southern submontane (1100 – 1500 m a.s.l.) elevations. Commonly nymphs remained in the submontane zone, up to 1350 m a.s.l. while adult forms dispersed to higher altitudes up to 1800 m a.s.l. (Hemp and Hemp, 2003; Hemp, 2013).

2.4 Acoustic behaviour in grasshoppers

Many grasshoppers produce sounds which cover a wide range of audible frequencies and extend well into the ultrasonic range (Robinson and Hall, 2002). Acoustic behaviour involves the production and detection of sound, the manner in which these activities are carried out and the stimuli that cause them. This acoustic behaviour plays an important role in the species` reproductive strategy for attraction of potential mates (Heldmaier and Werner, 2003); in detection of predators for survival (Latková *et al.,* 2012), and in spacing and distribution of individuals within the habitat (Rossler *et al.*, 2006). In tettigoniids, sound signaling is predominantly a male characteristic meant for attraction of females, declaration of territoriality and warning of conspecific rivals, (Robinson and Hall, 2002; Capinera *et al.*, 2004).

Sound signaling is a species-specific characteristic that helps scientists to carry out various researches on insects by use of sound detector technology (Rossler *et al.*,2006). This technology offers the most accurate and fastest information about the species including population densities, habitat quality, size of patches, and isolation (Diwakar *et al.*, 2007; Hemp *et al.*, 2010). By the absence-presence of the sound signal, the absence-presence of a katydid in a locality can be established and therefore, acoustic signal provides information of species identity, location, distribution, environmental quality, immigrations and emigrations of species (Grant, 2014). Sound detection is sufficient in identification of species because each species has distinct sound characteristics distinguished by their dominant frequency and pattern (Bondarenco, 2009; Wil and Lang, 2017). A typical sound signal comprises pulses, chirps and trills which together with the frequencies are used to identify a particular species (Greenfield, 2002). Songs of some members of tettigoniids, such as *Platycleis* spp however, cannot be easily distinguished because they closely resemble each other (Massa *et al.,* 2001).

Sound signaling in katydids goes with other life activities and can either be nocturnal or diurnal. *C. maculatus* males produce a calling song which is described as a continuous sequence of syllables, faintly audible with the unaided ear (Hemp, 2013). The time of acoustic activities in *C. maculatus* is not conclusively established (Grant, 2014). Investigation of acoustic behaviour in this study was very crucial in order to easily establish the time of sound signaling, and determine the distribution, of *C. maculatus* on a wider area and more accurately than visual observation alone could do (Berggren *et al.,* 2001).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

This study was carried out in administrative Kagera region which lies between 1.00^{o}S and 2.45^o S, and 30.25^o E and 32.40^o E in the north-western corner of Tanzania (URT, 2013). The target area involved six out of the eight districts of this Region, with various sites within them namely, Bukoba Rural (Itahwa, Maruku, Kasha, Mwemage, Katoma Kabalenge, Omukiisi, Katokoro and Igoma), Bukoba Municipal, (Mugeza, Kyakairabwa, Kitokozi, Bumai, and Bunyonya); Karagwe (Kayanga, Ndorage, Omurushaka); Kyerwa (Kaaro, Kasharara, Rukuraijo, Rwengaga, and Kyerwa), Missenyi (Bugorora, Kyaka, Mabuye, Kitengule, kabalenge, Bubale, and Mugana) and Muleba (Nshambya, Bugasha, Nshamba Mushasha, Kalambi, Kiziramuyaga, Rushwa). Detailed studies including sound characteristics, Distribution, abundance physical conditions, sex and age ratios were carried out at three randomly selected sites including Bugorora in Missenyi, Maruku in Bukoba Rural and Nshambya in Muleba. Much of the Kagera region is hilly terrain with thick tropical vegetation including forests, banana plantations and open grasslands. The Region experiences two rain seasons, the March – May Long (heavy) rains season and the September/October – December short rains season making up an average of 800mm to 2,000mm per annum with an average temperature of 20°– 30°C throughout the year (TCCIA, 2012; TMA, 2015). The two rainy seasons are separated by the two dry spells, the June – September/October long dry season and the January – February short spell. The study was carried targeting only the two rain seasons and the short dry season between them.

3.2 Study design

Cross-sectional research design was applied to study the distribution, abundance, population ratios and acoustic behaviour of *C. maculatus* in Kagera region. Six districts including Bukoba

Rural, Bukoba Urban, Karagwe, Kyerwa, Missenyi and Muleba, representing Kagera region`s topographic and climatic zones were randomly sampled. Furthermore, various locations were visited within these districts to study geographical distribution of *C. maculatus*. Three sites were particularly selected basing on altitudinal zonation of Kagera region for more detailed research on the population distribution and abundance of *C. maculatus*, and the physical conditions involved. Maruku (1360 m a.s.l.) found within the altitudinal zone of between 1200 – 1500 m a.s.l., 5 km south of Bukoba town. Nshambya (1510 m a.s.l.) found within the altitudinal zone of over 1500 m a.s.l., about 15 km North-west of Muleba town and 50 km south of Bukoba town. Bugorora (1140 m a.s.l.) found within the altitudinal zone of below 1200 m a.s.l., about 30 km west of Bukoba town (TCCIA, 2012; Shand, 1999). The sites also lie within the high rainfall zone of Kagera region with high insect abundances (Shand, 1999; Matojo and Njau, 2010).

The target population included all *C. maculatus* individuals occurring at various locations in the six districts. The sample size was determined by the total catch per sample collection per study site over a period of 9 months from September 2014 to May 2015. All Tettigoniids other than the target species were also collected for relative abundance estimations. A 50 m x 50 m quadrat was demarcated at each site of the sampling area. Within this quadrat fifteen 2 m x 2 m subquadrats were marked for detailed study of the target species.

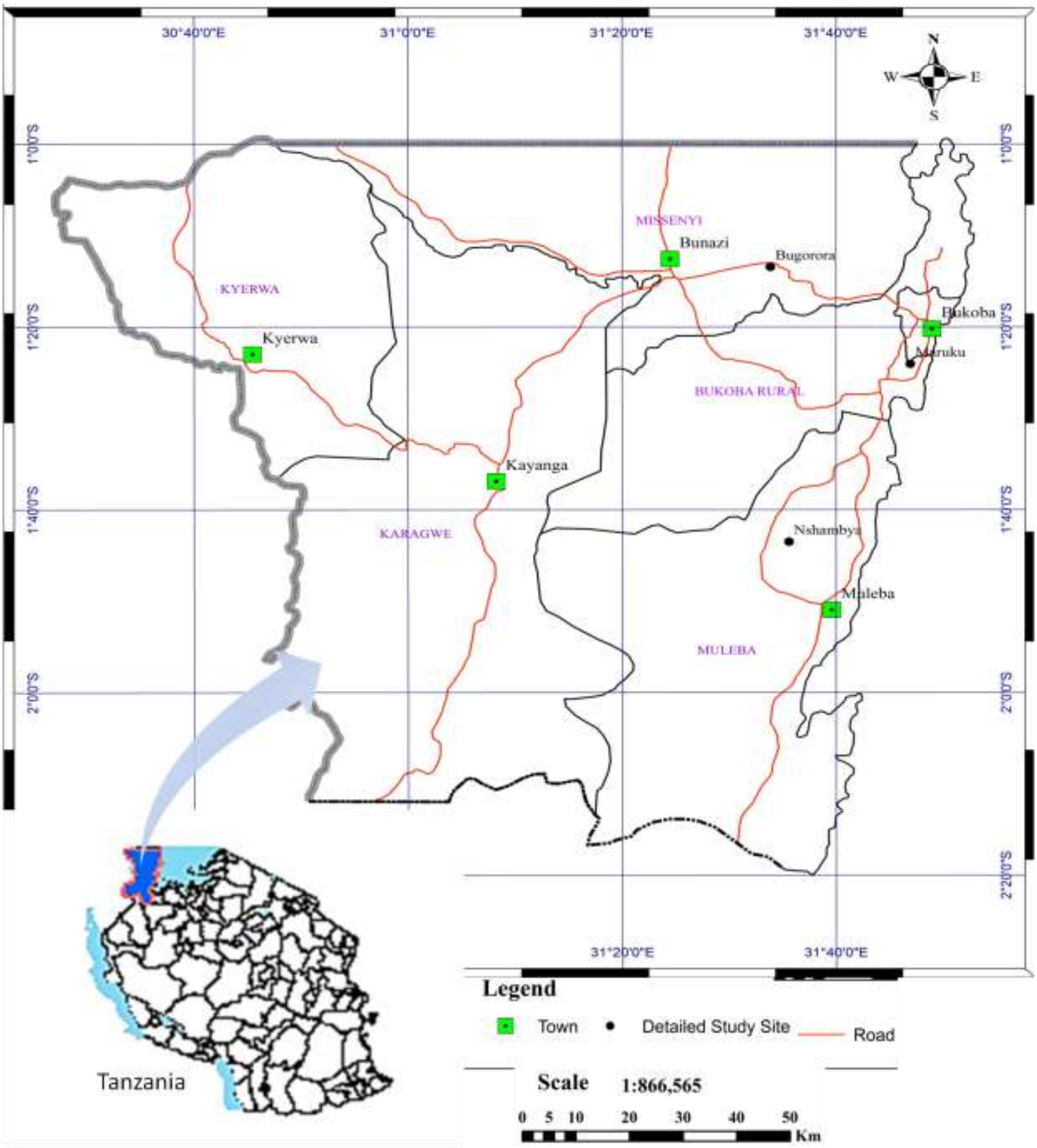

Figure 3.1: Map of Kagera region showing the study area and sites (Adapted from M.C Shand, University of Grasgow 1999).

3.3 Insects sampling

Insects sampling was done by sweep-netting (40 cm diameter and 1m long handle), hand picking upon direct search and acoustic identification of specimens in the selected sites (Kurth, 2007; Nagy *et al*., 2007; Hemp, 2013; Krištín *et al.*, 2013). At each of the three sites, a 50x50 m^2

permanent quadrat was demarcated with pegs at each of the four corners to ward off interference by people. Within each quadrat three 2 m x 50 m long strips were marked, running from one edge to the opposite edge separated by a 5 m wide transect from each other. Along each strip five subquadrats of 2 x 2 m^2 size and 10 m apart were marked making a total of fifteen subquadrats. Three researchers were employed at each site, one for five subquadrats. The researcher walked along, swiped, and picked any flushed insect from the quadrats and put it in net bags. This exercise took half an hour each day of collection. Collection time was alternating between morning and afternoon. *Conocephalus maculatus* population was monitored for nine months from September 2014 through May 2015. Estimation of the population changes was done by a continuous collection of *C. maculatus* two weekly. The collection in September – December period included all the Tettigoniids in order to gather enough data for studying the relative abundance of *C. maculatus*. Records of the numbers of adults, nymphs, males and females were made in order to establish the sex ratio and age structure, downsized to population age composition including only adults and nymphs divides without going into details of instar developments (Schowalter, 2011).

3.4 Identification of the species

Live specimens caught in sweep nets were provisionally observed in the field for visible features. From this field observation, only longhorn grasshoppers were retained, leaving out other arthropods of no interest. Samples were then sacrificed and taken to Maruku Agricultural Research Institute (ARI Maruku) laboratory situated at Maruku in Kagera. In the laboratory, they were observed to identification using a hand lens (10x) and a dissecting microscope. The identification of the insects was done using the conventional key from Orthoptera Species File Online provided by Eades and Otte (2017), and the key by Heinrichs and Barrion, (2004). Sampled specimens were preserved in 70% in separate containers for confirmatory identification.

However, as noted earlier by Wason and Pennings (2008), Tettigoniids preserved wet, especially in alcohols have a tendency to lose colour. Notably, the alcohol-preserved specimens turned black starting from the abdomen through the head, therefore becoming unsuitable for observation and analysis. To overcome this, live specimens were collected, caged in perforated plastic containers, labeled, and thereafter transported alive to the National Museums of Kenya, Entomology Section for confirmatory taxonomic identification.

3.5 Evaluation of distribution and abundance of *C. maculatus*

The aim here was to establish the pattern of distribution and the abundance of *C. maculatus* at the study sites and thereby the whole study area. Population means from the fifteen quadrats at each of the three sites of Maruku, Bugorora, and Nshambya collected in nine months were used. Additional sites were involved for distribution pattern evaluation. Three sweeps per quadrat per day in a fortnight made a total of ninety sweeps per month. Each sweep was accompanied by a hand pick whenever necessary, mainly in tall grass.

3.5.1 Evaluating the spatial distribution pattern of *C. Maculatus*

Both acoustic search and sweep netting were applied in obtaining information for distribution pattern. Population means from each subquadrat at each site were compared for establishment of differences. Also the presence or absence of the target species from the various micro habitats of the subquadrats was recorded (Vasconcelos *et al.*, 2011). Similar records and comparisons were carried out to compare sites. The pattern of spatial distribution of *C. maculatus* was classified by use of the *Index of Dispersion* method (Sedaratian *et al.*, 2010).

3.5.2 Estimation of abundance of *C. maculatus* in the research area

Calculation of abundances per site was carried out by recording the number of individuals collected from each sampling unit (Sileshi, 2007). Then the mean with the standard error (SE) of local population size at each sampling unit was taken for abundance (Kean, 2006). These abundances were compared to investigate spatial and temporal relationships between the study sites, seasons and months of collection respectively. Abundances of other tettigoniids found at the study sites were also recorded in order to estimate their relative abundances. The population size of *C. maculatus* was deduced from here since measures of relative abundance are highly correlated with measures of absolute population size (Collier *et al.*, 2008). The relative abundance of each of the Tettigoniids found in the research area was calculated using the formula:

$$R = \frac{a}{N}\ x\ 100$$ (Chakraborty *et al.*, 2014)

Where R = relative abundance,

a = number of individuals per species in the sample

N = total number of individuals in the sample.

3.6 Determination of the population ratios of *C. maculatus*

Population ratios were studied as one way of investigating the change in population composition, size and structure (Schowalter, 2011). The considered ratio here was the adult sex ratio which is the ratio of male adults to female adults with a greater probability of mating (Price *et al.,* 2011). The collection form format provided for categorization of individuals into sex and age groups. For sex, females were identified by the presence of the ovipositor and males by the absence. From the numbers collected calculations were made to establish the sex ratio in *C. Maculatus* population. For age study, the species was separated into two age groups which were the adults on one hand and nymphs on the other. All individuals after the last (sixth to seventh) instar were included in the adult group while all individuals before the last instar were grouped as nymphs (Senthilkumar, 2006). Then calculations were made to establish the adult/nymph ratio.

3.7 Establishment of factors affecting distribution, abundance and population ratios of *C. maculatus*

Vegetation and the physical conditions of temperature, humidity, rainfall and altitude were selected as the factors to be investigated. According to Linkimer (2012), vegetation composition and structure determine distribution and abundance of Tettigoniids (Linkimer, 2012). Also altitude, together with connecting factors of temperature, rainfall and humidity define habitat types (Doody *et al.*, 2001). Moreover, the study area and the site are found within the highly humid and high rainfall highland of Tanzania (Sarwatt and Mollel, 2000).

3.7.1 Vegetation (sampling and identification)

A Braun-Blanquette 5 point scale was used to estimate vegetation cover at the sites (Wratten and Fry, 1980). The percentage cover of the given plant species determined its abundance at the study sites. The percentage cover of vegetation was selected because it determines better the resources and hence abundance of the herbivore than plant richness (Fergnan *et al.*, 2008). Only grass, shrub and herbal vegetation was involved while any area covered by a large tree was regarded as one with no vegetation of interest together with their ground. Most plants were identified *in situ* using the Minziro Forest Reserve plant list (Crossborderbiodiversity, 2001). Few specimens were identified by the help of the Taxonomist at Minziro Nature Forest Reserve botanical laboratory located at Bunazi Missenyi district, Kagera region. Plant taxonomic details were collected from the 3 selected study sites of Maruku, Bugorora, and Nshambya plus the other sites where *C. maculatus* was traced by acoustic search. The additional sites included; Katoma, Itahwa, Mugeza, Kitokozi, Bumai, Kyakairabwa, Kaaro, Kyaka, Kabalenge, Omukiisi, Mwemage, Mugana, Kayanga and Kasharara. Then the relationship of *C. maculatus* presence, distribution and abundance with vegetation types and abundance was investigated at each site and the whole research area.

3.7.2 The physical conditions

Daily records of temperature, humidity and precipitation were taken for the whole period of the study. Temperature records for Maruku were obtained as secondary data from Bukoba Airport metrological station within 10 km from the site. Temperature records for Bugorora were taken by using an Outdoor mercury free min-max thermometer HX-JM001 made in China placed at the site. For Nshambya, the data were based on the records taken from Rubya Seminary metrological sub-station, located 3 km south east of the study site. Humidity data for Maruku and Bugorora were obtained as secondary data from Bukoba Airport metrological station while the data for Nshambya were obtained from Rubya. Rainfall data were recorded using a rain gauge set at each site except at Nshambya where they were based on the records taken at Rubya Seminary. Temperature, humidity and rainfall data were then tested for any relationship with *C. maculatus* population data. Altitude measures were taken using a GPS, Garmin GPSMAP64s.

3.8 Investigating the acoustic behaviour of *Conocephalus maculatus* species

Live *C. maculatus* individuals were kept in perforated transparent plastic cages in the laboratory and monitored day and night by listening for any sounds for comparison between the two. During the night the laboratory was lit with a white fluorescent tube. A heterodyne ultrasound detector, Petterson D-200 (Pettersson Elektronik AB, Sweden) was used for sound detection. This gadget was switched on and brought close to the cages. A voice recorder, Sony ICD-BX140 made in China was used to record the detected sound for field identification reference and sound characteristics analysis. The sound file of *C. maculatus* was downloaded from Baker *et al.*, (2015) for comparison sake. Laboratory sound characterization was followed by field acoustic records at various sites both during the day and during the night within the study area in order to compare the night and day as well as the laboratory and field sound characteristics. The elements investigated in the sound signal comprised pulses, chirps and trills and frequencies (Greenfield, 2002; Grant, 2014).

3.9 Data analysis

Data was analysed using the Statistical Package for Social Sciences (SPSS) version 22 and MS Excel. All the variables were checked for normality and outliers separately first whereby all population data was log transformed for normalization.

To determine the distribution pattern of *C. maculatus*, data on population was subjected to analysis in SPSS to obtain the measures of central tendency (Variance and mean) used to compute the index of dispersion and Z values to test for significance of the distribution pattern.

Dispersion (D) is the variance to mean ratio;

$D = S^2/m$

Where S2 = variance

m = mean (the mean of the means of population per quadrat over a given period of collection)

For random distribution $D = 1$; for a regular distribution $D < 1$ and for an aggregated distribution $D > 1$. Departure from random distribution was tested by using the index of dispersion (I_D), using the formula;

$$I_D = (n-1)S^2/m$$

where n = the number of samples. This index was tested using Z values by the formula;

$$Z = \surd(2I_D) - \sqrt{(2v-1)}$$

Where v = n-1

Data on distribution waypoints recorded on the GPS were displayed on the map to show the geographical locations of *C. maculatus* in Kagera region. Population sums, means and percentages were generated from collected population data in the SPSS for estimation of abundance and relative abundance estimations. Population ratios were determined by calculation of ratios of the sex and age population groups. The significances of the ratios were tested using T-test, to compare the population means of the two opposite sexes and ages respectively. T-test was used because there were only two groups to compare.

Linear regression and Pearson`s bivariate correlation were used to examine the factors affecting population distribution, abundance and ratios. A general linear regression model was developed to define the relationship between the population and physical conditions. The test model included one response and four predictors thus:- $Log(Y) = \beta_\circ + \beta_1 T + \beta_2 P + \beta_3 H + \beta_4 RH + \cdots \epsilon$

Where Y = population abundance

T = temperature

P = precipitation

H = altitude

RH = relative humidity

$\beta_\circ, \beta_1, \beta_2$ β_3 and β_4 are coefficients and ϵ is an error term representing unexplained variations.

Test regression was carried out in SPSS to check for the assumptions of linear relationship among variables, independence of observations, homoscedasticity, normality, outliers and multicollinearity. Checking for assumptions in the early stages of analysis helps the researcher to manage data information and time and to have an effective and accurate analysis, avoiding type I and II errors (Osborne and Waters, 2002; Stevens, 2009). Linear relationships among the variables were checked using scatter plots and partial regression plots. The independence of observations was checked using the Durbin-Watson statistic, which is a simple test to run using SPSS Statistics (De Boef, 2016). Normality and homoscedasticity are related in that normally distributed data is homoscedastic (Tabachnick and Fidell, 2007). In checking for normality of errors the histogram shape and P–P plot were observed. The homoscedasticity, which indicates that the variance of errors is equal and constant across all levels of the variables (Stevens, 2009) was tested using the standardized residuals (y) and predicted values (x) scatter plots. Collinearity was tested using VIF and tolerance values under the conditions that VIF < 5 and tolerance > 0.001. Presence of outliers was checked using the leverage distance.

One-way ANOVA tests followed by post hoc Latter Significantly Different (LSD) range test (assuming equal variance) was used to test spatial and temporal differences in mean population abundances and all the ecological factors between quadrats, sites, months and seasons. This tool was chosen because the compared groups were more than two. The Post tests were used to point exactly the differing sub-groups.

Acoustic behaviour was compared by establishing the correlation between the hour of the day and sound signaling using Pearson`s correlation to establish the time of acoustic signaling. Sound signals were analysed using, Audacity 2.1.0 spectra analysis function to examine the sound characteristics including Trill duration, chirp duration, intervals between each, number of chirps per trill, trill and chirp rate as well as the frequencies. These characteristics were analysed using T-test to compare in-captivity and field data.

CHAPTER FOUR

RESULTS

4.1 Distribution and abundance of *C. maculatus* in the study area

Distribution pattern of *C. maculatus* in the study area was aggregated ($z = 3.009$; $D = 17.223$) where $D > 1$ and $z > 1$ for an aggregated distribution. At Maruku the distribution was aggregated ($z = 2.51$; $D = 2.17$). At Bugorora the distribution pattern was aggregated ($z = 2.19$; $D = 2.00$). At Nshambya the distribution pattern was random ($z = -0.060$; $D = 1.00$) where $D = 1$ and $z < -1$ for random distribution (Table 4.1). A total of 3709 *C. maculatus* individuals were collected from September 2014 to May 2015 from Maruku, Bugorora, and Nshambya with a mean (±SE) of 68.69±6.72. There were significant differences in mean numbers of individuals collected from the three study sites ($f = 16.97$, $df = 53$, $p < 0.001$, ANOVA). Bugorora had the highest abundance (102.72±12.05) followed by Maruku (69.39±10.6) and Nshambya (33.94±5.16) with the lowest abundance (Table 4.1). Nshambya abundance differed significantly from the abundances at Maruku ($p = 0.013$) and Bugorora ($p = 0.000$). Bugorora abundance differed significantly from Maruku abundance ($p = 0.019$)

Table 4.1: Mean numbers (±SE) and distribution index values of *C. maculatus* in the study area

Site		Maruku	Bugorora	Nshambya	Total	Statistical parameters
Mean		69.39±10.6b	102.72±12.05a	33.94±5.16c	68.69±6.72	F 16.97
Sum		1249	1849	611	3709	df 53
Distribution indices	z	2.51	2.19	-0.06	3.01	p 0.00
	D	2.17	2	1	17.22	

Figure 4.1 is a map showing the geographical distribution of *C. maculatus* in the visited six out of the eight districts of Kagera region which are Bukoba Rural, Bukoba Municipal, Missenyi, Muleba, Karagwe and Kyerwa. The map shows all the recorded locations where this insect was searched for and found by use of sound detection and visual observation. Sound CS (characteristic sound) site shows the location where sound data were recorded. It also shows the three sites of Maruku, Bugorora and Nshambya where detailed population and sound characteristics were studied. The stars indicate further habitat locations where *C. maculatus* was found. A detailed table of geographical distribution is found in appendix I

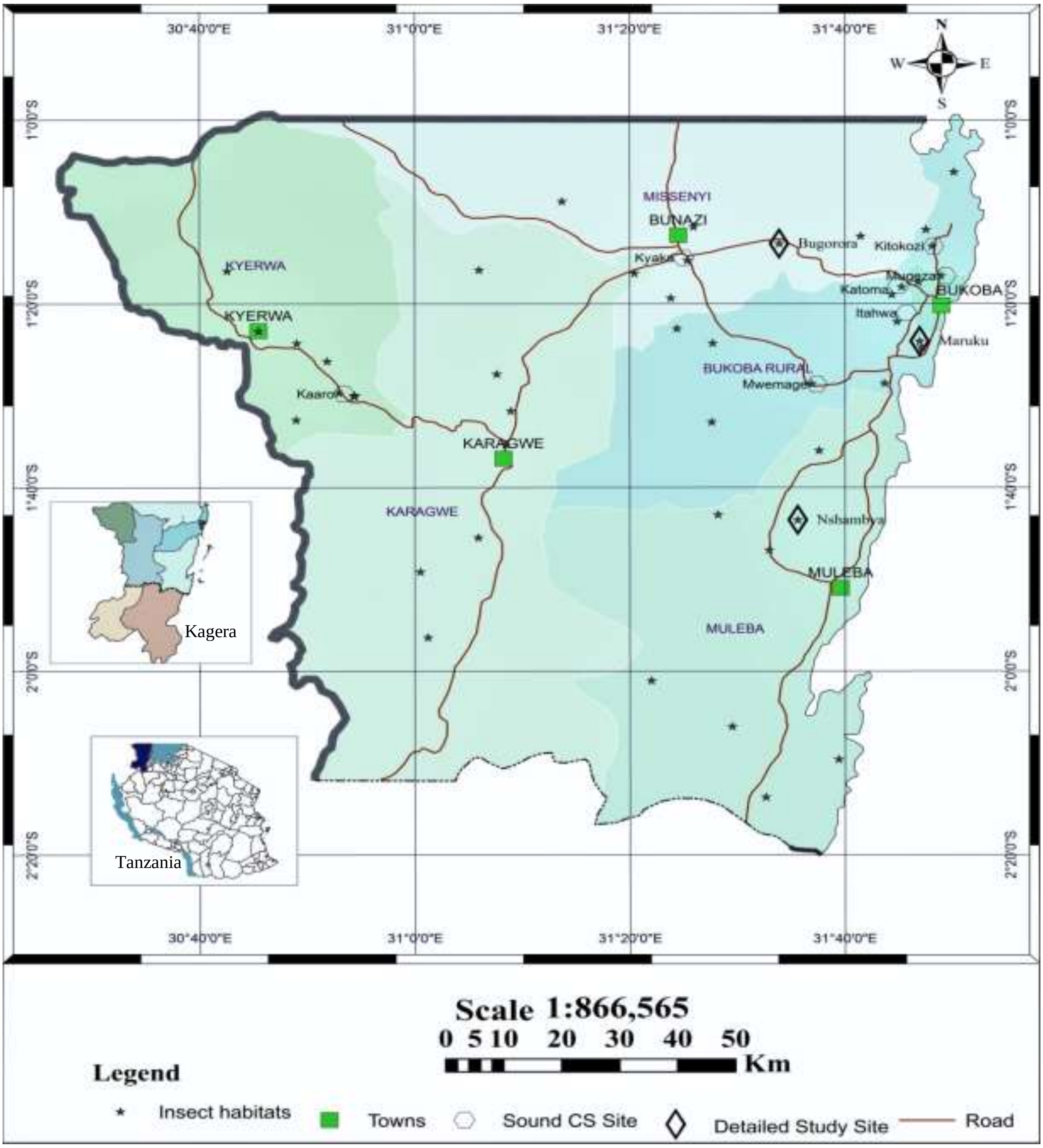

Figure 4.1: Distribution map of *C. Maculatus* in the visited districts in Kagera region.

Five species of the Tettigoniidae family were identified from the study sites of Maruku, Bugorora and Nshambya. These included *Conocephalus maculatus (*Le Guillou) and *Conocephalus iris* (Serville) Conocephalinae; *Phaneroptera sparsa* (Stål), (photo adapted from Reyes (2011), and *Horatosphaga heteromorpha* (Karsch) Phanerphtarinae; as well as *R. differens* (Serville) Copiphorinae (Plate 4.1).

Plate 4.1: Dominant tettigoniid species as sampled from the study sites (A) *C. maculatus*, (B) *C. iris*, (C) *P. sparsa*, (D) *H. heteromorpha*, (E) *R. differens.*

There were significant differences in mean numbers of the tettigoniid species from the study sites (F = 31.58; df = 119; p < 0.001). *Conocephalus maculatus* had the highest abundance of 96.08±11.99 with the relative abundance of 51.2% followed by *R. difference* with 41.29±4.6 at 22%; *C. iris* with 40.83±7.56 at 21.8%; *Phaneroptera sparsa* with 7.25±0.94 at 3.9%, and *Horatosphaga heteromorpha* with 2.25±0.26 at 1.2%. There were significant differences in mean numbers between *C. maculatus* and the rest of the species. The mean number of *R. differens* differed significantly from that of *P. sparsa* and that of *H. heteromorpha* but not from that of *C. iris*. The mean number of *C. iris* differed significantly from that of *P. sparsa* and that of *H. heteromorpha* (Table 4.2).

Table 4.2: Mean numbers (±SE) and relative abundances of species of tettigoniids as recorded in the study area

Species	*C. maculatus*	*R. differens*	*C. iris*	*P. sparsa*	*H. heteromorpha*
Mean number	96.08±11.99a	41.29±4.6b	40.83±7.56b	7.25±0.94c	2.25±0.26c
Relative abundance	51.2%	22%	21.8%	3.9%	1.2%
N	24	24	24	24	24
Statistical parameters	F 31.58 df 119 p <0.001				

Means within the same row followed by the same letter are not significantly different at p = 0.05 (ANOVA).

4.2 Population ratios of *C. maculatus*

The calculated overall sex ratio was 2:1 indicating that males had an edge over females. The adult sex ratio (adult male/ adult female) was 2:1; males had an edge over females. The nymph sex ratio was 1:1. The age ratio was 2:1 indicating that adults had an edge over nymphs. There were significant differences between the overall male and female mean numbers of *C. maculatus* (t = 3.473, df =53; p = 0.001). There were significant differences, between adult male and adult female mean numbers (t = 2.986; p = 0.005). There were no significant differences between nymph male and nymph female mean numbers (t = 1.107; p = 0.273). There were significant differences between adults and nymphs mean numbers (t = 5.578; p = 0.000), (Table 4.3).

Table 4.3: Paired sample test for sex and age population means

C. maculatus pairs		Means (±SE) differences	Ratio	t	df	Sig.
Pair 1	Males - Females	38.04±3.70 - 30.83±3.33	2	3.473	53	0.001
Pair 2	♂ adult- ♀adult	23.80±2.55 - 18.24±1.96	2	2.896	53	0.005
Pair 3	♂ nymph - ♀ nymph	14.37±1.64 - 12.83±1.72	1	1.107	53	0.273
Pair 4	Adults - Nymphs	41.91±4.12 - 26.98±3.05	2	5.578	53	0.000

The difference is significant at p < 0.01 and t > 2.006 (A t-test: paired two samples for means).

A male adult was quickly identified by the presence of fully grown forewings extended beyond the hind knees and distinguished from the female by absence of ovipositor: A female adult was identified by the presence of fully grown wings like a male but with an upward curved ovipositor. A nymph was identified by the presence of underdeveloped wings (Plate 4.2).

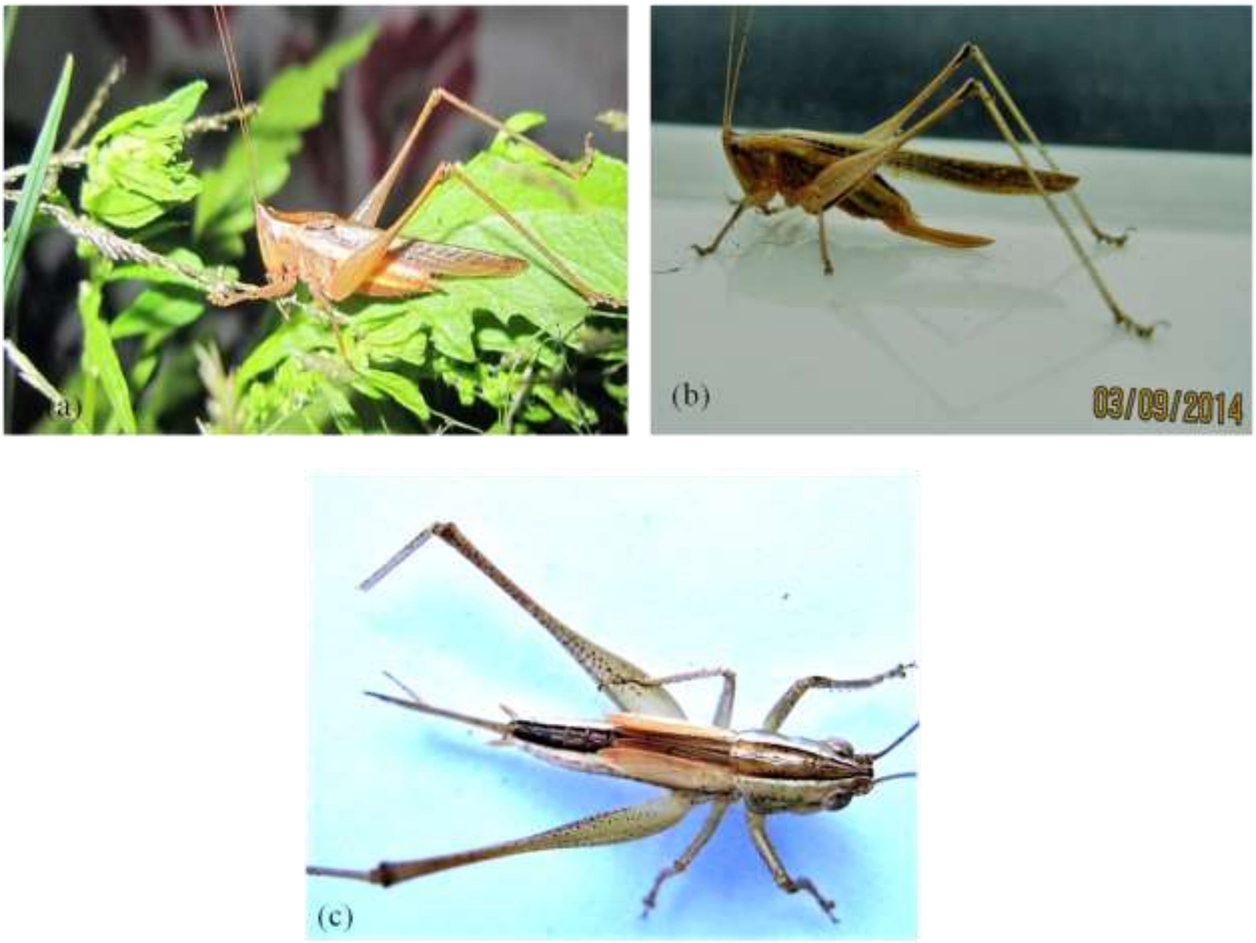

Plate 4.2: Adult male (a), adult female (b), and a female nymph(c), of *C. maculatus* from the study area.

4.3 Factors affecting population distribution, abundance and ratios of *C. maculatus*

4.3.1 Vegetation types preferred by *C. maculatus* in Kagera region

There was a significant positive regression between grass and *C. maculatus* abundances (r = 0.490; p = 0.001). There was a significant negative regression between *C. maculatus* abundance and herbal vegetation ($p = 0.022$, $r = -0.340$) and shrubs ($r = -0.387$; $p = 0.009$). There was no significant regression between abundance and others which included bare ground and basal areas of big trees (Table 4.4).

Table 4.4: Correlation between *C. maculatus* abundance and the vegetation types

	Vegetation	Grass	Herb	Shrub	Others
Abundance	r	0.490	-0.340	-0.387	0.038
	p	0.001*	0.022*	0.009*	0.805*
	N	45	45	45	45

*The correlation is significant at $p < 0.05$ and $p < 0.01$ (Pearson correlation)

Vegetation types recorded at Maruku included *E. blepharoglumis, H. rufa, D. scalarum* and *Eleusine* sp. The site was also characterized by the presence of P*inus carribaea,* on the western side and *eucalyptus* with herbs and shrubs on the eastern side, which formed part of the quadrat. The southern side of the site was bordered by a rough road towards ARI Maruku (Plate 4.3a and b). Vegetation types recorded at Bugorora included *I. cylindrical*, *Entolasia* sp, *Eleusine* sp, *H. diplandra*, *Setaria sphacelata* and *H. rufa*. The site was also characterized by the presence of Pinus *carribaea,* on the northern and western side, with herbs and banana plants on the eastern and southern parts some of which fell in subquadrats (Plate 4.3b and c). The population density was higher in quadrats with grass vegetation than any other types of habitats. Vegetation types recorded at Nshambya included *D. scalarum, Panicum sparsifolium, and Loudetia phragmitoides, H. diplandra* and *Eleusine* sp. The quadrat at this site constituted a somehow uniform extension of *D. scalarum* [Plate 4.3e and f).

Plate 4.3: Vegetation biotopes inhabited by *C. maculatus* in the study area.
(a) Maruku showing the grass part and trees; (b) a section of shrub and herbal vegetation at Maruku: I. cylindrical dominated grass part at Bugorora; (d) a section of pine trees part of vegetation at Bugorora: (e) *D. scalarum* dominated section at Nshambya (f) an extended view of Nshambya site

The most common grass species included *Hyparrhenia*, dominated by *H. rufa* with abundance of 20.5% followed by D. *scalarum* at 9.8%, Eleusine spp at 8.2%, *Eragrostis*, dominated by *E. blepharoglumis* at 8.2% and *Loudetia*, dominated by *L. kagerensis* at 7.4% (Table 4.5).

Table 4.5: A list of the common grass species in the study area

Species	Family	Abundance
Hyparrhenia	Poaceae	20.5 %
Digitaria	Poaceae	9.8%
Eleusine	Poaceae	8.2%
Eragrostis	Poaceae	8.2%
Loudetia	Poaceae	7.4%
Entolasia	Poaceae	4.1%
Chloris	Poaceae	3.3%
Panicum	Poaceae	3.3%

4.3.2 The physical conditions affecting distribution, abundance and population ratios of *C. maculatus*

The linear regression model that explained the relationship between the target species` population and the physical conditions was given by the equation;

$\boldsymbol{LogY = 0.21T + 0.075RH - 0.002H - 3.565}$, where Y = abundance, T = temperature, RH = relative humidity, H = altitude and 3.565 was a constant.

Rainfall was automatically removed from the model because it had $F > 1$ and its effect in the model was not significant ($\beta = -0.196$; $p = 0.126$). The Durbin-Watson value, $d = 1.57$ which was between values of $1.5<d<2.5$. The values of R were such that $R = 0.69$, $R^2 = 0.48$ (explains 48% of variation) and adjusted $R^2 = 0.44$ (Table 4.6).

Table 4.6: Summary table of the linear regression model of relationship between *C. maculatus* and the physical conditions

Model	R	R^2	Adjusted R^2	Std. Error	Change Statistics					Durbin-Watson
					R^2	F Change	df1	df2	Sig. F Change	
1	0.69	0.48	0.44	0.57	.48	11.34	4	49	.000	
2	0.67	0.45	0.42	0.56	-.03	2.42	1	49	.126	1.557

There was a strong significant positive regression between temperature and *C. maculatus* population (β = 0.689, p = 0.011). There was a strong significant negative regression between humidity and *C. maculatus* population (β = -0.520, p = 0.018). There was a significant negative regression between altitude and *C. maculatus* population (β = -0.408, p = 0.019). Variance inflation factor (VIF) values were 6.197, 4.118 and 2.608 for temperature, humidity and altitude respectively, with corresponding tolerance values of 0.161, 0.243, and 0.383. The mean leverage distance was 0.07 (Table 4.7).

Table 4.7: Table of coefficients of correlation between *C. maculatus* population and the physical conditions

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	SE	Beta			Tolerance	VIF
2	(Constant)	-3.565	4.324		-0.824	0.414		
	Temperat	0.210	0.079	0.689	2.650	0.011	0.161	6.197
	Humidity	0.075	0.031	-0.520	2.454	0.018	0.243	4.118
	Altitude	-0.002	0.001	-0.408	-2.418	0.019	0.383	2.608

The histogram was found to be closest to bell shaped and P-P plot showed many points aligned to the diagonal. The scatter plots of standardized residuals (y) versus predicted values (x) showed a vivid random scatter around the horizontal line, r_1=0 (Figure 4.2).

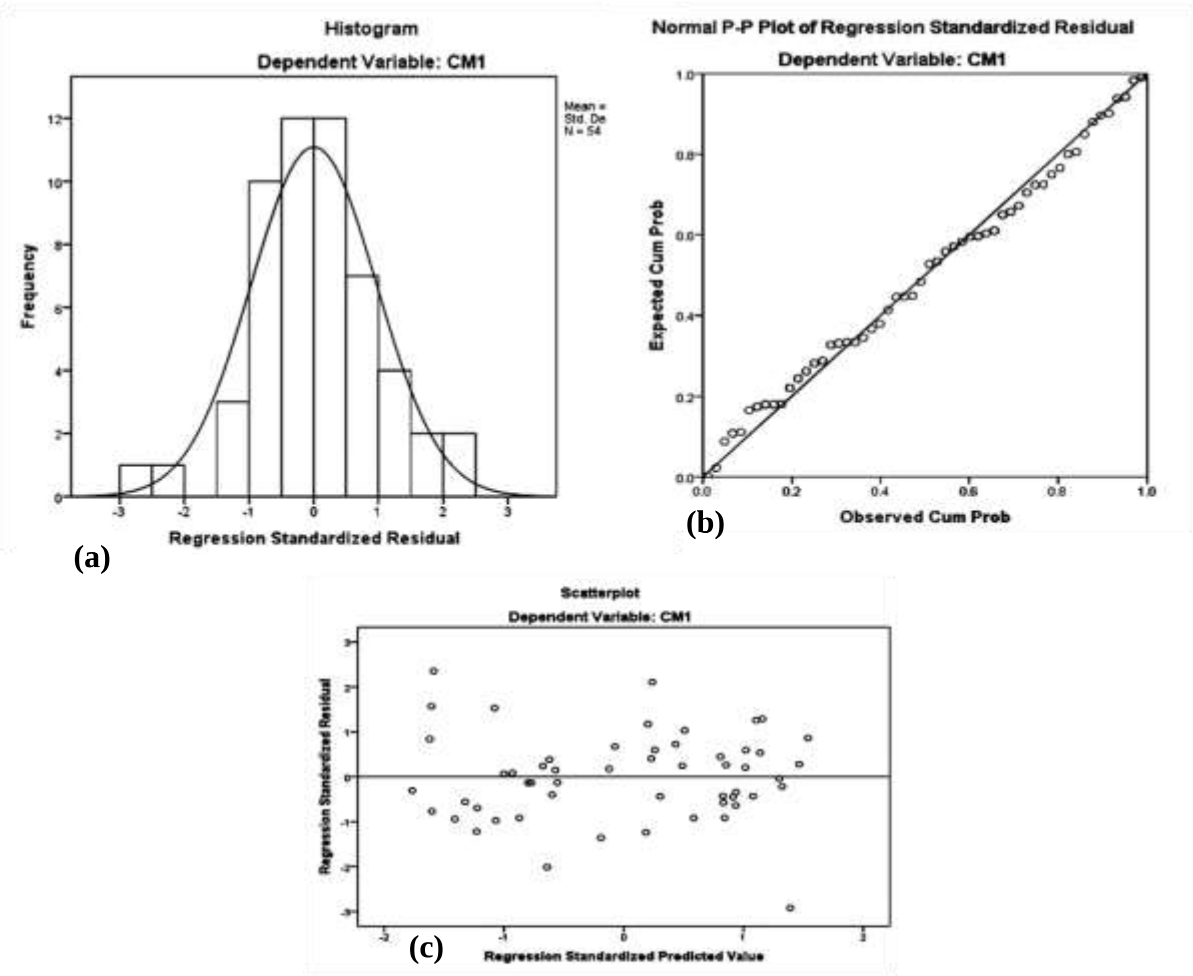

Figure 4.2: Assumption test results for the linear regression model between *C. maculatus* and the physical conditions (a) The histogram (b) Normal P-P plot of Regression Standard Residual (c) Scatter plot

There were significant positive correlations between temperature and *C. maculatus* population abundance ($r = 0.56$; $p < 0.001$). There were significant positive correlations between temperature and adults ($r = 0. 0.529$; $p < 0.001$), nymphs ($r = 0.546$; $p < 0. 001$), males ($r = 0.459$; $p < 0.001$) and females. There were significant negative correlations between humidity and adults ($r = -0.307$; $p = 0.020$), nymphs ($r = -0.386$; $p = 0.004$), males ($r = -0.281$; $p = 0.040$) and females ($r = -0.422$; $p = 0.001$). There were significant negative correlations between altitude and adults ($r = -0.581$; $p < 0.001$), nymphs ($r = -0.592$; $p < 0.001$), and males ($r = -0.500$; $p < 0.001$) and females ($r = -0.674$; $p < 0.001$). There was a significant negative correlation between rainfall and nymphs only ($r = -0.274$; $p = 0.045$) (Table 4. 8).

Table 4.8: Correlations between the physical conditions and the population abundances of *C. maculatus*

		Temperature	Humidity	Rainfall	Altitude
All	r	0.56	-0.34	-0.11	-0.61
	p	0.00*	0.01*	0.44	0.00*
Adult	r	0.53	-0.31	-0.01	-0.58
	p	0.00*	0.02*	0.95	0.00*
Nymph	r	0.55	-0.39	-0.27	-0.59
	p	0.00*	0.00*	0.05*	0.00*
Male	r	0.46	-0.28	-0.12	-0.50
	p	0.00*	0.04*	0.38	0.00*
Female	r	0.64	-0.42	-0.09	-0.67
	p	0.00*	0.00*	0.53	0.00*
	N	54.00	54.00	54.00	54.00

*correlation is significant at p = 0.05 (Pearson correlation)

There were significant positive correlations between humidity and mean populations of *C. maculatus* at Maruku (r = 0.56; p < 0.0001), adults (r = 0.50; p = 0.02), nymphs (r = 0.5; p = 0.02), males (r = 0.56; 0.01) and females (r = 0.54; 0.01). There was a significant negative correlation between humidity and females at Nshambya (r = -0.63; p < 0.01). There was no significant correlation between humidity and *C. maculatus* mean population at Bugorora (Table 4.9).

There was a significant positive correlation between temperature and female C. *maculatus* at Nshambya (r = 0.522; p = 0.013). There were no significant relationships between temperature and population abundance at Bugorora or Maruku (Table 4.9). There was no significant correlation between rainfall and population abundance at Maruku or Bugorora. There was a significant negative correlation between rainfall and nymph *C. maculatus* at Nshambya (r = -0.536; p = 0.011). There was no significant relationship between rainfall and adult abundance at any site (Table 4.9).

Table 4.9: Correlations between the habitat physical conditions and the population abundances of *C. maculatus* at individual sites

C. maculatus		Maruku			Bugorora			Nshambya		
		Temp	Humid	Rain	Temp	Humid	Rain	Temp	Humid	Rain
All	r	-0.22	0. 56	0. 2	-0.21	0.23	0.17	0.22	-0.34	-0.29
	Sig.	0.19	0.00*	0.22	0.21	0.18	0.26	0.19	0.08	0.12
Adult	r	-0.18	0.50	0.31	-0.25	0.28	0.16	0.21	-0.23	-0.09
	Sig.	0.24	0.02*	0.11	0.16	0.13	0.26	0.21	0.18	0.37
Nymph	r	-0.21	0.49	-0.02	-0.13	0.15	0.15	0.18	-0.38	-0.54
	Sig.	0.21	0.02*	0.47	0.30	0.28	0.28	0.24	0.06	0.01*
Male	r	-0.19	0.56	0.20	-0.04	0.05	0.02	-0.05	-0.07	-0.35
	Sig.	0.23	0.01*	0.21	0.44	0.42	0.48	0.42	0.39	0.08
Female	r	-0.25	0.54	0.18	-0.36	0.40	0.32	0.52	-0.63	-0.13
	Sig.	0.16	0.01*	0.24	0.07	0.05*	0.10	0.01*	0.00*	0.31
	N	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00

*Correlation is significant at p = 0.05 (Pearson correlation).

There were significant differences in mean temperature recorded from the three study sites (F = 79.95; df = 53; p < 0.0001). The highest mean temperature of 23.0±0.2^{o}C was recorded from Bugorora followed by Maruku at 22.0±0.1^{o}C and Nshambya at 18.0±0.5. There were significant differences in mean temperature between Maruku and Bugorora (p = 0.027); between Maruku and Nshambya (p = 0.001) as well as between Bugorora and Nshambya (p < 0.0001) (Table 4.10).

There were significant differences in mean relative humidity recorded from the three study sites (F = 27.16; df = 53; p = 0.000). The highest relative humidity of 83.4±0.8% was recorded at Nshambya followed by Maruku at 76.5±1% and Bugorora at 74.7±0.7. There were significant differences in relative humidity between Nshambya and Maruku (p < 0.0001); between Nshambya and Bugorora (p <0.0001) but not between Maruku and Bugorora (Table 4.10). There were no significant differences in mean precipitation from the three study sites.

There were significant differences in mean numbers of individuals collected from the three study sites (f = 16.97, df = 53, p < 0.001, ANOVA). Bugorora had the highest abundance (102.72±12.05) followed by Maruku (69.39±10.6) and Nshambya (33.94±5.16) with the lowest abundance (Table 4.10).

There were significant differences in mean overall sex ratios from the three study sites (F = 3.16; df = 53; p = 0.0142). The highest overall sex ratio of 1.78±0.3 was recorded from Nshambya followed by Maruku at 1.63±0.1 and Bugorora at 0.99±0.1 (Table 4.10). There were significant differences in overall sex ratios between Bugorora and Nshambya and between Nshambya and Maruku. There were no significant differences in overall sex ratio between Maruku and Bugorora. There were significant differences in mean adult sex ratio recorded from the three sites (F = 3.86; df = 53; p = 0.02). The highest adult sex ratio of 1.81±0.2 was recorded from Maruku followed by Nshambya at 1.79±0.3 and Bugorora at 1.00±0.1. There were significant differences in adult sex ratios between Bugorora and Nshambya and Maruku. There were no significant differences in adult sex ratio between Maruku and Bugorora There were no significant differences in nymph sex ratio from the three sites Table (4.10).

There were no significant differences in mean age ratios recorded from the three sites (F = 2.65; df = 53; p = 0.08). However, the highest adult/nymph ratio of 2.37±0.4 was recorded from Nshambya and differed significantly from that recorded at Bugorora which was 1.57±0.1 and the lowest. The age ratio recorded from Maruku did not differ significantly from that of any other site (Table 4.10).

Table 4.10: Mean (±SE) temperature, humidity, precipitation, numbers and population ratios of *C. maculatus* from the three study sites

Site	Maruku	Bugorora	Nshambya	Statistical Parameters		
				F	df	p
Temperature	22.0±0.1b	23.0±0.2a	18.0±0.5c	79.95	53	< 0.0001
Humidity	76.5±1.0b	74.7±0.7b	83.4±0.8a	27.16	53	< 0.0001
Precipitation	23.7±3.7a	14.2±1.9a	20.6±4.3a	1.98	53	0.148
C. maculatus	69.4±10.6b	102.7±12.1a	33.9±5.16c	16.97	53	< 0.0001
Overall Sex ratio	1.63±0.1a	0.99±0.1b	1.78±0.3a	3.16	53	0.012
Adult Sex ratio	1.81±0.2a	1.00±0.1b	1.79±0.3a	3.86	53	0.02
Nymph sex ratio	1.44±0.2a	1.23±0.2a	1.57±0.2a	0.85	53	0.43
Age ratio	1.85±0.2ab	1.57±0.1a	2.37±0.4b	2.65	53	0.08

Means within the same row followed by the same letter are not significantly different at p = 0.05 (ANOVA, LSD).

There were no significant differences in mean temperature recorded during the three seasons (F = 1.6; df = 53; p = 0.212). There were significant differences in mean relative humidity in the three seasons (F = 38.58; df = 53; p < 0.0001). The highest humidity of 79.54±0.46% was recorded during the short rains season followed by the long rains season at 78.90±0.93% and the short dry season at 69.88±1.11. There were significant differences in relative humidity between the short rains season and the short dry season (p = 0.013), which did not differ significantly from that of the long rains season (Table 4.11).

There were significant differences in mean precipitation in the three seasons (F = 4.68; df = 53; p = 0.014). The highest mean rainfall of 23.24±4.22 mm was recorded during the long rains season followed by the short rains season at 21.65±2.10 mm and the dry season at 9.53±2.12 mm. There were significant differences in mean rainfall between the short dry season and both the long rains season (p = 0.006) and the short rains season (p = 0.01). There were no significant differences in mean rainfall between the long rains season and the short rains season (Table 4.11).

There were significant differences in mean numbers of *C. maculatus* recorded during the three seasons (f = 5.591; df = 53; p = 0.005). The highest abundance of 94.9±12 was recorded during the short rains season followed by that of the long rains season, 52±5.9, followed by that of the short dry season, 41.3±8.2 which was the lowest. The abundance in the long rain season differed significantly from that of the short dry season (p = 0.001) and from that of the long rains season (p = 0.003). The abundance in the short dry season did not differ significantly from that of the long rains season (Table 4.11).

There were significant differences in mean adult sex ratio during the three seasons (F = 4.61; df = 53; p = 0.014). The highest adult sex ratio of 2.0±0.3 was recorded during the short rains season followed by the short dry season at 1.3±0.1 and the long rains season at 1.1±0.1. There were significant differences in adult sex ratios between the short rains season and both the long rains season and the short dry season. There were no significant differences in adult sex ratios between the short dry season and the long rains season (Table 4.11).

There were no significant seasonal differences in overall sex ratio (F = 2.76; df = 53; p =0.73). However, the highest overall sex ratio of 1.76±0.2 was recorded during the short rains season and differed significantly from that of the long rains season which was 1.21±0.1 and the lowest. There were no significant seasonal differences in nymph sex ratios (F = 0.53; df = 53; p = 0.59). The highest nymph sex ratio of 1.5±0.2 was recorded during the long rains season followed by the short rains season at 1.4±0.2 and the short dry season at 1.3±0.1 (Table 4.11).

There were no significant seasonal differences in age ratio (F = 2.2; df = 53; p = 0.12). However, the highest adult/nymph ratio of 2.2±0.3 was recorded during the long rains season and differed significantly from that of the short dry season which was1.4±0.1 and the lowest (Table 4.11).

Table 4.11: Mean (±SE) temperature, humidity precipitation and mean ratios of *C. maculatus* recorded during the three seasons

Season	Short rains	Short dry	Long rains	Statistical parameters		
				F	df	p
Temperature	20.41±0.54a	21.01±0.88a	21.78±0.39a	1.6	53	0.212
Humidity	79.54±0.46a	69.88±1.11b	78.90±0.93ab	38.58	53	0
Precipitation	21.65±2.10a	9.53±2.12b	23.24±4.22a	4.68	53	0.014
C. maculatus	94.9±12a	41.3±8.2b	52±5.9b	5.59	53	0.01
Adult Sex ratio	2.0±0.3a	1.3±0.1b	1.1±0.1b	4.61	53	0.014
Nymph sex ratio	1.4±0.2a	1.3±0.1a	1.5±0.2a	0.53	53	0.59
Overall Sex ratio	1.76±0.2a	1.24±0.1a	1.21±0.1b	2.76	53	0.73
Age ratio	2.0±0.2ab	1.4±0.1b	2.2±0.3a	2.2	53	0.12

Means within the same row followed by the same letter are not significantly different at p = 0.05 (ANOVA, LSD).

There were no significant differences in mean temperature during the nine months (F = 0.522; df = 53; p = 0.834). There were significant differences in mean relative humidity in the nine months (F = 16.61; df = 53; p < 0.0001). The highest relative humidity of 81.61±0.97% was recorded during the month of May and differed significantly from those of January (p < 0.0001), February (p < 0.0001), and March (p < 0.0001). The lowest humidity of 67.68±0.83% was recorded during the month of January and differed significantly from those of all the other months except February and October (Table4.12).

There were significant differences in mean precipitation during the nine months (F = 4.47; df = 53; p = 0.000). The highest mean rainfall of 37.88±8.60 mm was recorded during the month of April and differed significantly from those of the rest of the months except November. The lowest mean rainfall of 7.62±3.22 mm was recorded during the month of February and differed significantly from those of October, November and April (Table 4.12).

There were no significant differences in mean number of *C. maculatus* recorded during the nine months of study (f = 2.099; df = 53; p = 0.056). However, the highest abundance of 105.50±19.55 was recorded during the month of September and differed significantly from the abundances recorded in January (p = 0.002), February (p = 0.016), April (p = 0.023) and May (p = 0.034). The second highest abundance of 101.00±34 was recorded during the month October and differed significantly from the abundances recorded in January (p = 0.033), February (p = 0.025) and April (p = 0.035). The third highest abundance of 97.17±26.29 was recorded during the month of November and differed significantly from the abundances recorded in January (p = 0.046), February (p = 0.034) and April; p = 0.048 The lowest abundance of 39.50±9.63 was recorded during the month of February and differed significantly from the abundances recorded in September, October, November and December (Table 4.12).

Table 4.12: Mean (±SE) temperature, humidity, precipitation and numbers of *C. maculatus* Recorded during the nine months

Month		Temperature	Humidity	Precipitation	*C. maculatus*
Sept		20.57±0.88a	79.61±0.90a	16.80±4.51abc	105.50±19.55a
Oct		20.80±1.13a	78.48±1.14ab	23.27±4.17abc	101.00±34ab
Nov		20.10±1.25a	80.55±0.66a	29.63±2.96abc	97.17±26.29ab
Dec		20.17±1.28a	79.52±0.98a	16.92±3.49abc	76.00±17.70a
Jan		20.85±1.15a	67.68±0.83	11.43±2.83ab	43.00±14.29c
Feb		21.17±1.43a	72.08±1.69c	7.62±3.22ad	39.50±9.63c
March		22.60±0.52a	75.27±1.77bc	11.42±3.28abd	64.83±12.66ac
April		21.30±0.65a	79.81±0.69a	37.88±8.60c*	43.50±10.53c
May		21.43±0.80a	81.61±0.97a	20.42±4.97abc	47.67±5.76bc
N		54	54	54	54
Statistical parameters	F	0.522	16.61	4.471	2.099
	df	53	53	53	53
	p	0.834	0.000	0.000	0.056

Means within the same column followed by the same letter or group of letters are not significantly different at p = 0.05 (ANOVA, LSD).*Means that the mean is significantly correlated to the mean population of *C. maculatus* at p = 0.05 (Pearson correlation).

4.4 Acoustic behaviour of *Conocephalus maculatus*

There was a strong correlation between the time of testing and sound detection ($r = 0.798$, $p < 0.0001$) in the field. Day time correlated well with sound detection and night time correlated with absence of sound. In the laboratory the sound was detected both during the day and the night but in the field it was detected only during the day (Table 4.13).

Table 4.13: Correlation between time of acoustic search and detection of sound of *C. Maculatus*

			Sound	Time
Spearman's rho	Sound	Correlation Coefficient	1.000	0.798
		Sig. (2-tailed)		< 0.0001
		N	36	36

The average trill length (T) of the calling sound in *C. maculatus* was 0.94±0.02 s; the average interval between trills (Ti) was 1.5±0.08 s and the average number of trills per second (TR) was 1. The chirp length (C) was 0.02, the interval between chirps (Ci) was 0.005; the number of chirps per second (CR) was 51 and the number of chirps per trill (C/T) was 39. The maximum frequency (Max) was 23.4 kHz and the minimum (Min) was 6 kHz. There were significant differences in mean trill lengths and intervals between the call song of *C. maculatus* recorded in the laboratory and the field recorded song. The trill recorded in the laboratory was longer and differed significantly from the field recorded trill ($t = 6.86$; $p < 0.001$). The trill interval recorded in the laboratory was longer and differed significantly from the field recorded interval ($t = 6.28$; $p < 0.001$). There were significant differences in mean intervals between the chirps recorded in the laboratory and the field recorded chirp: the laboratory recorded interval was longer ($t = 9.3$; $p < 0.001$). There was no significant difference in chirp lengths between the laboratory and field recorded songs (Table 4.14).

Table 4.14: Characteristics of the sound signal of *C. maculatus*

		T	Ti	C	Ci	TR	CR	C/T	Max	Min
Mean values		0.94±.02	1.53±0.08	0.02	0.005	1	51	39	23.4	6
Laboratory		1.06±0.03a	2.02±0.13a	0.02a	0.006a	1	52	39	23.4	6
Field		0.82±0.02b	1.05±0.08b	0.02a	0.003b	1	51	39	23.4	6
Statistical parameters	t	6.86	6.28	-0.55	9.13					
	df	327	327	327	327					
	p	< 0.01	< 0.01	0.54	< 0.01					

Means within the same column followed by the same letter are not significantly different at p = 0.01 (T-test). T=trill duration; Ti=trill interval; C=chirp duration; Ci=chirp interval; TR=trill rate per second; CR=chirp rate per second; C/T=chirps per trill; Max=maximum frequency; Min=minimum frequency

The pictorial representation of acoustic signals was taken from *C. maculatus* recorded in the laboratory showing the trill, both in waveform and spectrogram. It also shows the interval between trill, chirps and the pulses in each chirp (Figure 4.3).

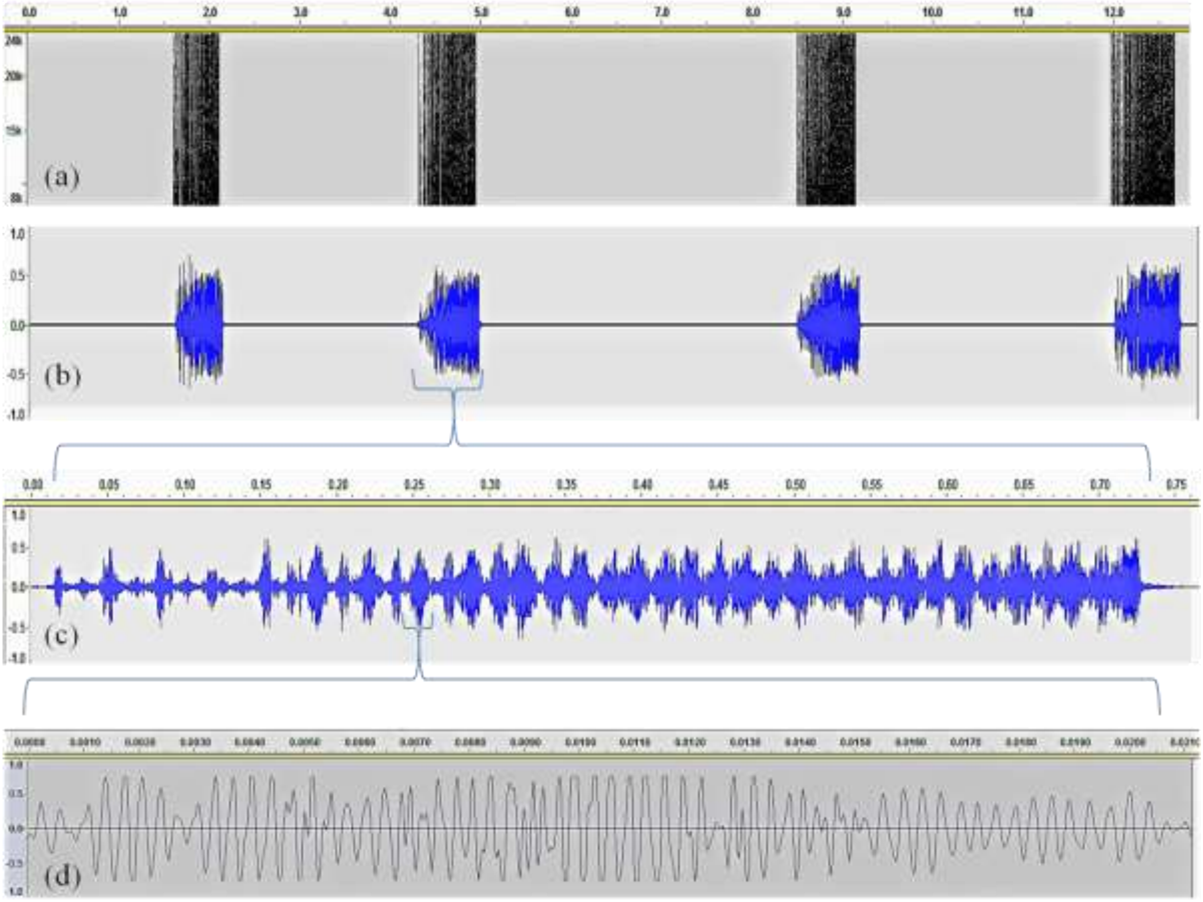

Figure 4.3: Acoustic signals of *C. maculatus* recorded in the laboratory

(a) Spectrogram displaying frequency (kHz) versus time (s) with darker colours representing higher decibels (dB) (b) displays the waveform associated with spectrogram displaying signal structure of amplitude modulations over time (12.7 s). (c) An expanded waveform of one trill in time (0.75 s) to display distinct chirps and (d) one expanded waveform of a chirp in time (0.021 s) to display distinct pulses.

CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Distribution pattern and abundance of *Conocephalus maculatus* in the study area

In general, results from this study suggest that the distribution pattern of *C. maculatus* in Kagera region is aggregated. However, there were differences observed in the three sites whereby the distribution was aggregated at Maruku and Bugorora but even at Nshambya. The aggregated distribution pattern at Maruku and Bugorora was caused by differences in vegetation composition across the quadrats. The population density was higher in quadrats dominated by grass than in those dominated by other types of vegetation. The presence was almost zero in patches without grass. A uniform distribution pattern observed at Nshambya was facilitated by the uniform presence of the grass, *Digitaria scalarum* which was dominant across the quadrats. Grass vegetation is therefore, an important determinant of the spatial distribution pattern. These results indirectly agree with the findings that report grass habitat preference of *C. maculatus* from which distribution pattern could be deduced (Panhwar *et al.*, 2013; Arya *et al.*, 2015). In South Africa it was reported to be present in grass habitats except of the arid regions (Bazelet and Naskrecki, 2014).

C. maculatus was highly abundant in this area. The species had the highest relative abundance compared to the other tettigoniids recorded in the study area. A similar finding was reported in Pakistan where *C. maculatus* was the most abundant of all the *Conocephalus* species studied (Panhwar, 2013). The species had a higher abundance than *R. differens* which has been reported to be the most noticeable tettigoniid in Kagera region (Matojo and Njau, 2010). Most likely, *C. maculatus* was less noticeable due to its small size and lack of swarming behaviour contrary to *R. differens* (Heinrichs and Barrion, 2004; Senthilkumar, 2006; Matojo and Yarro, 2012; Watson and Dallwitz, 2014). Moreover, the methods used to sample the insects, namely sweep netting and acoustic search suited *C. maculatus* better because it was found to be active throughout the period of collection, as has also been reported by Senthilkumar (2006). *Ruspolia differens* instead, leads a large portion of its life cycle in a solitary, less active phase while during swarming they congregate to various specific locations (Matojo and Yarro, 2012).

C. maculatus also had a higher abundance than *C. iris*. A similar relationship was also reported in South Africa and on Kilimanjaro Tanzania where *C. maculatus* was reported to be more abundant than *C. iris* (Hemp, 2013; Grant, 2014). The two cousin species had slight differences in habitat preferences whereby *C. iris* was observed to prefer comparatively more moist habitats dominated by herbal vegetation than its counterpart which preferred grass habitats. This is in agreement with the findings on Mt Kilimanjaro where *C. iris* was reported to appear in Savannah grasslands only during the wetter long rain season while *C. maculatus* was present throughout the year and occupied Hyparrhenia and ruderal vegetation in addition to the Savannah grassland (Hemp, 2013).

From the results, *C. maculatus* was present in high abundance in Kagera region as shown by the mean numbers of *C. maculatus* from each site. Therefore, *C. maculatus* is a common species in Kagera region because both its distribution and local abundance are high. Despite its high abundance and commonality, *C. maculatus* has no salient ecological significance in the area, contrary to Asia where it is an important rice biological pest control agent (Litsinger, *et al.*, 2006; Takahashi and Kiritani, 2008). The species was further found at various locations within the six districts of the study area proving a wide distribution following the presence of grass vegetations.

5.2 Population ratios of *Conocephalus maculatus*

Results revealed that the overall sex ratio and the adult sex ratios were skewed in favour of males. The overall sex ratio agreed with the sex ratio of *C. maculatus* derived from the work of Panhwar *et al.* (2013). When overall sex ratio was calculated from data collected in three years from four provinces in Pakistan it showed a slight skew of 1.3:1 towards males. Therefore, *C. maculatus* exhibited a skewed adult sex ratio, because males were remarkably more than females in natural population. These findings are supported by other findings that reported biased adult sex ratios in insects (Sören *et al.*, 1995). High female mortality was reported in the early nymphal stages of *C. maculatus* (Senthilkumar and Sanjayan, 2006). Therefore, most probably early female mortality, accounts for this male-biased sex ratio in this study too. Findings by researchers reported that male biased sex ratios can either be beneficial or detrimental to population depending on how the species behave (Sakurai and Kasuya, 2008; Carrillo *et al.*, 2012). In this study there was no indication of negative effects of this skewed ratio. The sex ratio in nymphs was 1:1. This is supported by the finding which report that the nymph sex ratio at birth or hatching is 1:1 (Donald, 2007; McKellar *et al.*, 2009).

Results also showed a 2:1 adult to nymph ratio. This means the ratio was skewed in favour of adults. These findings are indicative of a declining population as reported by Arya *et al.* (2010). But this was not the case in this study because both adults and nymphs were present throughout the whole period of study and most likely the whole year. The skew can be explained by the differences between the post embryonic development life span which is 45 – 55 days and adult life span which is 50 – 120 days (Senthilkumar, 2006). The adult life span is almost three times the nymph life span. The skewed ratio could have resulted from sampling bias as reported by Arya *et al.* (2010) and Panhwar et *al.* (2013). This should not be ruled out because the sweep net method used was more selective of the adults than the small nymphs especially in the tall grass habitats. However, handpicking was employed to countercheck this probable error.

5.3 Factors affecting distribution, abundance and population ratios of *Conocephalus maculatus*

5.3.1 Vegetation types

The findings revealed that the distribution and abundance of C. *maculatus* was affected by vegetation types. This did not apply to population ratios. The abundance and the species presence regressed significantly positively with grass but negatively with shrub and herbal vegetation types. These results are supported by the findings in Jordan, South Africa and Kilimanjaro where *C. maculatus* is reported to have been collected from grass vegetation (Mahasneh and Katbeh-Badera, 2004; Hemp, 2013; Grant, 2014). The findings in Pakistan and India are contrary to the results here because there the species was associated with all vegetation types including grass, herbs shrubs and trees (Panhwar *et al.*, 2013; Arya *et al.*, 2015). This is most probably because the species has been reported to have been found in vegetation as a predator preying on small herbivores (Chakraborty *et al.*, 2014).

Results revealed that the most common grass species that were associated with *C. maculatus* included *H. rufa*, *D. scalarum*, *Eleusine* spp, *E. blepharoglumis*, and *L. kagerensis* in order of decreasing abundance. In the present study *C. maculatus* was also observed on several occasions feeding on seeds and flowers of *H. diplandra*, *E. blepharoglumis* and *Eleusine* sp. These findings are in agreement with the findings in Asia where such grasses are the part of the common habitat and source of diet of *C. maculatus* (Kevan and Knipper, 1961; Oda and Ishii, 1998; Hemp and Hemp, 2003; Wason and Pennings, 2008; Tan *et al.*, 2013; Arya *et al.*, 2015). *Eragrostis blepharoglumis* and *L. kagerensis* seem to be exceptional because their association with *C. maculatus* is being reported probably for the first time. Because all these grass types are wide spread in Kagera region *C. maculatus* can most possibly, by association be found wide spread in the whole region.

5.3.2 The physical conditions

Results showed that the physical conditions of temperature, humidity, and altitude had effects on population abundance of *C. maculatus*. Temperature related directly with population abundance while humidity and altitude related inversely with population abundance. The effects of temperature, humidity and altitude are inseparable because of interdependence between temperature and humidity on one side and temperature and altitude on the other (Alduchov and Eskridge, 1996; Luotto, 2000; Lawrence, 2005; Hebda and Heinrichs, 2011). The positive effect of temperature on *C. maculatus* is supported by the findings that temperature favours insect species abundance (Kemp *et al.*, 1990; Kaspari *et al.*, 2000). In laboratory simulations *C. maculatus* was found to prefer temperature range of 20 – 30 and relative humidity range of 60 – 80% (Oda and Ishii, 2001; Senthilkumar and Sanjayan, 2006). From recorded data the average temperature in the study area for the period of study was 21°C. In that case an increase in temperature here towards the mean offered a more conducive environment for population growth, explaining the positive regression between the two. Rainfall had effects only on nymphs whereby the two regressed negatively. These findings are also in concurrence with the general conclusion that topography and climate are responsible for distribution patterns of populations (Storch *et al.*, 2003; Fattorini *et al.*, 2013).

Results revealed sex-biased and age-biased effects of the physical conditions on *C. maculatus*. Females were more sensitive to changes in temperature, humidity and altitude than males. Nymphs were far more sensitive to altitude, temperature and humidity than adults and were the only affected by rain outside the month of April precipitation. Nymphs were affected by rainfall throughout the study period and at Nshambya site while adults were affected during the long rains season only. These observations are in agreement with the findings that *C. maculatus* require more specific optimum moisture and humidity conditions in early stages of growth for survival (Senthilkumar and Sanjayan, 2006; 2008; Senthilkumar and Barthakur, 2013). It was reported that sex biased environmental effects play a great role in sex ratio determination of a population (Zajitsec, 2009; Tabadkani *et al.*, 2013). Therefore, biased environmental effects may explain the bised population ratios in this tettigoniid.

The results revealed that the effects of climatic factors on population abundance ratios differed from site to site. At Maruku only humidity had effects (positive) on the population abundances. At Nshambya humidity had effects (negative) only on females but did not have any effects at Bugorora. These findings are supported by the findings from laboratory simulations where the optimum humidity range for *C. maculatus* was reported to lie between 60% and 80% (Oda and Ishii, 2001; Senthilkumar and Barthakur, 2013). From recorded data from the study area the mean relative humidity in the region for the period of study was 78%. This fact probably accounts for the positive correlation at Maruku and no correlation at Bugorora where it was within the optimum range and the negative correlation at Nshambya where it was above the highest limit. Temperature had effects (positive) only on females at Nshamba while rainfall had effects (negative) only on nymphs at that place. The temperature effects on females here may be due to the fact that females were avoiding oviposition in extreme temperatures which would affect nymphs.

The results revealed that spatial differences in the physical conditions of altitude, temperature and humidity determined the spatial differences in distribution, abundance and population ratios of *C. maculatus*. The highest population abundance was recorded from Bugorora which was at the lowest altitude with the lowest mean relative humidity and the highest average temperature. Lower population abundance was recorded from Maruku which was at a lower altitude, with a higher mean relative humidity and a lower average temperature. The lowest population abundance was recorded from Nshambya which was at the highest altitude, with the highest mean relative humidity and the lowest average temperature. These results are in agreement with the findings in ivory Coast where high and low populations of *C. maculatus* were reported to have been found at low and high altitudes respectively (Heinrichs and Barrion, 2004). This is also supported by the findings on Kilimanjaro where the species was reported to have been recorded mainly at an altitude range of 700 – 1500 m a.s.l. above which very few were (Hemp and Hemp, 2003; Hemp, 2013). Thus, the Kagera findings conform with the Kilimanjaro findings proposing a probable general spatial distribution of *C. maculatus* in northern Tanzania. Here, the altitude seems to be the leading factor as it affects both temperature and humidity. The of difference in rainfall proves the independence of it from altitude.

The highest adult sex ratio was recorded at Nshambya while the lowest adult sex ratio was recorded at Bugorora implying that females were more affected at higher altitudes than males. It was observed that at Nshambya only females were positively affected by temperature and negatively affected by humidity while males were not affected at all. It is apparent that increase in temperature here increased female population and hence reduces sex ratio skewness while increase in humidity brings the opposite effect. In this case sex ratio changes in *C. maculatus* can be a good indicator of climate changes (Gwynne, 2001). Senthilkumar and Sanjayan (2006) already earmarked the species as an indicator of environmental change. This study has then revealed that adult females and hence adult sex ratio could be the best indicator of climate changes.

Adult to nymph ratio was largest at Nshambya and smallest at Bugorora reflecting that nymphs were more at lower, than higher altitudes. This concurs with findings on Mount Kilimanjaro where nymphs of *C. maculatus* were decreasingly traced from 700 to 1350 m a.s.l. only while adults were traced up to 1800 m a.s.l. (Hemp and Hemp, 2003). Young forms of this insect are reported to be more prone to reduced optimal physical conditions than adult as elevation increases (Hodkinson, 2005). Consequently, few nymphs were at the highest altitude where temperature was low and humidity was high. These conditions predisposed them to negative effects of rainfall.

Results revealed that seasonal variations in the physical conditions of temperature, humidity and rainfall shaped the seasonal variations in abundance and population ratios of *C. maculatus*. Population was lowest in the short dry season when precipitation and humidity were remarkably lowest. Similar findings were reported in Asian climate where *C. maculatus* was reported to be absent during the dry season and to appear during the rainy season from April to late July (Panhwar *et al.*, 2013; Arya *et al.*, 2015; FRD, 2015). Furthermore, in South Africa stridulating activities of Conocephalinae were reported to take place only during the rainy season when there was enough moisture (Grant, 2014). The population was highest in the short rains season when rainfall was moderate and humidity highest. These results suggest the optimum conditions required by this tettigoniid. There were no seasonal variations in temperature; therefore this factor did not affect temporal variations in abundance.

The highest adult sex ratio was recorded during the short rains season implying that the female population was lowest in this season. The lowest adult sex ratio was recorded during the long rains season implying that the female population was highest. This must have been caused by temperature which was relatively high in this season and to which females were more sensitive compared to males. The adult sex ratio trend followed well the temperature trend which increased from the short rains season to highest in the long rains season. The adult sex ratio affected the overall sex ratio which followed the same trend. The nymph sex ratio on the other hand remained constant across the seasons. Variation of the sex ratio with climatic changes was reported in this area on *R. differens* whereby it was alternating between male biased and female biased (Matojo and Yarro, 2010). The difference between the highest and lowest age ratios observed between the long rains and the short dry seasons respectively reflect the biased negative effects of rainfall on nymphs as discussed earlier. The relative numbers of the age group were close when rainfall was low but grew apart as rainfall increased.

Results revealed monthly variations in humidity, precipitation and abundance. The results further suggested that precipitation and humidity were responsible for monthly variations in *C. maculatus* abundance. The population abundance was lowest in February corresponding well to the minimum rainfall recorded. The population dropped drastically close to minimum when rainfall was maximum in April. These two observations suggest that *C. maculatus* population is negatively affected by extremely low and extremely high rainfall. Rainfall in this month was the only variable that had a significant effect on population. The results further suggested that *C. maculatus* thrives well within the optimum range of conditions. Therefore there are threshold values below or above which population growth is negatively affected.

The drop of population to minimum when rainfall was minimum ni February indicates that the amount was below the minimum limit for *C. maculatus* population growth. The drop of population close to minimum at the increase of precipitation to maximum in April indicates that the amount was above the maximum limit for *C. maculatus* population growth. Concurrently, during the dry season in Asia, *C. maculatus* was reported to have been only found in wetlands and irrigated rice fields (Kandibane *et al.*, 2004). The rainfall recorded in this study is in line with the general adequate mean annual rainfall of between 1500 – over 2000, characteristic of the study area of Kagera region (Shand 1999; TCCIA, 2012). For the whole study period the mean rainfall was 1054 mm and no single month was completely dry in Kagera region. For this reason *C. maculatus* can be available throughout the year if other factors are held constant.

The optimum ranges for temperature, humidity and altitude have been discussed in earlier sections. High temperature of 35^oC for instance, was found to shorten the incubation and post embryonic development periods thus accelerating growth and maturation in *C. maculatus* (Senthilkumar and Barthakur, 2013). However, such temperatures and those below 20^oC were found to cause high nymph mortality and to slow metabolic activities in adults (Oda and Ishii, 2001). The June – August long dry season would be expected to record the lowest population because of lower temperatures but not necessarily so because it is relatively wetter than the January – February short dry spell.

5.4 Acoustic behaviour of *Conocephalus maculatus*

The results revealed that stridulating activities of *C. maculatus* in its natural environment are carried out only during the day because no sound was detected during the night in the field. This observation is in agreement with the reports by earlier researchers that this is a diurnal insect (Heinrichs and Barrion, 2004; Bazelet and Naskrecki, 2014). However, the *in-captivity* individuals continued to stridulate even during the night in the presence of light from a fluorescent tube. This suggests that photoperiod affects sound signaling, and probably other life activities in *C. maculatus* (Senthilkumar 2006; Grant, 2014). Probably, this is why Panhwar (2013) characterized *C. maculatus* as both nocturnal and diurnal insect. Consequently there seems to be no clear seasonality of singing in *C. maculatus* (Grant, 2014). In Kagera region north-western Tanzania, sound signaling in *C. maculatus* was found to be a daylight activity in the natural environment. From this research experience, the best time to hear the insects sound was between 8.00 am and 12.00 Noon and between 4.00 pm and 6.00 pm. No sound was detected in the absence of light.

Results also suggested slight differences in sound signal characteristics between the *in-captivity* and *in situ* individuals. Consequently, there were differences between the laboratory and field recorded sounds. The trill duration, trill interval and the chirp interval recorded in the laboratory were longer than those recorded in the field. However, the necessary structural entities of chirp length and the frequencies remained constant. These findings are in agreement with reports from researcher that sound signaling is affected by various environmental factors Such as temperature, latitudinal gradients, wind speed and humidity (Gwynne, 1985; Franklin *et al.*, 2009; Cole, 2010; Grant, 2014; Lil and Wang, 2017). Also the sex ratio in a population affects the sound signaling behaviour in most katydids (Habel *et al.*, 2015). While in the laboratory conditions were kept at room standards in the field the conditions varied with time, day and altitude. Sex ratios were not taken to into consideration. These facts should have accounted for the difference in the acoustic behaviour of C. *maculatus* between the laboratory and the field.

Results revealed that the characteristics of *C. maculatus* recorded in Kagera region were closely supported by the findings of Grant (2014) in South Africa where the recorded trill duration of 0.8 s with an interval of 1.5; a chirp duration of 0.016 with interval of 0.005; a chirp rate of 48.2/s; the maximum, center and minimum frequencies of 23.4 kHz, 20 kHz and 9.4 kHz respectively. Also, the sound file of *C. maculatus* documented by Baker *et al.* (2015) revealed the frequency range from 1.2 kHz to 21 kHz which was closely related to that recorded in this study. These findings concretely establish the identity of *C. maculatus* in the study area.

5.5 Conclusions

The following conclusions can be drawn from the findings of the present study:

(i) *C. maculatus* is abundantly present and widespread in Kagera region north western Tanzania. This species exhibits a general aggregated spatial distribution following grass vegetation mainly of *Hyparrhenia* spp, *Eragrostis* spp *Eleusine* spp, *D. scalarum* and *Loudetia kagerensis*. which determine its spatial distribution pattern in Kagera region.

(ii) The population ratios of *C. maculatus* are characterized by skews in adult sex ratio, overall sex ratio and age ratio and by a balanced nymph sex ratio. Sex ratios are skewed in favour of males and the age ratio is skewed in favour of adults. This is caused by female-biased and nymph-biased effects of the physical conditions whereby these groups are more sensitive to changes in the physical conditions than their opposites. This sex ratio can be used as an indicator of climate changes because increase in temperature increases the number of females and vice versa.

(iii) Vegetation types determine mainly, the distribution and somehow, abundance of *C. maculatus* in the region. The species is found in grass vegetation and absent from other vegetation types. The physical conditions of temperature, humidity, rainfall and altitude shape its abundance within the area and across the seasons. Increase in temperature favoured population growth while increase in humidity, altitude and precipitation limited the growth of *C. maculatus* in Kagera region. These conditions determine temporal and spatial variations in the population abundance and ratios through effects on the age and sex groups.

(iv) Sound signaling of *C. maculatus* is exclusively a diurnal activity in the natural environment in Kagera region north-western Tanzania. This sound behaviour is affected by environmental conditions and photoperiod. Under artificial lighting the insect gives sound signals even during the night.

5.6 Recommendations for conservation measures

Because *C. maculatus* is a grassland dweller, the ministry of natural resource and tourism is called upon to put in place conservation measures of grass and pasture lands. All parks and reserves such as Minziro Nature Forest Reserve should incorporate an extension of the open grassland to provide for favourable niche for such arthropods. Control of Ranch lands to reduce overgrazing should continue in Kagera. The current situation is characterized by the practice of turning large areas of grasslands into built environments, exotic tree forests of pine and eucalyptus, and agricultural farmlands. The most notorious habit of burning grasslands and forests for fresher pastures should be strongly discouraged because a lot of biodiversity is adversely affected.

5.7 Suggestions for further studies

(i) Further studies can be carried out to study how *C. maculatus* survives in skewed population ratios.

(ii) Studies can be carried out to investigate the acoustic behaviour of *C. maculatus* when placed in dark conditions during the day.

(iii) Studies can be carried out to investigate the distribution and abundance of *C. maculatus* over a wider period of the whole year in Kagera region to include the long dry season.

(iv) Further research can be carried out to study the species diversity of Orthopterans found in Kagera region, north western Tanzania and their ecological roles.

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APPENDICES

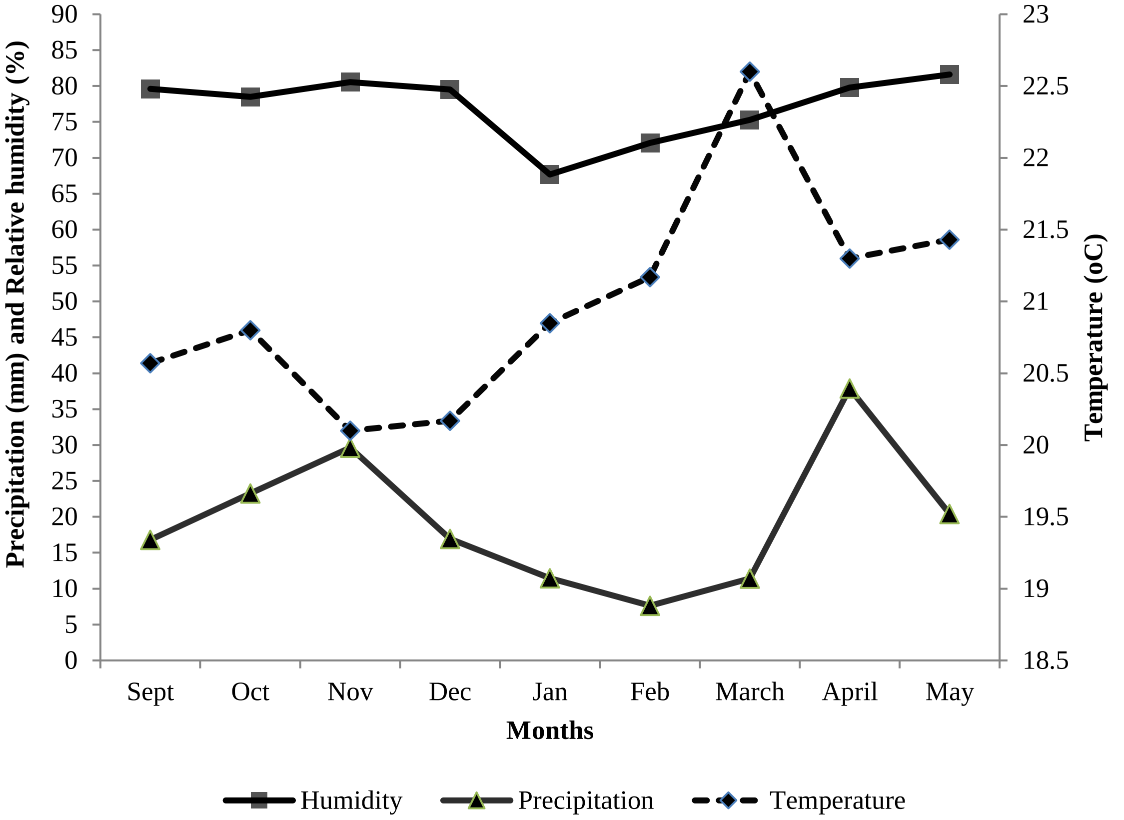
Appendix I: Distribution table of *C maculatus* in the Study sites. * means No *C. maculatus* found

PLACE	COORDINATES		ELEVATION
	X	Y	
Mugeza	368202	9858279	1313
Kitokozi	366711	9864222	1213
Bumai*	370447	9879100	1235
Bunyonya	365637	9867550	1160
Kyakairabwa	364328	9857034	1238
Nyanga	363904	9858124	1173
Mabuye*	325527	9868067	1123
Kyemamba	324443	9861328	1163
Kabalenge	321618	9853761	1211
Omukiisi	322687	9847652	1183
Katokoro *	328846	9844722	1167
Igoma	328697	9828898	1273
Katanga*	345149	9835876	1205
Mwemage	345907	9836603	1380
Bugorora	340315	9864680	1145
Mugana*	354362	9866227	1273
Kasha	364910	9843926	1314
Itahwa	360672	9849084	1219
Kitwe	359751	9854485	1267
Maruku	364578	9845136	1215
Nshambya	343559	9809273	1596
Bugasha	343547	9809368	1490
Nshamba	338630	9803213	1520
Bushaka	347225	9823201	1465
Rushwa	329780	9810319	1321
	338072	9753650	1217
Kiziramuyaga	350664	9761242	1276
Karambi	332267	9767819	1640
Burigi	329716	9759463	1523
	277983	9879043	1394
Katoma	361461	9856047	1313
	364583	9850383	1312
Rutimbiro	355447	9846970	1186
Ishozi	362904	9869677	1329
Kazi	358510	9836677	1349
Kitengule	315332	9858707	1169
Ndorage	291611	9838461	1624
Kayanga	294043	9831071	1611
Omurushaka	293182	9824310	1633

Appendix I continued

	266647	9834216	1571
	266625	9834223	1568
Rwengaga	267101	9834180	1577
	267148	9834034	1570
	267139	9834021	1569
	267074	9833924	1567
Kaaro	264353	9834629	1330
Nkwenda	265126	9835792	1348
Nyarutuntu	260664	9833682	1345
Kasharara	257045	9829232	1510
Rukuraijo	262354	9841013	1464
	278465	9798787	1327
	279787	9785609	1488
Mushasha	318338	9777012	1200
	329780	9810319	1224
Magata	288544	9859347	1535
Nyarugongo	228106	9876776	1321
Murongo	242483	9881880	1520
Kijumbura	255229	9881950	1629
Rutunguru	283301	9858989	1671
Chantonya	272245	9815579	1800
Kyerwa	250533	9847018	1302
Kigarama	257117	9844612	1443
Kaisho	245112	9859100	1529
	288466	9805651	1451

Appendix II: Temperature humidity and precipitation trends from September 2014 through May 2015

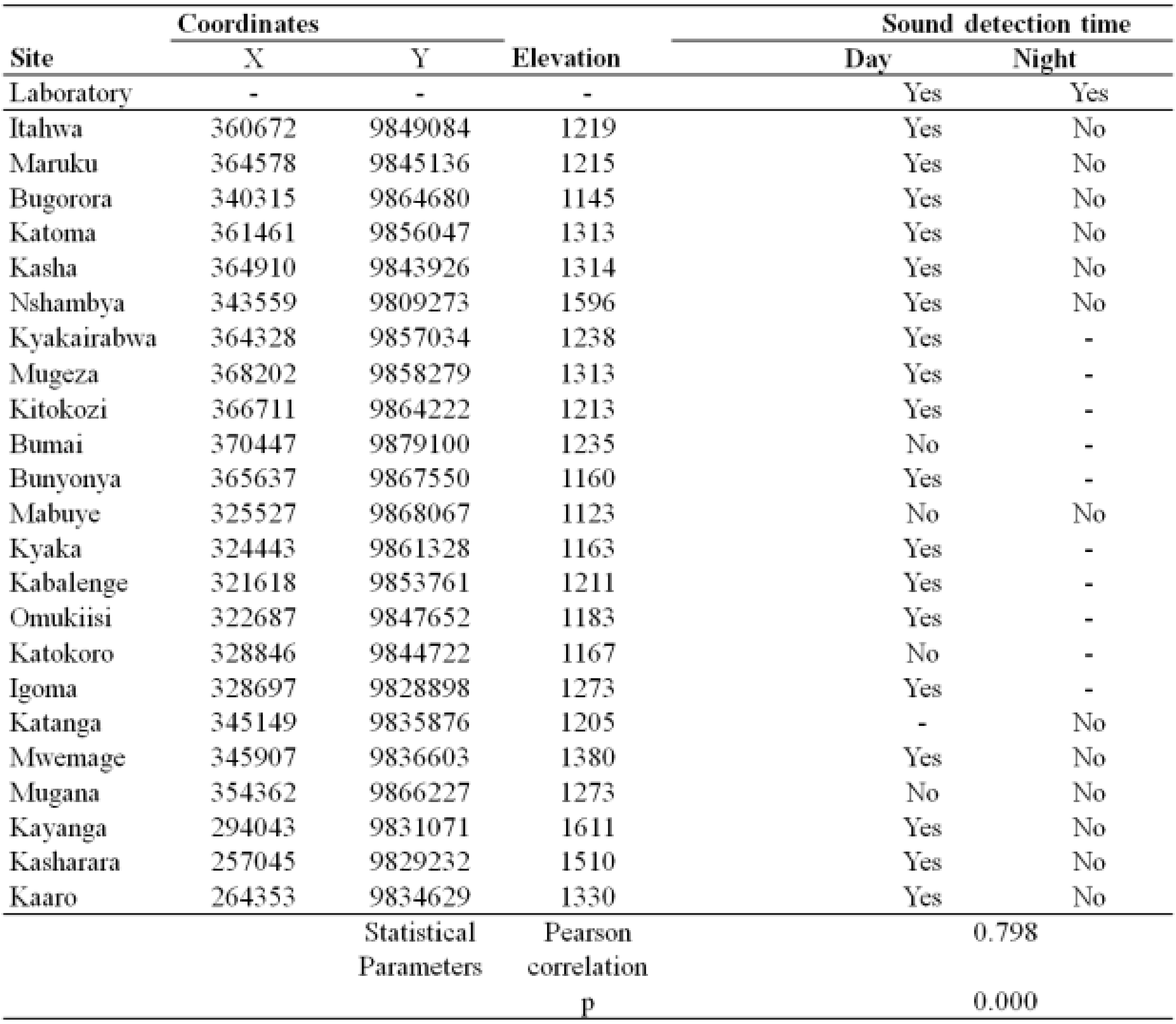


Appendix III: Data recorded from various study sites for the whole study period

Site	**Maruku**		**Bugorora**		**Nshambya**		**Total**		
Variables	Mean	Sum	Mean	Sum	Mean	Sum	Mean	N	Sum
Temperature	22	-	23	-	18	-	21	54	-
Humidity	76±1		75±1		83±1		78±1	54	-
Precipitation	24±4	-	14±2	-	21±4	-	20±2	54	-
All	69±11	1249	103±12	1849	34±5	611	69±7	54	3709
Adults	43±7	777	60±7	1084	22±4	402	42±4	54	2263
Nymphs	27±4	477	43±6	768	12±2	212	27±3	54	1457
Males	42±6	758	51±7	923	21±4	373	38±4	54	2054
Females	27±5	494	52±6	928	14±2	243	31±3	54	1665
Male adults	28±5	506	30±4	531	14±3	248	24±3	54	1285
Female adults	15±2	274	31±4	555	9±1	156	18±2	54	985
Male nymphs	14±2	254	22±3	394	7±1	128	14±2	54	776
Female nymphs	13±3	226	21±3	378	5±1	89	13±2	54	693

All values have been adjusted to one decimal place.

Appendix IV: Time and locations of acoustic search of *C. maculatus* in the study area



	Coordinates			Sound detection time	
Site	X	Y	Elevation	Day	Night
Laboratory	-	-	-	Yes	Yes
Itahwa	360672	9849084	1219	Yes	No
Maruku	364578	9845136	1215	Yes	No
Bugorora	340315	9864680	1145	Yes	No
Katoma	361461	9856047	1313	Yes	No
Kasha	364910	9843926	1314	Yes	No
Nshambya	343559	9809273	1596	Yes	No
Kyakairabwa	364328	9857034	1238	Yes	-
Mugeza	368202	9858279	1313	Yes	-
Kitokozi	366711	9864222	1213	Yes	-
Bumai	370447	9879100	1235	No	-
Bunyonya	365637	9867550	1160	Yes	-
Mabuye	325527	9868067	1123	No	No
Kyaka	324443	9861328	1163	Yes	-
Kabalenge	321618	9853761	1211	Yes	-
Omukiisi	322687	9847652	1183	Yes	-
Katokoro	328846	9844722	1167	No	-
Igoma	328697	9828898	1273	Yes	-
Katanga	345149	9835876	1205	-	No
Mwemage	345907	9836603	1380	Yes	No
Mugana	354362	9866227	1273	No	No
Kayanga	294043	9831071	1611	Yes	No
Kasharara	257045	9829232	1510	Yes	No
Kaaro	264353	9834629	1330	Yes	No
		Statistical Parameters	Pearson correlation	0.798	
			p	0.000	

"Yes" Sound was detected and "No" sound was not detected.

Correlation between time and sound is significant at $p < 0.01$ (Pearson correlation). At the sites of Itahwa, Maruku, Bugorora, Kasha, Katoma, Nshambya Mwemage Kaaro, Kayanga and Kasharara the sound was detected during the day and tested negative during the night. At Mabuye and Mugana the sound was absent both during the day and during the night. The sound was absent at Katanga which was tested only during the night. At the sites of Mugeza, Kyakairabwa, Kitokozi, Bumai, Bunyonya, Kyaka, Kabalenge, Omukiisi, Katokoro and Igoma which were examined during the day only, the sound was detected except at Bumai and Katokoro where it was absent.