NON-CHEMICAL CONTROL OF THE RED-BILLED QUELEA (*QUELEA QUELEA*) AND USE OF THE BIRDS AS A FOOD RESOURCE

BOAZ NDAGABWENE MTOBESYA

A thesis submitted in partial fulfilment of the requirements of the University of Greenwich for the Degree of Master of Philosophy

November 2012

DECLARATION

I certify that this work has not been accepted in substance for any degree, and is not currently being submitted for any degree other than that of Master of Philosophy (M.Phil.) being studied at the University of Greenwich. I also declare that this work is a result of my own investigation except where otherwise identified by references and that I have not plagiarised the work of others.

name……………………………………………
(Boaz N. Mtobesya, Student)

name………………………………………………
(Professor Robert A. Cheke, First Supervisor)

name……………………………………………….
(Dr Steven R. Belmain, Second Supervisor)

D E D I C A T ION

Dedicated to my God and Jesus Christ my Saviour in whose hands my life is.

ACKNOWLEDGEMENTS

First my sincere gratitude goes to almighty God who bestowed upon me his love and mercies throughout the entire period of my research. This work would not have been possible without Him and the help of my supervisors. I would like to express my profound gratitude to Professor Robert A. Cheke my first supervisor and my second supervisor Dr Steven R. Belmain for their invaluable advice and encouragement throughout the period of my research. Bob your constructive critique and kindness steered me along profitable pathways. Your visits in Tanzania during my field work, suggestions and thoughtfulness gave me the impetus to balance the tightrope of my research. Thank you for the countless moments of informal talks and emails that you sent me, for which you sacrificed your time. I am also indebted to Dr Stephen R. Young for assistance with statistical analyses of the trapping data.

My gratitude also goes to Professor Andrew Westby, Dr. John Orchard and Mark Parnell whose empathy towards the needs of research students facilitated the completion of this thesis.

Secondly, I would like to thank my sponsor the Southern African Development Community (SADC) and the University of Greenwich through the SADC – ICART – ICRARF Project without whose funds this research might only have been a dream.

Professor Rhodes Makundi my home supervisor receives my thanks for his keen interest in the research and his encouragement. I am indebted to my wife Veneranda Boaz Mtobesya for her help in many parts of the research, and her enduring encouragement. My thanks go to Dr. Clive C. H. Elliott for his dedicated support and advice during the field work. I am grateful for his timely and helpful assistance and encouragement.

Thirdly, numerous people had impacts on my research findings and were key facilitators to my getting results. These include the Plant Protection Research Institute (PPRI) team from South Africa (Etienne van de Walt, Jan de Klerk, and Pietie van Niekerk), Collen Mbereki and his colleagues from Botswana, Richard Magoma and the drivers from the Ministry of Agriculture, Food Security and Cooperatives, Tanzania, for their hard work and commitment throughout the duration of the project.

I owe thanks to the staff of the Plant Health Services, Dodoma Office, Central Zone, District Agricultural Office, Kondoa and Regional Administration Office, Dodoma, for their invaluable support and encouragement. I am indebted to my dependable field assistants, especially Damas Shumbusho, Shaban Katetemera and others who were my companions through thick and thin in the field. I would like to thank the communities of Kelema, Pongai, Solya, Piho, Iyoli, and Mamba villages for their enthusiastic contribution to this work, also for their friendship and hospitality.

I would like to express my special thanks to Ms. Flora Nyange for her persistence in typing of this work during which she suffered a lot with power cuts, a common phenomenon in developing countries like Tanzania.

Lastly my appreciation goes to my children, Tumaini, Emmanuela, Eunice and Hannar, who missed my comforting presence throughout the field work, your sacrifice of letting me go is inestimable and I am sure I will make up for the lost time. I am also eternally grateful to my loving wife Veneranda who encouraged me right from my very first steps. Thanks for the countless hours of prayers and labour of love. To all these people and to numerous men and women whom I met, consulted with, participated together, shared my vision and fears, I express my deep appreciation.

ABSTRACT

The Red-billed Quelea *Quelea quelea* is the most numerous terrestrial bird and the most destructive avian pest of small-grain crops throughout sub-Saharan Africa. The birds occur in 60% of the cereal production areas of Tanzania almost every year. Quelea can cause serious local damage to millet, rice, wheat and sorghum and cause considerable hardship to subsistence farmers. Spraying with the organophosphate avicide Queletox®, (60% fenthion a.i.) remains the preferred control measure despite its negative impact on the environment and high cost. As an alternative control measure, the mass trapping of quelea and harvesting their chicks to use both as a source of protein and for income generation was investigated. Two traps using very large nets, based on designs used successfully to catch birds in Tunisia and the USA, failed with quelea; but success was achieved with four other methods. With traditional basket traps made of grass, an average of 286 birds could be caught per trap per day, this increased to 574 birds by using a replica wire mesh version. When using mist nets in a breeding colony the number of birds caught per day per 12 m long net varied from 445 for the first day to 231 on the tenth day. Trials with a roost trap yielded 5,000 to 17,000 birds per day. Cooking and preservation methods were investigated to maximise the potential utilization of quelea meat as a food resource. The best preservation method was achieved by boiling with added salt and drying, while the cooked product rated most highly by volunteer tasters was fresh meat. Proximate analysis was conducted on preserved, milled, quelea meat which confirmed the highly nutritive value of quelea for human consumption. It was concluded that mass-trapping and chick harvesting methods were more environmentally friendly control methods than spraying or use of explosives, with the added benefits of providing high-quality proteinaceous, uncontaminated, food and income generation for the trappers and their families.

CONTENTS

CHAPTER TWO

DESCRIPTION OF THE STUDY AREA

CHAPTER THREE

THE GEOGRAPHICAL DISTRIBUTION, BREEDING SEASONALITY AND FORECASTING OF BREEDING OPPORTUNITIES FOR THE RED-BILLED QUELEA IN TANZANIA

CHAPTER FOUR

INVESTIGATIONS OF STAKEHOLDERS' KNOWLEDGE AND NEEDS REGARDING QUELEA TRAPPING AND USE OF QUELEA AS FOOD

CHAPTER FIVE

MASS-TRAPPING METHODS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

ABBREVIATIONS

DFID	Department for International Development (United Kingdom)
ICOSAMP	Information Core for Southern African Migrant Pests
MAFSC	Ministry of Agriculture, Food Security and Cooperatives
NRI	Natural Resources Institute
SADC	Southern African Development Community

CHAPTER ONE

1.1. INTRODUCTION

Tanzania and its agriculture

Tanzania lies south of the equator between the great lakes of Victoria to the north and Nyasa to the south, Lake Tanganyika to the west and the Indian Ocean to the east. Tanzania is located in the Eastern Africa region between longitudes 29 and 41 degrees East, latitude 1 and 12 degrees south. The average temperature varies between 15 – 27 °C depending on the altitude, which varies from 0 – 1900 metres above sea level.

The main climatic feature is the long dry spell from May to October, followed by a period of low rainfall which is often concentrated into relatively few days of heavy showers. The main rainy season on the coast is from March to May but there is a second season from October to December. Total rainfall increases towards the north. Around Lake Victoria, rainfall is well distributed throughout the year with a peak during March to May.

The mainland of Tanzania is divided into 21 administrative regions. Each region is divided into districts (rural and urban). In total there are 119 administrative districts and five cities.

The total area of Tanzania is approximately 945,000 sq. km. which includes approximately 60,000 sq. km. of inland water. Out of the 945,000 sq. km., over 100,000 sq. km. are devoted to reserves and national parks. The potential arable land is 9.5 million hectares and the area under agriculture is about 5.2 million hectares.

The country's economy is highly dependent on agriculture, subsistence and commercial agricultural activity (National Sample Census of Agriculture, 2007). Its contribution to GDP is about 51% as of 2006; 80% of the produce is grown on small scale farms.

Thus, over 80% of the population lives in rural areas and depends on agriculture for their livelihoods (United Republic of Tanzania, 2008; National Bureau of Statistics-Agriculture, 2007). It provides full time employment to over 70% of the population as well as the bulk of the food. It is estimated that the country is fully self-sufficient in food and, in good years, is a net exporter of cereals (National Bureau of Statistics-Agriculture, 2007).

Agricultural produce may broadly be divided into food and cash crops, the most important of the former are maize, sorghum, millets, paddy rice, wheat, cassava, sweet potatoes, pulses and banana. Important cash crops include cotton, sisal, coffee, tobacco, cashew nuts and flowers. Cereal crops cover about 4 million hectares.

The need to support growing populations which are dependent on agriculture has increased the pressure to develop marginal areas by irrigation. Moreover, irrigation has been seen as a means towards increased food self-sufficiency as well as ensuring a source of foreign exchange from food and cash crops.

In Tanzania, the irrigation potential is estimated at 2.9 million hectares, of which 310,745 hectares is currently utilized. The modern schemes account for about 50,070 hectares, whereas the small scale or traditional schemes account for 225,675 hectares. Production in these schemes includes paddy rice and flowers (Ministry of Water and Irrigation, 2008).

Like elsewhere in the world, crop production in Tanzania has its share of pest problems. There are field pests as well as post-harvest pests. Among the most important field pests are migratory pests such as the African Armyworm (*Spodoptera exempta*), the grain-eating Red-billed Quelea (*Quelea quelea*), the Red Locust (*Nomadacris septemfasciata*) together with field rats (*Mastomys natalensis*). Of these the most serious pests of small grain cereals are the quelea, which in Tanzania occur in swarms ranging from thousands to a few million birds. They have been responsible for famines of varying proportions in some areas like Dodoma (Haylock, 1959) and Singida regions in the central part of the country.

Serious quelea damage to crops is not a recent phenomenon. One of the earliest records is of “Lihamba” in Gogo (Haylock, 1959; Brooke, 1967; Tarimo, 1994), attributed at least in part to quelea. Small grain crops which are damaged by quelea are those grown in drier areas and irrigated farms. Large flocks of quelea occur in areas with permanent water bodies (Allan, 1996) and they become a major pest of agricultural crops when grass seeds are scarce and they cause heavy damage to cultivated cereals such as millet, sorghum, rice and wheat (Jarvis and Vernon, 1989).

Tanzania has a very rich tree flora resulting from the varied physical and climatic conditions. In some areas at higher altitudes the rainfall is reliable, temperatures are low and the vegetation is “bush”, whereas lowland areas are generally hot and arid with unpredictable rainfall patterns. This wide range of ecological conditions provides favourable environments for many species of plants, animals and birds (Mbuya *et al*., 1994; Campbell *et al*., 1996; Moyo *et al.*, 1993).

Some semi-arid areas of the country host Acacia trees which are favoured by quelea for breeding in and sometimes for roosting in. Such regions include central regions Dodoma and Singida, part of the northern part of the country and a few other western regions (Bridges, 1990; Stons, 1995).

1.2. BACKGROUND TO THE STUDY

Tanzania has been plagued by the attacks of quelea on its small grain crops, millet, sorghum, wheat and rice, probably since agriculture began. There have been attempts to prevent losses to the crops attributable to the birds since the 1940s (Elliott, 1989). For example, in 1942 an estimated crop loss valued at US$ 60,000 occurred in central Tanzania (Dodoma) that forced the importation of about 5080 tonnes as relief food (Elliott, 1989). Although scanty rainfall was reported to be the primary cause, the invasion of quelea from the north also contributed to the low production.

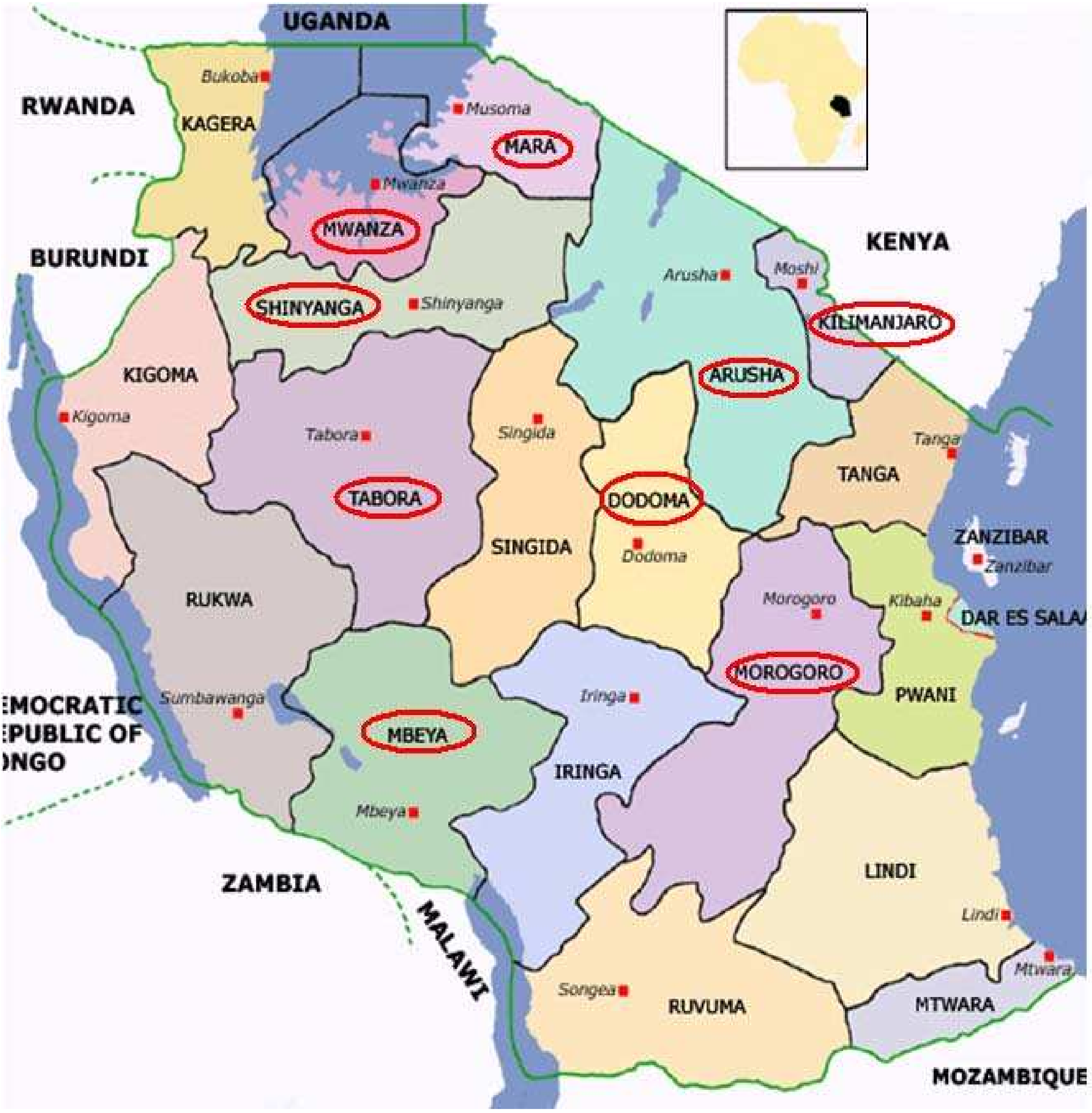
The problem of quelea was, however, recognized by the colonial government in early 1950 in Northern Tanzania (Arusha and West Kilimanjaro) where heavy damage was observed on large, well established, wheat and barley farms (Elliott, 1989; Tarimo, 1994). Since then action against the quelea birds has been an annual and continuing activity. Local damage can have a number of indirect demoralizing effects on the process of production. It has been observed that heavy bird pressure on crops forces local farming populations to abandon fertile land in favour of less fertile areas with less bird pressure. This has resulted in government policies to encourage development of high yielding drought-resistant millet and sorghum varieties to replace maize to be undermined by quelea damage. Such indirect effects must be taken into consideration when deciding national policies towards the management of quelea (Dyer and Ward, 1977).

In Tanzania quelea invasions are annual events and occur in 60% of cereal production areas between 3 and 8 degrees South, and 33 and 37 degrees East where large populations of breeding birds are a major pest of small-grain cereals in which they cause losses worth millions of Tanzanian shillings (Ministry of Agriculture, Food Security and Cooperatives, 2000; 2003). In a day, each quelea is capable of consuming and destroying up to its own body weight (18g) (Elliott, 1989). Therefore a population of one million birds can destroy up to 18 tonnes of crop in a day. In years of heavy invasion, crop damage can be as high as 50% of potential crop harvests, and in some cases the entire crop may be destroyed (pers. obs). The most affected areas in Tanzania comprise 11 out of the 21 regions including Arusha, Manyara, Dodoma, Mbeya, Mwanza, Shinyanga, Singida, Tabora, Mara, Kilimanjaro and Morogoro regions (Fig. 1.1). Vulnerable cereal crop production amounts to about 2.7 million metric tonnes. Damage caused by quelea in Tanzania is estimated at more than Tsh 198.7 billion (US$ 2.4 million) annually (Ministry of Agriculture, Food Security and Cooperatives, 2003) All this production is at risk during heavy quelea invasions.

In 2001, 700 ha and 40 ha fields of wheat at Basuto and Mulbadaw in Manyara region, experienced 100% losses (Ministry of Agriculture, Food Security and Cooperatives, 2002). The problem of bird infestation in the country is growing in line with the expansion of irrigated cereal production schemes and non-irrigated new areas. These new areas provide food for quelea during both the rainy and dry seasons.

However, experience has shown that bird pest problems in agriculture have proved difficult to resolve due in large part to the birds' behavioural versatility associated with flocking and seasonal movement (Elliott, 1989).

Figure 1.1. MAP OF TANZANIA SHOWING THE AREAS MOST AFFECTED BY QUELEA IN TANZANIA (REGIONS WITH NAMES ENCIRCLED PLUS SINGIDA).



1.3. RATIONALE FOR SELECTING THE STUDY

The rationale for selecting the study is based on a number of issues, listed separately below.

1.3.1. Bird population increase and re-distribution

The need for increased food production has necessitated the allocation of more land to agricultural use. Irrigated land for cereal crops has been increasing gradually every year (Ministry of Water and Irrigation, 2008), with a progressive increase in areas of small and large grain production and changes in ecological conditions prevailing in the birds' preferred breeding habitat of grasslands. Quelea have increased breeding activities in new areas where they have become associated with millet, sorghum, rice and wheat production. The species has expanded its geographical range as a result of the availability of cereal crops in new areas (see Table 4.1). In the past twenty years the areas most affected by quelea were a few regions such as Arusha, Kilimanjaro, Manyara, Mbeya, Morogoro, Dodoma and Singida. These regions were growing wheat and barley for business and rice and sorghum for food. Later, other regions such as Tabora, Shinyanga, Mwanza and Mara introduced paddy rice production. In the past three years other regions such as Tanga, Coast and Kagera have had attacks by quelea reported on paddy rice and sorghum, which they have started to grow for food and business, respectively. Irrigation schemes have also increased in number in many areas in the country. All of these factors have contributed to the spread and or the increase of quelea in many areas of the country. It is anticipated that the increase in small grain production may contribute to some extent to the increase of quelea populations in the country.

1.3.2. Quelea control methods

Several techniques have been tried to reduce bird populations to levels where crop damage is minimal (Matee, 2002). Traditional methods such as the use of slings, scare-crows and bird-scaring, e.g. by making loud noises by cracking whips, are still being used in many areas. Modern techniques of frightening devices, chemical repellents, less preferred crop varieties and alternative cultural practices have been evaluated by various authors (Tarimo, 1994; Bashir, 1989; Bruggers, 1989; Meinzingen, 1993; Elliott, 1989; Elliott and Allan, 1989; Allan, 1996). However, all methods have minimal value in situations where bird pressure is high and where habituation is likely to develop through repetitive repellent use and other methods, so they may only alleviate damage in small plots or in large fields for a short time. To alleviate the problem, aerial spraying using Queletox (fenthion) has been carried out in Tanzania for the last few decades. Queletox and explosives together have been employed in West Africa and in South Africa, Kenya and Botswana (Omolo, 2004; Bruggers *et al.* 1989; Meinzingen *et al*, 1989; pers. obs). The aerial spraying technique can be very effective, killing sometimes many hundreds of thousands of the pest birds in a single operation (see Table 3.1).

Fenthion is known to be hazardous to many forms of life and environmental contamination is of great concern in sprayed areas, as control operations can pose both direct and indirect health hazards to humans and other non-target organisms (McWilliam & Cheke, 2004). It has been observed that birds killed after being sprayed with fenthion are fed on by raptors, scavenging mammals and people, leading to secondary poisoning. There are also incidences in which non-target organisms, including raptors and passerines, insects, reptiles, amphibians, etc. are killed during quelea bird control operations where fenthion has been used (Bruggers *et al*., 1989; McWilliam & Cheke, 2004; Meinzingen, *et al*., 1989; De Grazio, 1989; pers. obs.).

The method is also very expensive as it requires the use of a spraying aircraft and extensive logistic support which have been borne entirely by the Government. Organophosphate pesticides such as fenthion used during Red-billed Quelea control operations also affect cholinergic tissues in the body of mammals. Serum (AChE) and plasma (BChE) cholinesterase activities are therefore good biomarkers for pesticide exposure (see Appendix 7a for details of an investigation on such effects conducted in conjunction with the present study). Explosives and fire-bombs also have effects on the environment and non-target organisms (See Appendix 7b, for details of effects on soil).

Thus, there is a compelling case for attempting to find alternatives to aerial spraying of pesticides, in order to reduce the costs of quelea control to the Government, to limit the use of pesticides and to minimise the negative side-effects on human health and the environment.

The risk of human health problems and environmental damage can be mitigated considerably by development of integrated environmentally sound control strategies to be described later (Miller, 1998). Exposure to these methods will educate farmers to becoming custodians of the environment. The methods offer more rapid prospects for implementation and enable farmers to continue making their own decisions about control of quelea in their areas and are people-centered through participatory approaches. Farmers are able to adopt the practice to changing circumstances because they own the process and not just the conclusion of someone else's process. Follow-up group activities will generally be mobilized using local resources including local government or community organizations. The methods will provide uncontaminated quelea for food.

The study described in this thesis seeks to investigate new approaches and / or improve the traditional methods that would empower farmers to take more pest control actions themselves. The emphasis should be upon maximum protection of the crop at its most vulnerable stage and providing uncontaminated quelea as food for local people.

1.3.3. Use of quelea as a resource

Birds have been important to man in many ways. Humans have used wild birds as a source of food, art, social manifestations of culture and sport. Wild birds and their eggs have also been used as source of food by many people (Berman *et al.*, 1996).

Since the rise of agriculture, the relationship of man with birds has become more complex. In many parts of Africa quelea occur like locusts, in plague proportions so numerous that alighting flocks may break the branches of trees. Some colonies of quelea have been estimated to exceed 1,000,000 individuals (Senar, 1988).

Control operations against these birds using fenthion to protect crops produce tonnes of dead birds, yet the quelea constitutes a potential source of protein. Jaeger and Erickson (1980) estimated that in 1978 colonies and roosts in the middle Awash River Valley of Ethiopia contained 7.5 million adult quelea, 70% of which were killed during control operations. At a weight of 7 g per dried prepared bird (Uk and Munks, 1984) 37 tonnes of potentially edible birds would have been available. A similar rate of control conducted in colonies found throughout Kenya, Somalia and Tanzania would yield about 345 tonnes (Jaeger *et al*., 1989).

In some parts of Tanzania quelea control operations using avicide spraying produce a large amount of potential food and people do collect dead quelea after control operations (Jaeger and Elliott, 1989; pers. obs). Quelea are a source of protein in some peasant populations (Bruggers & Elliott, 1989) and as such the image of the species should, perhaps, be shifted from that of a pest to that of a resource with potential for sustainable utilization.

Many communities in Africa collect quelea at their colonies or roosts using techniques that do not require pesticides in order to supplement their diet (Jaeger and Jaeger, 1977; Mullié, 2000) either by harvesting chicks from nests or by mass-trapping using traditional methods or nets. Chicks are collected at almost any age, although it would seem most productive to take them at 10-14 days old just before they leave the nest. Different ways in which quelea can be prepared for food and possibilities for long-term storage were investigated during this study.

1.4. AIMS AND OBJECTIVES OF THE STUDY

1.4.1. Aims

The aims of the research were to investigate different methods of harvesting the birds, particularly in Tanzania where the subspecies *Q. q. aethiopica* is a major pest, and to develop improved methods for utilizing the birds as a food source and for income generation.

Towards these aims, research was conducted on:

(i) Mass capture methods

(ii) Use of quelea as a source of food free of harmful chemicals

(iii) Devising integrated environmentally sound and cost-effective control methods, after investigating environmental impacts of current methods

(iv) Promoting the use of such methods amongst farmers in Tanzania

1.4.2. Objective of the research

The overall objective of the study was to test and apply alternatives to using pesticides for quelea control, with a view to minimizing control costs, and reducing the negative side-effects of control on human health and the environment. Ultimately the application of the alternatives could lead to quelea being considered as a resource instead of as a pest. More specific objectives were:

- To investigate and test various possible methods for catching quelea under different conditions, determine the extent of their applicability and adapt any successful ones to sub-Saharan conditions. The potential methods investigated and tested included mist-nets, a Tunisian mass-capture funnel trap adapted to the conditions that apply to quelea breeding colonies and roosts, a big net covering a roost (a “roost trap”) and traditional basket traps some of which have been used for mass capture of roosting birds in other places.
- To determine the feasibility of harvesting chicks manually from colonies.
- To determine how best to use the birds for humans, including preservation methods. In the event of successful application, consider how the technique(s) could best be expanded and what regulations would be necessary to ensure that the traps were used exclusively for quelea, avoiding their use for protected birds or other non-target organisms.

1.4.3. The research output

The research focused on developing/recommending alternatives to aerial spraying of pesticides for quelea bird control that have the potential to make radical changes to farmers' attitudes to the problem of the losses caused by grain-eating birds, in the light of environmental impact assessments of control activities. New techniques were tested and those already proven to be effective in other countries' agricultural systems were adapted for application specifically in Tanzania and more generally in sub-Saharan Africa.

1.5. The Research Questions

Characterizing the people’s use of quelea requires an exploration of how their world view influences the control and use of quelea and environmental conservation. The examination of the peoples’ world view and its relationship with quelea trapping and their use was based around fundamental questions dealt with in this thesis including:

1. Do people in the study area prefer to use quelea for food and for income generation rather than allow control by spraying?

2. Do the current trapping methods (if any) used for catching quelea satisfy the trappers or farmers or both?

3. Are there any effects on the environment associated with the current trapping or control methods of quelea?

4. Is there a possibility of exploring potential mass-trapping or control methods of quelea safe for the environment?

5. Is there a possibility for potential utilization of quelea for food and for income generation in the community leading to poverty alleviation?

6. Will the technology transfer for quelea mass-trapping, processing and preservation methods contribute to the interest of the community on the potential utilisation of quelea?

1.6. Delimitation and Limitation of the Research

The research was initially designed to cover three regions, namely Arusha, Kilimanjaro and Dodoma. However, due to the seasonal distribution of quelea, and especially breeding colonies, most of the research work was done in the Dodoma region. Based on the onset of the short rains, quelea depart north-eastern Tanzania for southern Somalia, whence they initiate a south-westward wave of breeding back to central and south western Tanzania by March (Ward, 1971). Breeding colonies are usually found in central Tanzania (Dodoma region) from late February to late March or, sometimes, early April (see Appendix 2a). Most of the work in breeding colonies was done in March, although there were breeding colonies in May, in Kondoa District (See Appendix 2a). Other work using a roost trap on roosting birds was also done in Arusha and Kilimanjaro. The research was based on the distribution of populations and migration patterns of quelea in Tanzania (see Chapter 3).

Another issue concerns the limitations of the study. Little assessment of many more mass-trapping methods was possible, due to lack of time, and funds. Quelea, when scared or threatened, can desert breeding colonies or roosting sites in the early stages of their development. This means the stage of the development of the colony can affect the results. Vegetation cover is an important factor in mass-trapping of quelea, as they normally choose dense thorn acacia trees as the vegetation in which to roost and breed, which has sharp leaves and is often in flooded terrain which is difficult for trappers to penetrate (Johnson and Burrows, 1994). Late rainy seasons also affected the availability of breeding colonies in the research area. The traps used, and especially the mist-nets, are a danger to non-target birds if not properly handled.

Generally, the focus was to observe the stakeholders' willingness regarding mass-trapping, use of quelea as food source and income generation.

1.7. Thesis outline

The research study and findings have been organized into six chapters. Chapter 1 outlines the background to the study, introducing the rationale to it. Chapter 2 deals in detail with a description of the study area. Chapter 3 explains the geographical distribution and breeding seasonality of quelea in Tanzania. Chapter 4 explains the investigations of stakeholders' knowledge and needs regarding quelea trapping and use of quelea as food. Chapter 5 deals with mass-trapping methods. Chapter 6 is a general discussion.

CHAPTER TWO

DESCRIPTION OF THE STUDY AREA

2.1. Introduction

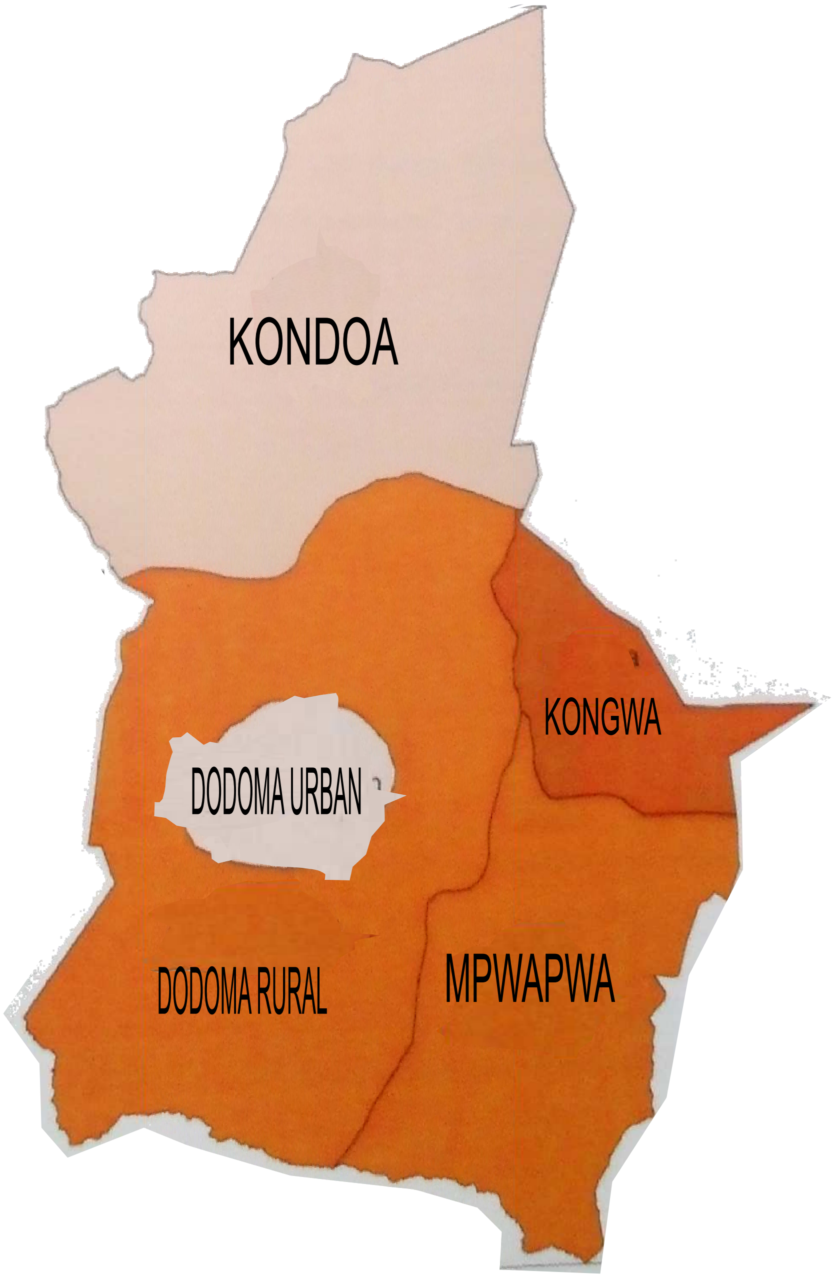
The study was carried out in the Dodoma region which is in the central part of the country. The region lies inland, very close to the centre of mainland Tanzania (Figure 1.1). Geographically the region lies between latitude 4º 7' and 7º 21' South of the Equator and also between longitudes 36º 43' and 35º 5' East of the Greenwich meridian (The United Republic of Tanzania, Dodoma Region, 2003).

The area was selected based on the author's knowledge and experience, using the following criteria intended to achieve representation for the entire country where quelea are a problem. The criteria included suitable vegetation for breeding and roosting, with grass-seed for food, the growing of cereal crops favoured by quelea for food such as bulrush millet, sorghum and rice, and local people with knowledge of quelea trapping and who use them as a source of food and income generation.

2.2. Administrative units

At Independence, the Dodoma region was a part of what was the Central Province. In 1963, the Dodoma region was created. It was separated from the Singida region, which with the Dodoma region, were the components of the former Central Province. At its inception the region consisted of the three rural districts of Dodoma, Kondoa and Mpwapwa. The urban district of Dodoma made up the fourth district later on. Mpwapwa district was later divided into the two districts of Mpwapwa and Kongwa. The Dodoma region has a total land area of 41,311 square kilometres, making it the 12th largest region on mainland Tanzania out of the total of 21 regions in the country (Figure 2.1) (The Regional Commissioner's Office, Dodoma, 2002). All of the districts in Dodoma region are attacked by quelea since they all grow sorghum and millet.

Figure 2.1. Dodoma region and its constituent districts.



2.3. Population characteristics

The Dodoma region has for centuries been dominated by Bantu-speaking peoples who even today form about three quarters of the population. Indigenous Bantus are the Wagogo, Warangi, Wanguru, Wazigua, Wakaguru and Wasagara. Nilo-hamites form the next largest group which includes the Maasai, Wafyomi, Wataturu, Wambulu and Watoga. In this latter group the Maasai are the only ones who lead a totally nomadic pastoralist life and are hence to be found all over the region. With urbanization and the breakdown of tribal borders, many tribes in Tanzania are represented in the region including Indians, Arabs and Somalis from beyond Tanzania's borders, who are mainly merchants. Kiswahili is the *lingua franca* of the region as it is throughout Tanzania (The Regional Commissioner's Office, Dodoma, 2002; The United Republic of Tanzania, Dodoma Region, 2003).

2.4. Climate

The Dodoma region is mostly semi-arid due to low and erratic rainfall. The region has a unimodal rainfall pattern. It falls in a single rainy season between November-December and April-May. Generally these rains fall in heavy storms resulting in flash floods. Consequently about 60% of the precipitation becomes run-off rather than penetrating the soil for crop growth. The month of January normally experiences unpredictable drought. Such very dry spells cause stress to crops and consequently low yields of crops or even crop failure. There is significant variation in the rainfall pattern in different parts of the region where 80 percent rainfall probability is only about 200 mm, although the rainfall in neighbouring areas can exceed 700 mm. In the long dry spell between late April and late November persistent desiccating winds and low humidity contribute to high evapo-transpiration. This dry spell leads to frequent shortages of soil moisture causing stress to crops, which are normally dependent on rain, and consequently low yields which are dangerous if an invasion of many quelea appears (The United Republic of Tanzania, Dodoma Region, 2003).

2.5. Physical features

Topographically, the Dodoma region forms part of the Central Plateau of Eastern Africa extending from Ethiopia in the north to the Transvaal in the south. The region is dissected from north to west by a number of mountain chains. They are steep sloped with table-top summits. Between and around these mountain ranges are low-lying relatively flat areas.

A number of depressions are associated with these lower areas. They are generally water-logged in the rainy seasons, have a tendency to salinity because of their limited outflow, and are locally known as *mbuga* (The Regional Commissioner's Office, Dodoma, 2002).

2.6. Drainage

There are three major drainage systems in the region which favour quelea for breeding, roosting and, in the dry period, getting drinking water. These are:

To the north, the Bubu and Kinyasungwe streams collect the rainfall excess from almost one half of the area of the region. The Kinyasungwe flows east and eventually joins the Wami river which discharges into the Indian Ocean. The Bubu flows in the south-west direction and drains into the Bubu swamp where quelea are seen almost all year.

To the south, numerous tributaries run almost due south and drain into the Ruaha river system, which ultimately discharges into the Indian Ocean via the Rufiji River.

The third system consists of the peripheral systems, which drain into the Maasai steppe system. A very small portion of the steppe drains north via the Tarangire area into Lake Manyara, the remainder is patternless impeded drainage (The Regional Commissioner's Office, Dodoma, 2002).

2.7. Vegetation

Quelea occur throughout the short grass Acacia steppe or shrub savannah of Africa. Within this range, the birds seek areas where there is an abundance of wild grass seed, a plentiful supply of fresh drinking water and a dense enough cover in which large numbers can assemble to roost or breed (Allan, 1996). Therefore, the presence of birds within an area is largely dependent on such factors as suitable habitats and availability of food and water as well as shelter and security (e.g. absence of predators) (Matee, 1999).

The natural habitat of quelea is semi-arid Acacia country where the species relies on wild grass seeds (*Setaria* spp., *Echinochloa* spp., *Sorghum* spp., *Panicum* spp., *Eragrostis* spp., *Digitaria* spp., *Brachiaria* spp. and *Cynodon* spp. etc.) and natural water holes, migrating locally in a seasonal search for sustenance (Roming, 1988; Jarvis and Vernon, 1989a).

The characteristic vegetation of the region consists of thickets, formed wherever the natural vegetation has been destroyed by agricultural activities, grazing and fire, regenerating bushes, mainly *Acacia* spp., mixed with short lived annual grasses and herbs (Stuart *et al.*, 1990; Kideghesho, 2001; White, 1983). There are also areas of wooded grasslands in depressions, which are seasonally inundated *mbugas* (areas with impeded drainage).

There are many different types of vegetation in Dodoma, but inter-related factors determine where and how trees grow. The most important of these factors are the amount of rainfall and length of the season, the range of temperatures, the slope of the land and the activity of man. The natural conditions over very long periods have caused the vegetation types which are found in Dodoma today, but it is the activity of man over the past 100 years, which has brought about the most dramatic changes, and these are usually for the worse (Hamilton and Bensted Smith, 1989). The destruction of forest, e.g. by fire, will lead to the formation of woodland, and in turn the destruction of woodland will eventually result in open grassland (White, 1983; Hamilton and Bensted Smith, 1989; Beentje *et al.* 1994) which produces grass seed essential for quelea food.

Quelea can utilize a variety of vegetation for breeding and roosting. In nearly all cases breeding vegetation may be described as thorny. Quelea can, however, also breed in exotic plantations that have no thorns, apparently in situations where preferred vegetation is absent (Jarvis and Vernon, 1989). This phenomenon has been observed where thorny trees are not numerous and they are mixed with other non-thorny trees. In other areas, quelea have been observed breeding in *Phragmites* reeds. Quelea roost in dense vegetation. This may be woodlands, *Typha* spp. (*T. latifolia*), dense *Panicum* spp. (*P. maximum*) and even *Acacia* spp. (Frost, 1996). The *Acacia* spp. most preferred for breeding and roosting by quelea (Mbuya *et al.*, 1994; Stons, 1995) are *A. hockii*, *A. lahai*, *A. mellifera*, *A. nilotica*, *A. polyacantha*, *A. senegal*, *A. seyal*, *A. tortilis* and *A. xanthophloea.*

2.8. Agro-economic zones

Identification of different agro-economic zones in the Dodoma region has been based mainly on topographic and geographic features as well as climatic conditions. For practical purposes, the region can be sub-divided into three agro-economic zones (Regional Commissioner's office, Dodoma, 2002; The United Republic of Tanzania, Dodoma Region, 2003).

Zone I:

This is predominantly dry, flat or undulating plain with a low density human population. Rainfall in these areas is very unreliable. It receives an annual rainfall below 500mm. The area covers the Maasai steppe in the north-east part of Kondoa, the southern part of Dodoma Rural district and the south-west of Mpwapwa district. The soils in this zone are reddish-brown loamy sands and grey clays in depressions.

Zone II:

This zone covers the central and southern part of Kondoa district, the northeastern and central parts of the Dodoma Rural district, the whole of Dodoma Urban and Kongwa district and parts of Mpwapwa. The area has a rainfall regime ranging from 500 - 700 mm annually. Dark-brown, dark reddish loamy sands predominate in the area. The zone is principally a maize producing area. Sorghum and bulrush millet are also grown.

Zone III:

Areas within this zone are the central parts of Mpwapwa district, mainly hilly areas and the Bereko highlands in Kondoa district bordering Manyara region. The zone has the highest rainfall regime, 700 to 1000 mm per annum, in the region. Soils are deep dark reddish brown clay loams with black clay soil in depressions and valleys. Main food crops grown are maize, sorghum, bulrush millet, finger millet, cassava and sweet potatoes.

2.9. Agriculture

About 85% of the estimated 1.6 million population (2001) in the region live in rural areas relying on agriculture and livestock keeping activities for subsistence and income. The agricultural sector generates much of the region's Gross Domestic Product (GDP) while providing labour for over 90% of the work force. More than 75% of the land area in the region is semi-arid. Soils have low nutrient contents. Rainfall is low and occurs only seasonally with considerable variation over the region and from year to year. It is estimated that the region has 2,593,000 ha of arable land, and 1,406,518 ha or 54%

(2008/2009 season) which are under crops. Distribution by districts is given in Tables 2.1 to 2.4.

The region is unfortunate in that it does not have any traditional export crops. What is grown as a food crop is also considered as a cash crop (Tables 2.5 and 2.6). Bulrush millet and sorghum, which are favoured by quelea for food, are grown more extensively in Dodoma and Singida in the central part of the country than in other regions. The two regions make up the central part of the country. The planted area for these crops is bigger in the Dodoma region than in the Singida region, which is why Dodoma was chosen as a research area. The planted areas for the seasons 2007/2008 and 2008/2009 are shown in Table 2.7 for Dodoma and Singida and Table 2.8 for the Dodoma region by districts. These tables were provided to show the hectares of cereal crops planted during the study period.

Table 2.1. Distribution of arable land and area under cultivation by district, Dodoma region (2007/2008 and 2008/2009 seasons).

District	Arable land area (Ha)	Area under cultivation 2007/2008		Area under cultivation 2008/2009	
		Ha	% Arable	Ha	% Arable
Mpwapwa	223,000	117,684	53	127,158	57
Dodoma Rural	893,000	383,846	43	453,239	51
Kondoa	925,000	456,689	49	610,259	66
Kongwa	364,000	109,552	30	124,110	34
Dodoma Urban	118,000	92,225	78	92,752	79
Total	2,593,000	1,159,996	45	1,406,518	54

Source: Regional Commissioner’s Office, Dodoma, 2007/2008 and 2008/2009

Table 2.2. Estimated area (ha) under major crop production by District, Dodoma Region 2008/2009. This show the importance of cereal crops in the region.

Crop	Dodoma Urban	Dodoma Rural	Kongwa	Kondoa	Mpwapwa	Total	% of Total Crop Area
Maize	10,288	32,078	58,000	92,917	12,775	206,058	19
Sorghum	22,214	112,879	40,700	90,800	36,836	303,429	28
Bulrush Millet	39,427	87,645	1,870	82,927	2,941	214,810	19
Cassava	12,657	40,216	4,610	46,459	19,416	123,358	11
Paddy	450	8,706	-	150	306	9,612	1
Sweet Potato	1,121	41,410	850	30,972	4,550	78,903	7
Beans	-	-	750	15,456	5,442	21,678	2
Bambara nuts	18,101	38,536	12,960	46,459	22,577	138,633	13
Total	104,258	361,470	119,740	406,170	104,843	1,096,481	100

Source: The Regional Commissioner’s Office, Dodoma 2008/2009.

Table 2.3. Distribution of land area by district, Dodoma Region.

District	Land Area in km^2	% Regional share
Dodoma Rural	14,004	33.9
Kondoa	13,209	32.0
Mpwapwa	7485	18.1
Kongwa	4,041	9.8
Dodoma Urban	2,572	6.2
Total Region	41,311	100.00

Source: The Regional Commissioner's Office, Dodoma 2008

Table 2.4. Estimated area (ha) under major crops production by district, Dodoma region 2007/2008. This show the importance of cereal crops in the region.

Crop	Dodoma urban	Dodoma Rural	Kongwa	Kondoa	Mpwapwa	Total	% of Total Crop Area
Maize	9,260	28,870	52,200	83,625	11,496	185,451	18
Sorghum	19,993	101,591	36,630	81,720	36,836	276,770	25
Bullrush Millet	35,485	78,880	1,683	74,634	2,647	193,329	18
Cassava	11,390	36,195	4,150	41,813	17,475	111,023	10
Paddy Rice	405	7,836	-	135	307	8,683	1
Sweet Potatoes	1,010	37,269	765	27,875	4,095	71,014	6
Beans	-	-	683	13938	6,047	20,668	2
Bambara nuts	16,290	34,683	11,664	138,813	103,989	1,086,474	20
Total	93,,428	35,324	107,775	455,553	103,989	1,086,474	100

Source: The Regional Commissioner’s Office, Dodoma 2007/2008

Table 2.5 Planted areas of bulrush millet and sorghum in Dodoma and Singida regions.

Season	Crop	Area (ha) planted Dodoma	Area (ha) planted Singida
2007/08	Bulrush Millet Sorghum	202,300 275,000	87,855 155,340
2008/09	Bulrush Millet Sorghum	275,800 305,546	88,933 157,693

Source: The Regional Commissioner's office, Dodoma and Singida 2007/8 and 2008/9.

Table 2.6. Planted areas of bulrush millet and sorghum Dodoma region, by District.

Season	Crop	Dodoma Rural (Ha)	Dodoma Urban (Ha)	Kondoa (Ha)	Kongwa (Ha)	Mpwapwa (Ha)
2007/2008	Bulrush Millet Sorghum	77,481 122,100	58,262 11,000	46,529 46,750	12,947 33,275	7,081 61,875
2008/2009	Bulrush Millet Sorghum	103,425 137,496	78,051 13,750	67,571 53,470	19,306 36,665	7,447 64,165

Source: Regional Commissioner's Office 2007/08 and 2008/09 seasons.

2.10. Irrigated agriculture

Irrigated agriculture has contributed to the persistence of quelea in the country, because grain seed crops are mostly irrigated, including rice, wheat and barley. Rainfall in Dodoma is too low and irregular in many parts of the region for crop production to be reliable. On this basis there is a need to bring into crop production areas with potential for irrigation, which in the region comprises 16,152 ha. Their distributions by district are: 5,305 ha. in Dodoma Rural, 2,238 ha. in Mpwapwa, 7,796 ha. in Kondoa and 813 ha in Dodoma Urban district. Table 2.9 shows that out of 16,152 ha potentially available for irrigation in the region only 3,756 ha or 23% are under production. Irrigation production in the Dodoma region is not common but is desirable and it is feasible. What is needed is the will and resources to develop the potential into irrigation schemes producing tons of crops under irrigation. Rainwater harvesting techniques could be used more extensively in the region. By this approach many hectares in the Bahi depression area (Dodoma Rural district) have been put into production by irrigation through tapping the Bubu river water that flows through the area. Kondoa district has exploited only 5% of its irrigation potential. Mpwapwa district shows the highest utilization of its irrigation potential at 73% (Table 2.9). Water from the river supplements water moisture after the rain stops to allow the crop to mature. The water is not used throughout the year as very little water is available in the dry season.

Table 2.7 Irrigation Prospects in the Dodoma Region 2007.

District	Division	Potential area (Ha)	Area under Irrigation (Ha)
Dodoma Rural	Bahi	1,600	1,295
	Chilonwa	500	30
	Mwitikira	1,700	-
	Makang'wa	750	8
	Mundemu	75	30
	Mvumi	300	-
	Chipanga	380	183
	Total	**5,305**	**1,546 (29%)**
Mpwapwa	Rudi	920	595
	Kibakwa	520	420
	Mpwapwa	173	73
	Miscellaneous area	625	541
	Total	**2,238**	**1,629 (73%)**
Kondoa	Kondoa mjini	2,450	27
	Kolo	2,969	53
	Bereko	1,187	228
	Mondo	195	33
	Kwamtoro	350	7
	Farkwa	45	5
	Goima	600	8
	Total	7,796	361 (5%)
Dodoma Urban	Total	813	220 (27%)
Regional Total		**16,152**	**3,756 (23%)**

Source: Regional Commissioner's Office, Dodoma 2007

CHAPTER THREE

THE GEOGRAPHICAL DISTRIBUTION, BREEDING SEASONALITY AND FORECASTING OF BREEDING OPPORTUNITIES FOR THE RED-BILLED QUELEA IN TANZANIA

3.1. INTRODUCTION

The Red-billed Quelea *Q. quelea* is a superabundant weaver bird which is characterized by its habit of seasonal migration. These abundant birds breed colonially when conditions permit (Venn *et al.,* 2002). Seasonal long distance migrations have been suggested (Ward, 1971) and movement of more than 2000 km by ringed birds is known (Mundy and Herremans, 1997; Oschadleus, 2000).

The migration patterns and the timing of the annual cycle are believed to be governed by seasonal changes in availability of the birds' principal food and seasonal patterns of rainfall across sub-Saharan Africa. The principal food includes seeds of annual grasses and insects (mainly caterpillars and nymphal grasshoppers) to provide sufficient protein for females to form eggs and for the parents to feed chicks (Jones, 1989a,b&c; Jones and Ward, 1976; Jones *et al.*, 2007; Jaeger *et al.*, 1989; Manikowski *et al.*, 1989; Dallimer *et al.*, 2002; Dallimer and Jones, 2002). Quelea are highly mobile, commuting considerable distances between roosts, food and water on a daily basis. The seasonal movements and breeding cycles are closely tied to movement of the rain front (Intertropical Convergence Zone – ITCZ) and the subsequent production of grass seeds (Elliott 1979; Jaeger *et al.,* 1979, 1986; Ward 1965 a&b; Ward and Jones, 1977; Elliott, 2006).

The array of physiographic features within eastern Africa, such as the mountains and lakes associated with the Rift Valley System, together with the proximity to the equator and Indian Ocean results in a complex pattern of rainfall (Brown and Britton, 1950; Brown *et al.*, 1983). Although rainfall patterns in sub-tropical southern Africa are more complex, the basic patterns north and south of the equator are mirror images of one another, with their seasons being six months out of phase. The slow movements of the rain fronts cause important regional differences in the timing of grass growth and are responsible for quelea migration patterns (Jones, 1989a). Consequently, quelea breeding can occur somewhere within the region throughout most of the year and simultaneously at two or more widely separated locations (Jaeger *et al.,* 1989). An ability to forecast where and when colonies could be established will greatly improve the efficiency of control measures (Cheke *et al*., 2007). When preparing for control measures, forecasting suitable breeding conditions for the quelea is very important.

Geographical coordinates of places found suitable for breeding colonies in the southern and central part of Tanzania are shown in Appendix 2a. Some of these areas were included within the zone covered by the forecasting model developed by Venn *et al.* (2003) used for forecasting breeding opportunities for quelea in southern Africa. The model is based on, and provides a partial test of, the conjectured rainfall-migration model of Ward (1971) whereby quelea movements are determined by rainfall patterns and grass seed availability (Cheke *et al.,* 2007).

3.2. REVIEW OF LITERATURE ON THE GEOGRAPHICAL DISTRIBUTION AND TIMING OF BREEDING BY RED-BILLED QUELEA IN TANZANIA

The Red-billed Quelea *Q. quelea*, is the most abundant bird in Tanzania, being much more numerous than the other species of *Quelea*, the Cardinal Quelea (*Q. cardinalis*) and the Red-headed Quelea (*Q. erythrops*), and has the greatest impact on the Tanzanian agro-ecosystem of any pest bird (Elliott, 1990). Quelea populations in Tanzania are classified into three categories depending on occurrence, abundance and extent of damage caused to crops as follows:

(1) The most abundant and major pest of cereal crops. This classification is appropriate for the major cereal regions such as Dodoma, Singida, Manyara, Arusha, Kilimanjaro, Mbeya, Shinyanga, Morogoro;
(2) Intermediate importance, covers Musoma, Tabora and Iringa, and
(3) An occasional pest, covers Dar es Salaam, Coast and Tanga Regions (Tarimo, 2006).

Large flocks of quelea occur in Tanzania after the onset of the long rains. The rains normally start from November to February in central, east and southern Tanzania between 3^0 and 8^0 South, and 33^0 and 37^0 East where large breeding colonies are found. For example, an average of 45 colonies were located and controlled annually between 1979 and 1985 in an area that lies diagonally from northwest to southwest of the zone

(Tarimo *et al*., 2006). With the increase in irrigated rice quelea are seen almost throughout the year in rice-growing areas, but these birds are normally non-breeding, roosting, birds.

In Tanzania *Q. q. aethiopica* are believed to migrate north-east from central Tanzania to southern Somalia and then back to central and south-western Tanzania following the rain front as it moves north and south across the equator (Jaeger, *et al.* 1989*;* Ward, 1971). The migratory movements of quelea are generally governed by changes in the availability of the birds' principal food, the seeds of annual grasses such as *Panicum, Setaria, Urochloa* and *Echinochloa* which grow and set seed during the rainy season (Jones, 1989a&d).

3.2.1. The 'early-rains' migration

Much of the following account is based on texts by Peter Jones (1989a&d). In years of scattered or poor rains the quelea may not move far, or may not move at all. During this time, quelea mainly subsist on fallen seed of annual grasses produced during the previous rains (Ward, 1965a). Seeds fall onto the soil surface during the dry season remaining ungerminated, and thus available for birds. Quelea will remain in one area only for as long as seeds are available. The enormous roosts, to which the birds return every evening, may be disbanded as quickly as they are formed. With the availability of grass seeds, some roosts may persist throughout the dry season. As other quelea may remain in one area for the entire dry season, there is considerable interchange of others among nearby and distant roosts. Such movements do not have any set pattern and are governed only by the local depletion of food stocks, so they may be termed nomadic. They differ greatly from the movements that take place at the start of the rains (Jones, 1989a&d).

The beginning of the early rains usually starts with frequent local showers, which are insufficient to cause seed germination. As the showers become continuous the result is a sudden and widespread germination of the remaining seeds, hence leaving the ground covered with growing grasses (Jones, 1989a). This deprives the birds of their preferred food and although insects, such as moths or grasshoppers, are plentiful at the start of the rains, they are mostly in active adult stages and difficult for quelea to catch (Jones, 1989a&d). Thus, the birds are compelled to move. If the rains are widespread the birds may be obliged to travel some considerable distance to find new food sources. In this they are aided by the flush of insects, particularly termites, which are promoted by the rains. For a short time the birds gorge themselves on this rich food source, building up a fat reserve sufficient to sustain them on their migration. The average amount laid down by the quelea population is proportional to the minimum distances that the birds must expect to fly before encountering freshly matured seeds (Ward and Jones, 1977). This suggests that they have to predict how far they must travel. This migration through the rains is known as the “early rains’ migration (Ward, 1971; Allan, 1996).

During this first migration, quelea may seek places where it has not yet rained and where ungerminated seeds still exist, or fly to areas where it has rained sufficiently long for the germinated seeds to have grown.

3.2.2. The Red-billed Quelea breeding migration in Tanzania

After 4 to 6 weeks grasses in areas where sufficient ‘growing rains’ fell, begin to set seed thus maintaining the food source and, possibly, allowing the birds to attain breeding condition. Quelea involved in the early-rains migration arrive at sites where most grass heads are setting seed. After feeding on such seeds in these “early rains quarters” (Ward, 1971) the plumage of some of the birds changes so that they come into full breeding condition. The facial masks of the males become black and the bills of the females change from red to yellow. Some birds then quickly establish small colonies, but often birds beginning to attain breeding condition in the early rains quarters move back on a “breeding migration” towards the rain front to nest where the grass has already grown sufficiently to set seed. For quelea to breed again in a season, they have to move once again along the line of the advancing rain fronts, returning to areas where they had been concentrated at the end of the dry season (Meinzingen, 1993).

The breeding migrations, particularly in southern Africa, often follow river valleys as the birds search for ideal sites at which to establish their breeding colonies (Allan 1996). After reaching a suitable site, nest building starts immediately but it may be two or three days later before a colony is established. Males normally arrive at chosen sites before the females and only males build the nests (pers. obs). After the females arrive, colony establishment is quick and synchronous egg-laying begins. In most cases nests are built in thorny acacias such as *Acacia tortilis, A. mellifera* and *Dicrostachys cinerea* or other thorny plants such as *Faidherbia albida* or *Zizyphus* spp., although colonies have also been found in reed-bed grasses or sugar canes. The breeding cycle is usually completed in 5 to 6 weeks.

The adult birds, which first breed in the early-rains areas, may continue their breeding migration along the advancing rain fronts to regions where grasses are still flowering and breed again when their seeds are set. Such birds in prime condition may attempt to breed two or more times in the same rainy season. This type of breeding is known as 'itinerant breeding' (Meinzingen, 1993; Jones, 1989a). Quelea that were not among the first to breed have two options. First, they may remain in the early-rains quarters until ready to breed and then make a long flight to catch up with the zone of newly seeding grasses. Secondly, they may move slowly along the same leading edge as the rain front, but remain within the seeding zone as it advances. As soon as they are ready to breed they stop migrating and begin nesting. Whichever option they follow, they would not need to deposit pre-migratory fat for this breeding migration. They may feed on fresh seed or insects at any point, and there is no urgency for the journey to be made non-stop. Eventually, the breeding migration will bring birds back to the areas where they had concentrated at the end of the dry season and from where they departed on their early-rains migration (Jones, 1989a). In regions where quelea have been breeding itinerantly, most will complete their breeding attempt of the season in the area that was the last to receive rain. The end of the breeding migration leaves quelea in areas that become the major concentration zones for the dry season and where they will resume their nomadic life until the next rains (Jones, 1989a). These are birds in poor condition and birds which have reached the limit of suitable breeding habitat for that season. They will disperse to areas where the season's grass seed is available to them exposed on open ground. This condition characterizes the beginning of the dry season. During this time good feeding grounds become scarcer and the quelea gather in increasingly larger roosts to exploit the diminishing food reserves. It is generally in these dry season concentration zones that irrigated crops may be at risk to quelea as the dry season advances (Allan, 1996).

When the adults have deserted the colonies, the young birds left behind usually remain in the area using the site as a roost for a few weeks. After the local seed supply diminishes the juveniles have to move away to areas better for finding food in. During the movements some may join adults on their breeding migration but, alternatively, they may stay put, often finding fields of cereals to feed on. Thus, it is usually the young birds that cause the greatest losses to rain-fed crops. Eventually, many of the young birds move on to catch up with the adults in their dry season concentrations. The remaining young disperse throughout the breeding areas and join the main body of quelea moving back on their early-rains migration to start the annual cycle again (Ward, 1965b, 1973; Jaeger *et al.*, 1979).

The northward movements of quelea from central and southern Tanzania in February / March to breed again in May / June is well known (Disney and Haylock, 1956). Normally, quelea migrate from the northern half of Tanzania to northern eastern Kenya or southern Somalia in December. During the onset of the short rains in November quelea move north-east into southern Kenya where some nesting could occur during December and January before the birds move back to southern Tanzania in February and March to start a new breeding cycle (Disney and Haylock, 1956).

Very rarely breeding colonies have been found in dry periods, although juveniles have been caught in areas near national parks at such times. This indicates that sometimes there is some breeding in the national parks during the dry period, normally following the last harvest when rains have been prolonged.

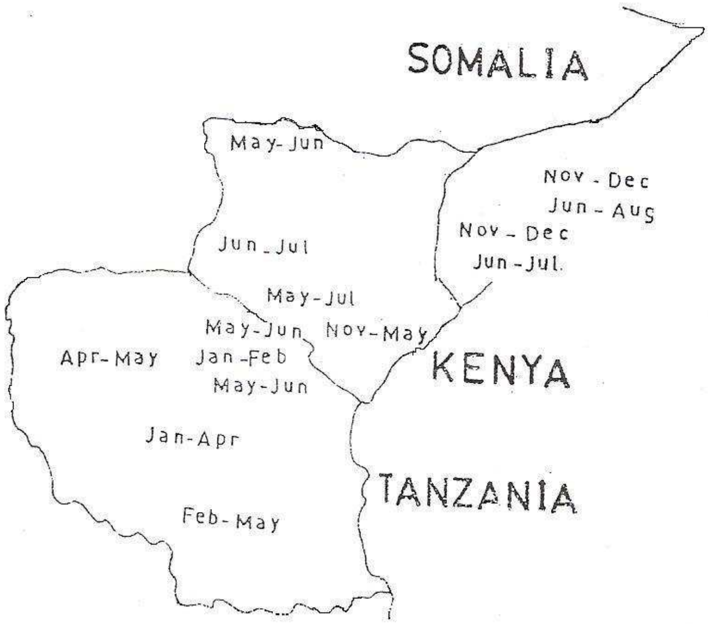
Breeding activity is a regular feature for quelea occurring in all areas with favourable conditions, although locations can change from year to year depending on the rainfall patterns. In years with widespread rains the same birds can continue breeding as many as three times in different areas. The cycle may start from February in the south and central parts of Tanzania and end towards the northern part in late July where colonies sometimes are found (Jaeger *et al.*, 1989). The months which have been recorded as breeding periods for quelea in Tanzania, including the six weeks of colony establishment to the production of independent young, are shown in Figure 3.1.

Breeding activity is a regular feature in all of the areas shown in good rain years, except for January and February in northern Tanzania and May and June in northwestern Tanzania. Nevertheless, some breeding in January within Lake Manyara National Park was recorded by Ward (1971). This was not recorded again between 1978 and 1986, but in March 1987 Tarimo (1994) located one colony there at its last stage of development. This colony was established in late January or early February which is not normal in the area (see Figure 3.1). In northwestern Tanzania, colonies are only found in May and June but occur between March and May in the northeast colonies. Elsewhere, breeding appears to be sporadic.

The annual breeding quelea population in Tanzania has been estimated to be about 62 million breeding adults (Elliott, 1989a). This figure doubles to about 120 million birds to account for chicks fledged by each pair in each colony per year. A typical quelea clutch consists of a mean of 2.8 eggs (Jones, 1989d) from which 1-3 young are hatched, varying from 1.6 to 2.8 (Jackson and Park, 1973; Morel and Bouliere, 1956). Under normal weather conditions, an average of 2.57 young can be reared to fledglings (Ward, 1965). All females probably make at least one breeding attempt per year (Ward, 1977). However, itinerant breeding has been reported at Hanang wheat complex farms (Elliott, 1989a; Erickson *et al.*, 1982) and if conditions are favourable two or three breeding attempts per year may occur (Elliott, 1990; Tarimo *et al*., 2002).

However, there is evidence that the breeding pattern in Tanzania has changed considerably since the times described by Elliott (Tarimo *et al*., 2006). For example, between 1994 and 2004 it was observed that most of the quelea population remained in northern Tanzania sometimes up to April because the rainfall patterns were either too little or too much or came too early or too late to allow normal breeding migration (Tarimo *et al.,* 2006). In 1997, after minimal control in the previous season, only eight colonies occurred at Hanang Wheat Complex Farms compared to more than 25 colonies a year before, when the farm was relatively wet. In the 1996 season no effective control measures were undertaken in many parts of the country. Breeding colonies established in western and central Tanzania were not effectively controlled. It is possible that some of the birds moved north or southeast to breed for the second time in areas with wheat.

Figure 3.1. The months of active breeding and migration of quelea in East Africa (Source: Elliott, 1990).



In the 1997/1998 season, there was no colony established in northern Tanzania nor in the Hanang Wheat Complex Farms due to the nature of the long rains in that season. The unusual heavy and continuous rains supported abundant growth of grasses in November and December. The grasses dried early and were completely replaced by broad-leaved plants by February to April the following year. This situation deprived the birds of suitable building material as well as food for successful breeding. Quelea remained in the northern zone where they caused heavy losses to both rain-fed and irrigated rice and wheat. The years 1995 and 1999 had inadequate rains and grasses to allow breeding and precluded the possibility of the birds moving to the south. This resulted in the birds remaining in northern Tanzania as resident populations as the area had enough paddies, wheat, and wild grass seeds for their survival (Tarimo *et al.,* 2006).

In May and June 2001, six colonies with an estimated population of more than thirty million adult birds were located in Hanang Wheat Complex Farms. The colonies were at different stages of development. Two colonies at Gairo Hill and Marjanda in the Wheat Complex Farms were divided into three and four distinct sections with eggs, nestlings and fledglings at different stages suggesting itinerant breeding. This showed that quelea breeding may occur in one locality more than once but also they can breed within the same site more than twice in a season (Tarimo *et al*., 2006; pers. obs). In this season, over 90 per cent of the farm (9,000 ha) was not cultivated as the former growing company had finished its contract and left, no other company was taking over. The few workers who were left cultivated 10 per cent of the farm. This resulted in the availability of abundant grass seed coupled with adequate and even distribution of rainfall.

The widespread rainfall allowed several grass species to grow, including dense love-grass (*Setaria verticulata*) which covered more than 70 percent of the uncultivated farm. Other grasses included couch grass (*Digitaria* spp.), wild sorghum (*Sorghum halepense*), liver grass (*Urochloa* spp.) and Sudan grass (*Sorghum vulgare var. sudanense*). These provided a continuous supply of new small grass seeds for quelea, possibly from February to June.

This prolonged period coincided with the south-north migration of birds that had probably bred in central and western Tanzania. The favourable conditions allowed for itinerant breeding for the second and possibly the third time. Another reason for breeding in several sections in one site may be lack of favourable and adequate breeding sites at Wheat Complex Farms. Ecological changes, changes in rainfall patterns and introduction of irrigated rice in many places in the country have possibly altered the normal movements of the quelea in Tanzania (Tarimo *et al*., 2006).

3.3. RECORDS OF ROOSTS AND BREEDING COLONIES REPORTED IN THE CENTRAL ZONE IN TANZANIA DURING THE STUDY PERIOD (2006-2010)

During the study period the rainy seasons differed year after year. Some years had normal rainfall patterns, but others had long droughts. This situation led to some early and late migration of quelea in the area. The 2006/2007 and 2007/2008 seasons received normal rainfall compared to the 2008/2009 season which had a long drought. The rainy season started at the end of March, which appeared to be below normal in central Tanzania. This situation made farmers complain as the rain was generally insufficient for the maize crop, although good enough for bulrush millet. This led to late migration of quelea in the area.

In the Dodoma area roosts are normally established from mid-February onwards when the rainy season is normal. By this time the birds are usually prepared for breeding and colonies are normally established from early March. This situation is followed by several heavy rain storms which do not last long, although they appear to improve the breeding condition. The located roosts and breeding colonies are shown in Appendix 2a&b.

3.4. CURRENT STATUS OF THE RED-BILLED QUELEA IN TANZANIA BASED ON RECENT MINISTRY OF AGRICULTURE REPORTS

Farmers in Tanzania have known bird pests for a long time (Yahia 1957; Crook, 1957; Tarimo, 1999), with weaver birds (Family Ploceidae) constituting the greatest problem in agriculture. Williams (1953) reported heavy damage to wheat in Tanzania in the early 1950s. Most crop depredations were caused by *Q. quelea*, which occurs in almost 60 per cent of the country's grain production area. As it occurs in large congregations of several thousands to millions each year, if uncontrolled, it can cause serious damage but where control has been carried out effectively from the onset of the breeding colonies, damage to cereal crops has been minimized and many birds killed (see Tables 3.1 and 3.3). If such birds were not killed a lot of crops would have been damaged.

Quelea damage begins in the field at the time of sowing seeds. If the seeds are scattered and not covered properly with the soil, the seeds will be picked up by the birds. Also, the birds feed on ripening seeds especially during dough or milky stages of millet and sorghum. Serious damage takes place when the crop has reached physiological maturity before and after harvesting, mainly where crops are stacked in the fields waiting to be shelled and bagged (Elliott, 1989; Matee and Tarimo, 2006).

Although the quelea is probably the most studied bird species in Africa (Elliott and Bruggers, 1989) and heavily killed bird species in Tanzania (Tarimo *et al.,* 2006), the problem remains the same. Quelea research and control, therefore, remains an area for active research for crop protectionists.

Table 3.1. Quelea control operations undertaken in Tanzania from 2001 to 2009

Year	Regions	Districts	Villages	Colonies	Roosts	Invaded Area (ha)	Quele-tox used (litres)	Birds killed (millions)
2001	7	15	130	15	3	1565	830	56.00
2002	10	14	60	27	27	1648	4705	100.00
2003	9	21	81	1	80	2643	6153	169.00
2004	6	12	37	9	31	1184	2595	93.00
2005	9	12	49	29	20	1572	3535	147.00
2006	3	9	27	17	20	1236	3120	79.52
2007	6	13	54	23	29	1527	3197	128.45
2008	6	11	42	22	34	1635	4230	130.00
2009	10	21	74	36	41	2365	6465	185.5

Source: (MAFSC) Quelea Control Operation reports from 2001 to 2009.

The annual cereal production at risk during quelea invasion is shown in Table 3.2. Tables 3.3 and 3.4 show the numbers of hectares damaged by quelea in some regions in Tanzania during 1998-2002 and percentage damage estimates in some villages from 1995 to 1998, respectively (Quelea Control Operation, Tanzania, 2008). Estimates of the extent of damage by quelea were based on wheat and rice ears visually examined within quadrats (Otis, 1984; Ubaidullah, 2004). The tables show the extent of the quelea problem to cereal crops in the country.

The problem of bird invasion in the country is apparently growing in magnitude in line with the expansion of cereal cropping, especially irrigated paddy in new areas like Kagera (Kale village), Chato district and Tanga region, Muheza district and Musisi village where more than 3 million birds were reported to damage paddy and sorghum. These crops were introduced to these regions for food security and as cash crops respectively (sorghum was needed for brewing) (Quelea Control Operation, Tanzania, 2008).

Table 3.2. Annual cereal production ('000' tones) at risk during quelea invasions if control is not undertaken.

Region	**Sorghum**	**Millets**	**Paddy**	**Wheat**	**TOTAL**
Arusha/Manyara	32.1	5.7	21.3	65.5	12.6
Dodoma	80.594	20.0	1.1	0.0	101.894
Kilimanjaro	7.393	2.5	17.2	4.3	31.393
Mara	42.557	18.6	0.3	0.0	61.457
Mbeya	8.291	17.4	114.1	0.4	140.191
Morogoro	30.469	0.4	84.2	0.0	115.059
Mwanza	19.664	9.8	73.5	0.0	102.864
Shinyanga	88.6	23.5	26.7	0.0	137.8
Singida	39.362	32.8	4.8	0.0	78.762
Tabora	36.131	9.9	41.7	0.0	87.762
TOTAL	**385.151**	**140.4**	**383.9**	**70.2**	**979.651**
Pricing Tshs/kg	150	250	230	250	-
Produce worth (Tshs '000,000)	57,772.65	35,100.00	98,279.00	17,550.00	198,719.65

*1 US dollar = 1097 Tshs

Source: MAFS report 2000

Table 3.3. Hectares damaged by quelea in some regions in Tanzania 1998- 2002, confirming regular damage in Dodoma region.

Region	1998	1999	2000	2001	2002
Manyara	320.5	165	0	0	288
Dodoma	145	600	430	186	230
Mbeya	170	522	573	342	190
Mwanza	24	370	110	80	0
Shinyanga	56	0	41	194	123
Singida	150	0	41	194	123
Kilimanjaro	0	102	0	0	0
Morogoro	0	254.5	36	202.5	191
Tabora	0	215	663	0	127
Total	**865.5**	**2228.5**	**1894**	**1198.5**	**1272**

Source: MAFSC report 1998 – 2002

Table 3.4. Percentage damage estimates for some villages from 1995 to 1998.

Year	Village	Crop	Area under crop (ha)	% Damage
1995/1996	West Kilimanjaro	Wheat	10	10
	Arusha Seed Farm	Wheat	800	26.5
1996/1997	Usa, Majimoto and King’ori	Rice	Variable	12 - 100
1998/1999	Lower Moshi	Rice	1125	23
1999/2000	Ndungu	Rice	680	18
2000/2001	Lower Moshi	Rice	1325	15
	Basuto/PV	Wheat	2000	44
	Basuto	Wheat	170	>50
	Mulbadaw	Wheat	40	100
	Hannang	Wheat	1000	5 - 100
	Magugu	Rice	700	6
	Mto wa Mbu	Rice	300	>7

n.b. The table shows only years when crop assessments were done, limited by the availability of experts to do the exercise.

Source: MAFSC report 1995/1996 – 2000/2001

3.5. FORECASTING BREEDING OPPORTUNITIES FOR THE RED-BILLED QUELEA *QUELEA QUELEA* IN TANZANIA

Timely information on location and onset of breeding activities is an essential support for effective quelea control. Weather conditions, especially rainfall, are important and can affect the locations as well as the behaviour of quelea. Thus, the breeding migration of quelea is influenced by rainfall (Meinzingen, 1993). Knowledge of migration strategies could help to inform decisions relating to the management of quelea as a pest (Dallimer and Jones 2002). Sæther *et al*. (2006) wrote that environmental conditions are of great importance in controlling migration and population processes at various scales. Evidence is mounting that migration patterns are altering with current changes in weather conditions (Cotton, 2003; Jenni and Kéry 2003; Anthes, 2004). Climatic conditions have been determinants of the evolution of many migration systems and the processes that bring about seasonal changes are exploited by migrants to keep them on their journeys (Cheke and Tratalos, 2007).

3.5.1. Breeding Forecasting Model

For effective management it is essential to control quelea during their breeding period. The physiological stress of nest-building and egg-laying makes the birds vulnerable to minimum application rates of avicides. Hence, control efforts should be concentrated during this specific period (Meinzingen, 1993).

In a breeding forecasting model a database providing information on both the location and time of breeding is necessary. The colony data should contain all known historical colony records and should be regularly updated. The DFID-funded NRI project ‘Models of quelea movements and improved control strategies’ assembled a computerized database of 3543 historical records of quelea breeding occurrences throughout southern Africa, from which a forecasting model has been developed to assist pest managers in predicting control needs and targeting them effectively (Jones *et al.*, 2000).

The project involved the collection of data from the surrounding countries of the Southern African Development Community (SADC) (but excluding Tanzania) that share the same quelea populations, i.e. *Quelea quelea lathamii* (*Q. q. aethiopica* is the subspecies occurring in Tanzania). The model covers most of the southern African countries as well as the southern and central parts of Tanzania, which are the first to receive breeding colonies in each year. A general model of quelea migrations in southern Africa was first described in detail by Jones (1989b) and that account forms the basis of the predictive model developed by the NRI project (Jones *et al.*, 2000, Cheke *et al*., 2007). The latter two references were relied on for much of the following descriptions in this section.

The DFID-funded project was concerned only with alleviating damage to rain "fed" subsistence crops. Therefore, the model was intended to forecast the timing and locations of quelea breeding colonies that would require control to prevent successful fledging of juveniles. The forecasting model developed by the NRI project was, therefore, designed to predict where and when breeding colonies will be established (Jones, *et al.*, 2000). The basis of the model is the conjectured migration pattern of quelea in southern Africa first proposed by Ward (1971) and elaborated by Jones (1989b). Within this pattern, the timing and distribution of rainfall and the resultant growth of annual grasses is the main determinant of the birds' movement (Cheke *et al.*, 2007). On arrival in the early rainfall areas, some birds breed immediately while others come into condition more slowly and begin breeding later. Some places provide good breeding conditions reliable for queleas in most years, even under a variable rainfall regime, and can be regarded as traditional breeding sites to which the birds return year after year. Other areas may be occupied only if the traditional breeding sites prove unsuitable, or only in years of above-average rainfall. Areas that are suitable for breeding in all aspects may remain unoccupied in a particular year if the birds first settle elsewhere (Cheke *et al.*, 2007, Jones *et al.*, 2000).

The model was based on that used successfully for forecasting outbreaks of African armyworm *Spodoptera exempta* in Tanzania (Tucker and Holt, 1999; Holt *et al.*, 2000). Figure 3.2 provides information on the reported occurrences of various migrant pests, the sort of data which can be used to validate such forecasting models. The rule-based forecasting model for quelea, incorporating state changes by logical 'if then' type rules, was described conceptually before any programming was started by Jones *et al.* (2000). To construct the quelea forecasting model, the timing and amount of rainfall necessary to initiate breeding have been established from correlations between past rainfall records and the dates of breeding attempts in the quelea database. Example outputs showing areas where conditions were suitable, based on satellite-derived rainfall data, for quelea to breed are given in Fig. 3.3.

Validation of the model for *Q. q. lathamii* was based on the dates and coordinates of breeding colonies reported to agricultural departments and control teams by farmers. Not all the colonies were reported with exact times of breeding. Information such as nest-building activities, presence of eggs, nestlings or fledglings when reported was used to calculate a more precise date when the colony was likely to have been founded, bearing in mind that nest-building and egg-laying take about 7 days, incubation 10 days, fledging 11-13 days (Ward 1965) and the post-fledging period is about 7 days (Cheke *et al.*, 2007).

As described by Cheke *et al.* (2007), the model was run at weekly intervals during the quelea breeding season in southern Africa (September to May). Each week a forecast map was produced which was colour-coded as follows. At the start of the computer runs in September, all grid squares in the maps were either white or grey, the latter denoting squares where *Q. quelea lathamii* have never been known to breed (i.e. habitat unsuitable or where *Q. q. aethiopica* occurs, as in Tanzania).

Once a first rainfall threshold (60mm) has been reached in a particular square, a white square turns light green indicating that the birds must vacate the area, as seeds will be germinating and a grey square turns dark green. Only once a second rainfall threshold (>240mm of additional rain) has been passed and sufficient time has elapsed for conditions to become suitable for quelea breeding does a light green square turn red and a dark green square changes to dark red. Finally, after too long a time has passed (6 or more weeks) since a square turned red for quelea breeding to remain likely there, a red square turns yellow and a dark red square becomes khaki.

The model performed well compared to an expected null distribution of breeding colonies within southern Africa, but excluding Tanzania, among quarter-degree grid squares. In a more refined analysis of a small subset of colonies for which precise dates of their establishment were known, their spatio-temporal distribution matched predictions in 95%, 85% and 99% of cases in three successive seasons. This success rate shows that predictions from the model, the first of its kind for any African bird, can aid in planning of quelea control strategies (Cheke *et al.*, 2007).

Figure 3.2. Migrant Pest Situation Map for SADC Region: March 2003

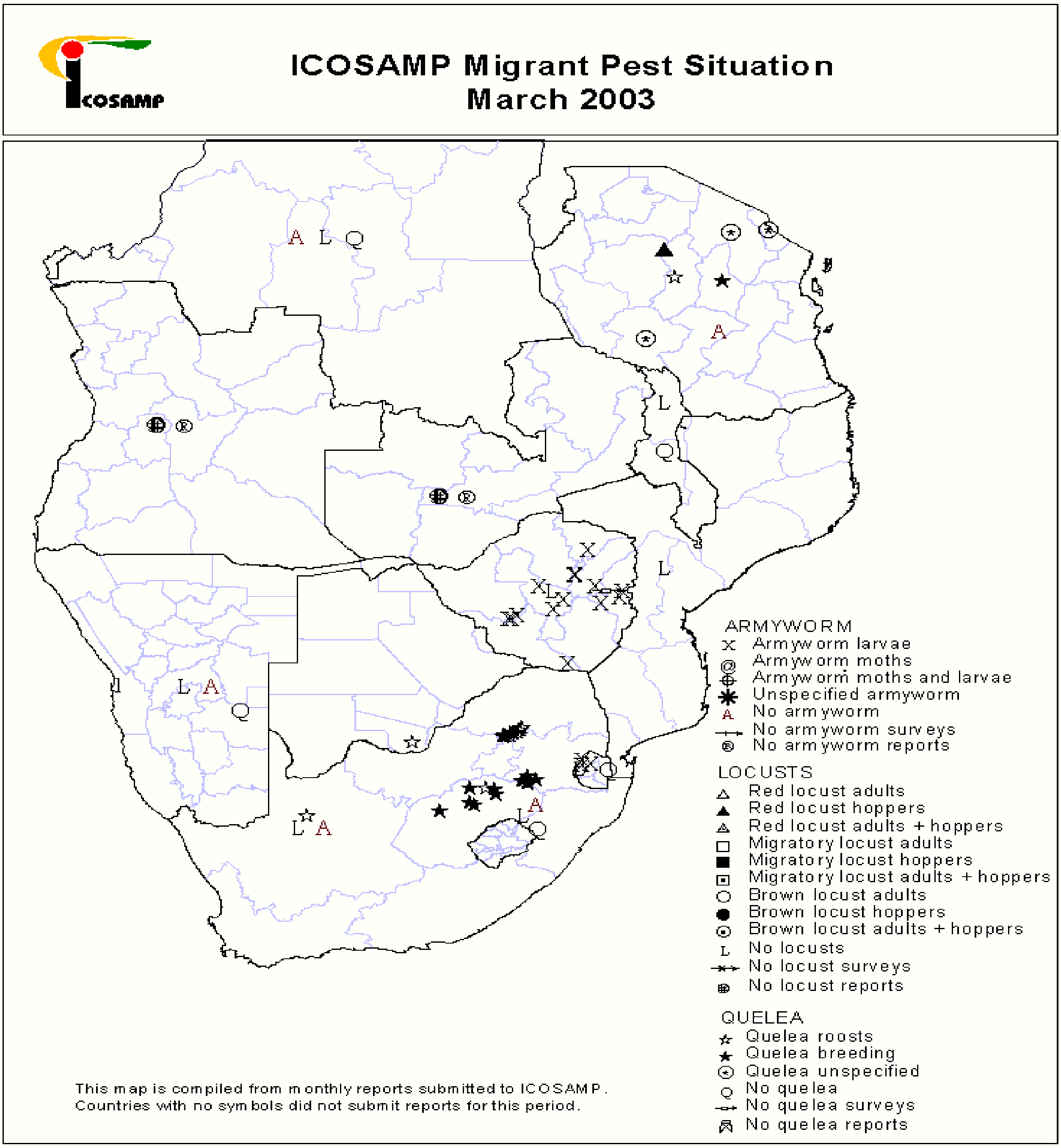
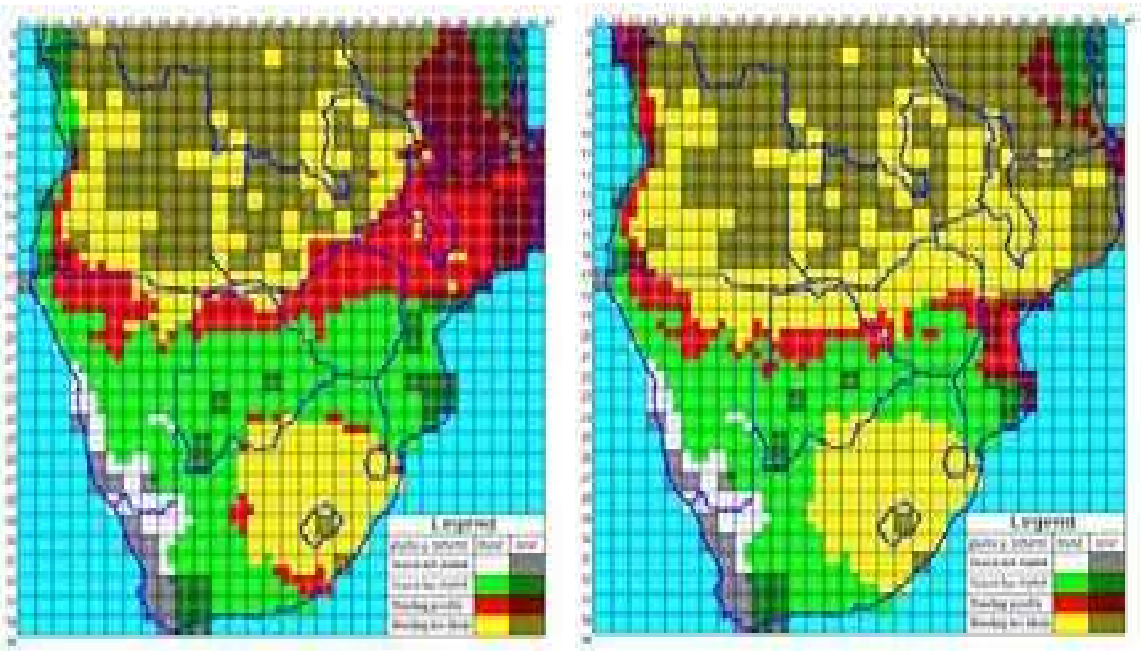


Figure 3.3. Quelea forecasting model for southern Africa 2002/2003. Samples of outputs for weeks ending 16 Feb. 2003 (left) and 16 March 2003 (right) and summary key for colour codes (R. A. Cheke, pers. comm.). For explanations of colour codes see text above.



Quelea q. lathamii	*found*	*never*
Season not started		
Season has started		
Breeding possible		
Breeding less likely		

3.5.2. Results and Discussion of validating the model with Tanzanian data

To begin to incorporate Tanzania into the model, coordinates for locations where colonies have been established in the country, dates and the colony status were collated (Appendix 2a). Given that the output of the model includes predictions for southern and central Tanzania up to 6 degrees S, i.e. approximately as far north as Dodoma, it has been possible to validate the model using Tanzanian data for the first time (see Appendix 2a). Outputs from the model for the years 2002 to 2009 were available from websites and unpublished data (Table 3.5). The model output shows red for 0.25 x 0.25 degree squares where *Q. quelea lathamii* colonies are predicted to be possible (see Figure 3.3) and, in northern areas, dark red where breeding by *Q. q. aethiopica* might be possible. As described above and by Cheke *et al*. (2007) it also shows, for *Q. q. lathamii* white in squares where the first rainfall threshold has not been exceeded, green for when it has and finally yellow when more than 6 weeks have elapsed since the square first became red, i.e. breeding remains possible but is less likely. From the data in Appendix 2a, 44 colonies in Tanzania were recorded at sites and dates covered by the forecasting periods (Table 3.5). Table 3.6 gives details of which colour square they were found in, when the colonies would have been first established based on information on presence of eggs or young of various ages. For the first three seasons the results were excellent with all colonies occurring at locations predicted as suitable for quelea breeding by the model. However, in later years and especially in 2007-2008 the results were poor or very poor. Overall, 66% of colonies were in places predicted as suitable.

Obtaining information at the right time on the location and onset of breeding activities of quelea is important for effective management of these pests. Information on the exceeding of thresholds of rainfall is necessary for ascertaining (a) when grass seed has germinated, initiating the “early rains migration” by the birds out of their dry season quarters (Meinzingen, 1993; Cheke, 2003) and (b) when sufficient rain has fallen to allow breeding by quelea to start.

The normal early rains in Tanzania start in November in southern and central regions of the country. These rains are needed to cause sufficient widespread germination of grass seeds important for determining quelea migrations and allowing the birds to begin breeding. Thus, the availability of preferred food sources for quelea allow them to move in from elsewhere to these regions. This migration is believed to move from Somalia to northern Tanzania in November/December (Elliott, 1990). The first breeding colonies are normally located in southern and central regions from the end of February and early March (see Appendix 4a&b). Given this information and knowledge of recent rainfall patterns, quelea movements can be predictable and possible to forecast.

Using the ‘rainfall-migration model’ that was first proposed by Ward (1971), it is possible to predict where and when populations of the southern Africa subspecies of Red-billed Quelea *Q. q. lathamii* might breed and which regions they may expect to avoid (Cheke *et al*., 2007).

Cheke *et al*. (2007) tested the rainfall-migration hypothesis and showed that it is possible to model the birds' breeding activities using information on rainfall alone. They devised a computer model using spatio-temporal information obtained from satellite imagery. This forecast model was intended to be used within the Southern African Development Community (SADC) to target pre-emptive control operations against quelea breeding colonies more effectively. As was stated in Chapter 3.5, the model was for forecasting outbreaks of *Q. q. lathamii* in southern Africa, but not for *Q. q. intermedia* in Tanzania. However, the model's output included the continental area between 5ºS and 35ºS latitude and 11ºE and 41 º E longitudes, i.e. parts of the geographical breeding range of *Q. q. intermedia* in southern and central regions of Tanzania (see Appendix 4a&b).

Some of these colonies reported in Appendix 4 occurred too far north for any predictions from the model and others were found at times (e.g. August) long after the forecasting for the southern subspecies had ceased for their season. However, 44 colonies were reported from times and places covered by the model's output. For the first three seasons that could be analysed (2002-2003, 2003-2004 and 2004-2005) all of the colonies were found in places where the model forecasted that the areas would have been suitable for quelea breeding. For these same three seasons Cheke *et al*. (2007) also had high success rates (>85% correct in all seasons) for *Q. q. lathamii*. Results in Tanzania for 2005-2006 and 2006-2007 were also good, but thereafter few of the colonies were found in areas predicted as suitable (Table 3.6). Reasons for these later failures are unclear. Perhaps *Q. q. aethiopica* needs less rainfall than *Q. q. lathamii* for successful breeding or it is forced to breed in sub-optimal conditions when the rains are late, as happened in the Dodoma area in both 2007-2008 and 2008-2009.

Therefore, for effective forecasting using this model in Tanzania more precise validations and more research are needed to be able to report for Tanzania as was concluded by Cheke *et al*. (2007) for *Q. q. lathamii* who wrote that 'We are confident, however, that even in its present simple form and without real-time information on the activities of the birds themselves, this model is capable of providing useful forecasts. It shows, uniquely for any African bird species, where Red-billed Queleas most probably will not breed in a given year, and will enable quelea control teams to focus their attention on breeding areas most likely to be colonized by the birds if they are near to vulnerable croplands. This capability may be invaluable when allocating limited time and resources to control operations'.

Table 3.5. Sources of forecast data used for validating the quelea forecasting model with Tanzanian data on dates and locations of breeding by *Q. q. aethiopica* taken from Appendix 2a.

2002-2003 (8 Sept 2002 to 4 May 2003)

http://www.nri.org/quelea/arc2002-3/index.htm

2003-2004 (7 Sept 2003 to 25 April 2004)

http://www.nri.org/quelea/arc2003-4/index.htm

2004-2005 (5 Sept 2004 to 24 April 2005)

http://www.nri.org/quelea/Weeks.htm

2005-2006 (11 Sept 2005 to 16 April 2006)

NRI unpublished data (R. A. Cheke, pers. comm.)

2006-2007 (10 Sept 2006 to 9 April 2007)

NRI unpublished data (R. A. Cheke, pers. comm.)

2007-2008 (9 Sept 2007 to 20 April 2008)

http://www.sadc.int/fanr/aims/rrsu/quel/2007-2008/weeks.htm

2008-2009 (7 Sept 2008 to 12 April 2009)

http://www.sadc.int/fanr/aims/rrsu/quel/weeks.htm

Table 3.6. Numbers of breeding colonies of *Q. q. aethiopica* reported in Tanzania within the zones and periods for which predictions from the model were available and the colours of the 0.25 x 0.25 degree squares in which they were found. Dark green: season has started, 60mm rainfall threshold exceeded; Dark red: breeding possible as 6 or more weeks have elapsed since the 60mm rainfall threshold was exceeded and >240mm of additional rain has fallen; Khaki: 6 or more weeks have elapsed since the square became suitable for breeding (dark red). * colony in dark green square but neighbouring a red one (i.e. a "near miss"). ** 2 colonies in dark green squares but adjoining dark red ones (i.e. two "near misses").

Season	Colour of square in model output			
	Dark Green	Dark Red	Khaki	% correctly forecasted
2002-2003		2	3	100
2003-2004			6	100
2004-2005		6	2	100
2005-2006	1 *	7		87
2006-2007	2 **		2	50
2007-2008	7 **			0
2008-2009	5		1	17
Total	15	15	14	66

CHAPTER FOUR

INVESTIGATIONS OF STAKEHOLDERS' KNOWLEDGE AND NEEDS REGARDING QUELEA TRAPPING AND USE OF QUELEA AS FOOD

4.1. Introduction

The research questions posed in section 1.5 enabled consideration of the type of information to be elicited and thus define an appropriate methodology (Creswell, 2003; Punch, 2000). This chapter discusses the choice of methods made for the research to obtain information and data.

The objective sought to understand the people's practical experience and opinions of trapping and processing of quelea meat technologies, what they see as the benefits and draw-backs of these technologies and how they interact with their community and impact on the people and processes. The research process aims to gather information and / or data from which ideas are induced (Easterby-Smith *et al.*, 2002) and tested with qualitative and quantitative methods.

The initial literature review has, through investigating mass-trapping methods, revealed a significant number of factors which could play prominent roles in the quelea control strategy. These factors generated research questions which in turn could be translated into a series of questions which could be measured via a questionnaire.

This chapter provides details of the research design, i.e. specifically how the information was obtained. The study applied a mixed methods approach (Creswell, 2003; Babbie, 1997; Johnson, *et al*., 2007) to explore the views of key stakeholders on quelea mass-trapping and the use of the birds as a food source and for income generation. Adolph (1999), Ellis (2000) and Sabates–Wheeler (2002) have used similar mixed method approaches to investigate stakeholders' participation in natural resource management in India and sustainable livelihood analysis in eastern Africa. This can also be possible when dealing with a poorly understood phenomenon like quelea mass-trapping technology (Rocheleau, *et al*., 1988**;** Edmondson and McManus, 2007).

In the choices made for methods of inquiry, the chapter commences in section 4.2 with methods used to gather information on the knowledge of mass-trapping and use of quelea as a food source and income generation from the stakeholders. Section 4.3 depicts the results obtained. The chapter ends in section 4.5 with the discussion.

4.2. Methods used in collecting information. Knowledge of mass-trapping and use of quelea as a food source and income generation

Before starting the research, various possibilities for catching quelea with different methods and under varying circumstances were evaluated and discussed in a workshop and meetings with various stakeholders. Walk-in traps made of chicken wire, large cage traps, basket traps with live quelea or food baits, mist-nets, sticky traps and very large funnel traps, roost traps and other methods used to capture free-flying birds were discussed. Different ways in which quelea were prepared for food and possibilities for long-term storage such as drying and pickling were also discussed. Literature reviews (e.g. Bub, 1991) and consultations with people (e.g. C.C.H. Elliott and E. Bashir) who have observed and even worked on quelea trapping were conducted. Questionnaires were used to collect information as shown in Appendix 1 (Oppenheim, 1992).

The field work on mass-trapping was started using methods which were considered to be possible for Tanzanian conditions. After conducting quelea trapping, trapping methods, processing and preservation of quelea meat were demonstrated, for two consecutive years, at the national Farmers' Show conducted in the Dodoma region during the study period.

4.2.1. Workshop

A workshop and training course on "Environmental impact assessment of quelea control", at which various mass-trapping methods for birds and use of quelea as a food source were discussed, was held from 4-8 June 2007 at the Impala Hotel, Arusha, Tanzania. The course was facilitated by R.A. Cheke and C.C.H. Elliott. Eighteen members of staff of the Plant Health Services, Ministry of Agriculture, Food Security and Co-operatives, from zonal offices and one representative from the Department of Resource Assessment, University of Dar-es-Salaam, attended.

The purpose of the workshop was to sensitize the participants to the objectives of the research, identify the various stakeholders in quelea mass-capture and also seek their views for incorporation into the Government policy as at that time it was illegal to trap birds without permission from the Ministry of Natural Resources. Also the policy on aerial spraying was discussed. Environmental Impact Assessment (EIA) is now a requirement for any undertaking in Tanzania that affects the environment under Section 81 (1) of the Environmental Management Act No. 20 of 2004 which came into effect in July 2005. Aerial spraying, including against quelea, requires an EIA to be conducted as stipulated under Schedule 3 of the Act. Trapping methods possible for Tanzanian conditions were proposed, including big nets modelled on the Tunisian/Funnel trap, a roost trap, locally made mist nets and traditional baskets (the use of replicas of which was proposed). Lastly a questionnaire was given to them and the results are summarized in Appendix 1.A.

4.2.2 Meetings

Meetings with stakeholders (farmers, trappers, users and government officials) in the study area were conducted. Objectives of the research were introduced. The research was shown to be interesting to all the stakeholders as none was being undertaken on the topic. Farmers, trappers and users were interviewed through a questionnaire (Appendix 1 b, c & d).

It was observed that in the study area, bird trapping has been done for at least 50 years, and, in parts of the Kondoa district, was said to have been done over 100 years ago, hence Kondoa and its environs was suitable for investigations on mass-trapping, especially as the trappers there have been trapping birds as a source of food and for income generation. Although birds have been destroying their crops, the trapping was not done to reduce the population, but to provide a resource. During the interviews (Appendix 1), one person, aged 65 years, said he got most of his school requirements from selling trapped quelea. His father was one of the trappers. The traditional way of trapping birds using baskets woven from grasses (*Cynodon* spp.) was used.

4.2.3. Farmers' Show

The Farmers' show, the *Nane-nane* Shows, were initially a brainchild of the Arusha-based, Tanganyika Farmers Association (TFA) which started to organize the event in the late 1980s. Later the Zonal chapter for the Tanzania Agriculture Society (TASO) took over the show after establishment of the TASO grounds in different zones, which went into operation for the first time in 1995.

In 2000 the Government decided that the *Nane-nane* Show should rotate among the country's zones. The show is normally attended by large- and small-scale farmers from Tanzania, Kenya and Uganda and beyond, and is organized at National level. Agricultural experts, institutions and farmers' groups use the gathering to demonstrate the use of simple technology and modern farming in transforming agriculture and increasing food security.

The event took in a large number of people from various economic sectors ranging from thousands of rural small-scale farmers from many parts of the country, business people, industry representatives and high ranking officials from both Non-Government Organizations and Government officiated agencies including Ministries, some of which were also exhibiting. School children and college students also attended in great numbers.

The show demonstrated some findings of the research as well as the possible processing and preservation methods of quelea meat. People were allowed to taste and rank the cooking methods from the best to the least. Questionnaires were distributed to get their views (see Appendix 1. e)

4.3. Results

The results obtained during the workshop and interviews are summarized in Appendix 1.

4.4. Discussion

From the investigations it was found that people in areas affected by quelea are willing to do quelea trapping as well as use quelea as a food resource and for income generation. The results showed that the introduction or expansion of quelea trapping and consumption among people, and others who do not traditionally trap and eat quelea can motivate them to continue trapping and eating quelea. This was also publicised during the national Farmers' Show in Dodoma for two years running. Processed and preserved quelea were made available for tasting, which many people were eager to do. People who did not, traditionally, eat quelea, also ate them and everyone who ate quelea liked them.

This was indicated by the eagerness of people to get more than what was given to them for tasting.

The availability of chicks in many colonies raises a number of questions about their potential as a food source and for income generation. It was observed that if a large quantity of quelea can be harvested or trapped then there is a need for effective processing and preservation methods.

After the Farmers' shows many people showed their interest in getting quelea as a potential food source for both humans and animals, if possible. It was proposed to be used in the diets of specific groups of people such as children, the sick and old people. Quelea can also be used as an important component in animal feed especially for chickens if trapped in large enough quantities to exceed immediate human requirements. This needs further investigation. The nutrient content of a milled sample of quelea analysed by Sciantec Analytical Services Ltd is shown in Appendix 4a. Also their safety for human consumption with regard to micro-organisms was analysed and is shown in Appendix 4b. Milled or minced quelea, both adults and chicks, can be used in a variety of foods like soup, sauce and mixed in foodstuffs for making snacks (Plates 4.1 and 4.2).

Plate 4.1. Milled / minced quelea for making soup or snacks.

Plate 4.2. Boiled and dried quelea birds (both adults and chicks).

CHAPTER FIVE

MASS-TRAPPING METHODS

5.1. INTRODUCTION

This chapter describes tests of different methods for the mass-trapping of quelea as a means of pest control to reduce crop damage to acceptable levels. If such methods proved to be effective, particularly at vulnerable times of the year such as the breeding season, it would reduce environmental contamination, be cheaper than aerial spraying and contribute to conservation and wildlife management. However, any quelea mass-trapping method adopted must be legal, humane and carried out with sensitivity and respect for other countryside users.

The trapping described here was carried out in close collaboration with villagers that were complaining about quelea attacking their crops. The villagers were expected to provide all necessary labour to carry out the trapping, additional to what the investigator could do. The selected villages were in areas favoured by quelea for breeding or roosting and where the birds are traditionally used as a food source and put on sale for generating income.

Various traditional methods which are used by local people were evaluated, but of these only the basket trap was tested. Other methods which have been used for killing or trapping birds worldwide were also evaluated and a few which were possible for Tanzanian conditions were tested. These included large nets of the same design as those used for catching pest birds in Tunisia (Tunisian trap, C.C.H. Elliott, pers. comm.), a modified Tunisian trap (Funnel trap), a roost trap, mist nets, wire mesh equivalents of local basket traps and harvesting chicks from nests.

The techniques were checked in different types of habitats to determine under what conditions they would work well and what difficulties would be encountered. Other factors including the acceptability to local people, costs and availability of the materials needed in local areas were also considered. In carrying out the tests, proposals were made for regulating the use of the traps strictly so that they would only be used for catching quelea and never to catch beneficial or other non-target birds. The quelea caught were provided to the villagers for food. Each trap tested is considered separately.

5.2. Field work

At the start of this study, trapping of quelea was illegal as the authorities feared that protected non-target birds would be caught as well. Also some of the trappers were involved with the cage bird trade, sometimes acting illegally, but, also, sometimes acting legally with permits. Before the research, bird trapping of any kind was prohibited partly because of the bird influenza, but largely due to the general law of protection of bird species. It was suggested by the Ministry of Agriculture to the Government that the law should give room for farmers and trappers to trap bird pests like quelea for food and income generation for poverty alleviation. Possible trapping methods suitable for Tanzanian conditions should be allowed with specified directions. During the trapping exercise other non-target birds should be released unharmed. The field work involved trapping site allocation (survey) and planning and design of trapping activity.

5.2.1. Survey

Before undertaking any trapping activity target trapping sites were identified, an important activity to locate areas where quelea were breeding, roosting, drinking or feeding. The simplest and the most reliable way to locate and identify quelea flocks for trapping is on foot, when each flock can be checked clearly (Ndege, 2007).

Necessary information is collected in order to assess the quelea situation, and then trapping activities can be initiated with the most suitable trapping method. Sometimes quelea can roost or breed in areas which are inaccessible, e.g. dense thorn bushes or water-logged areas where a certain trapping method may not be feasible.

5.2.2. Planning and design of trapping activity

The trapping activity was conducted at suitable times of the year, in trapping sites suitable for the type of the trap to be used. The trapping was done at various sites including breeding colonies, night roosts, drinking sites, feeding places and threshing grounds.

5.2.2.1. Planning

The big nets, the Tunisian/Funnel type were planned to be used in both breeding and roosting sites depending on the availability and time planned. The roost trap was planned to be used only for roosting birds in grassy vegetation. This was to avoid thorny vegetation which can easily damage nets.

The locally made mist nets were planned to be used in various trapping sites like breeding, roosting, drinking and feeding sites including threshing grounds.

The traditional trap and its replicas were planned to be used only at drinking sites in the dry season when drinking sites are limited to allow quelea to concentrate in a few areas. During the rainy season water is available in many places which might make trapping difficult and hence affect the results.

With chick harvesting, it was planned to provide local people with iron hooked bars to observe how many birds they can collect in 6 hours. Local people were using hooked sticks or felling trees to collect chicks.

5.2.2.2. Design

Where both grass-made basket traps and wire-mesh version replicas were used, they were randomly mixed. But the grass-made ones were also tested alone to observe their efficiency.

For chick harvesting, it was planned to involve 15 local people selected randomly from the group of people involved in chick harvesting at various sites.

5.3. TRAPPING METHODS TESTED

5.3.1. The "Tunisian" trap

5.3.1.1. Introduction

In 2000, C.C.H. Elliott (pers. comm.) participated in two catches of starlings *Sturnus vulgaris* carried out by professional Tunisian trappers. One catch had yielded 15,000 birds, the other 3,000. The starlings roosted in eucalyptus trees through which the trappers could walk at night after the moon had set and the night was darkest, using minimal torch light. Minimal noise was used and the birds were quietly chivvied into the trap. The trap was funnel-shaped, about 25m across its mouth and 8-10m high. The funnel narrowed into a tube about 1m in diameter and 8m long. The birds were chased into the tube, the trap end of which was then closed off. The captured birds were shaken out of the tube into sacks and were killed by asphyxiation.

5.3.1.2. Materials and Methods

The version of the Tunisian trap used in this study was constructed on 10-11 June 2007 at the Plant Health Services' ground in Arusha. The trap was constructed from a big plastic net and the design was similar to nets used for mass-trapping of Red-winged Blackbirds *Agelaius phoeniceus* and Starlings *S. vulgaris* in the United States of America (Seubert, 1963; Mitchell, 1963) and Starlings in Tunisia (C. C. H. Elliott, pers. comm.). A "shade netting" plastic material used for shading crops was utilised. The net had a small mesh (about 0.5cm across) and was black rather than the orange colour of the Tunisian net. The netting material used was taken from a ream 100m long and 4m wide. The trap was constructed by joining 6 pieces cut from the main ream of netting material. The pieces had different dimensions. One piece was 25m long and 4m wide. Five pieces 10m long and 4m wide were also used. The five pieces were joined at their narrow ends to the 25m long piece along its length (Fig. 5.1, Plates 5.1. & 5.2). Then the five pieces were also joined together, but not straight along their lengths. Rather they were sewn overlapping so that a funnel shape would result when the net was erected. When joining the five pieces to the 25 x 4m pieces a distance 2.5m long was left on each side.

Figure 5.1. Diagram showing how six pieces of netting were joined to make the Tunisian trap. The diagram shows the layout before the five pieces were overlapped to form the funnel.

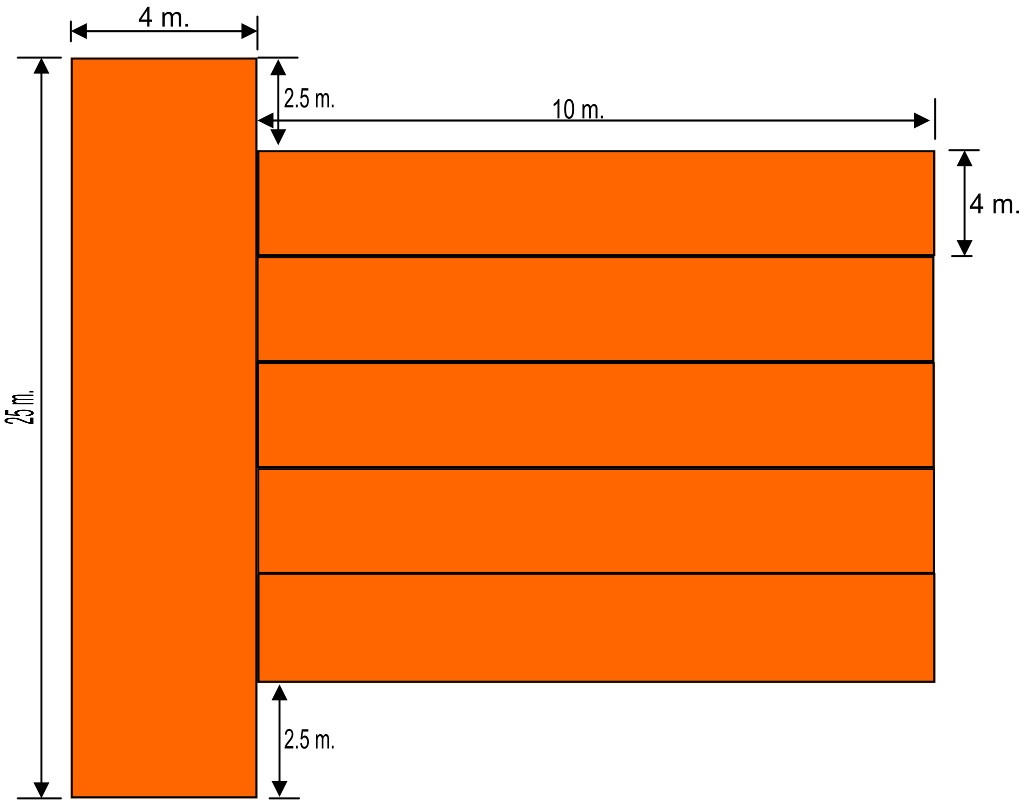


Plate 5.1. Preparation of pieces of the netting material (Photo: R. A. Cheke).

Plate 5.2. Joining of the five pieces to the 25m x 4m piece. (Photo: R. A. Cheke)

When erecting the trap, it was supported at its mouth with two cast-iron poles 9m in height and 3.75 cm in diameter. Each pole was supported by three lengths of nylon ropes 4mm in diameter and 20m long from the top to stakes driven into the ground to secure the poles. The shape of the erected trap is illustrated in Plate 5.3. The completed erected net cost about Tshs 1,110,000.

The erected trap was funnel-shaped, about 22m across its mouth and 9m high. A tube-like tunnel was made from the remaining piece of the netting material. This was attached at the opposite end to its mouth, which was reduced to about 10m in width. The tube was 9m long and 1m in diameter which was attached at the bottom for catching the birds to be chivvied into that end. The tube-like tunnel acted as a decoy escape route for the birds that entered the trap looking for a way out. The birds were collected at the closed end of the tube furthest from the main net’s entrance.

The trap was so big that it needed clear ground to be erected. If erected at a proper place for the birds to fly towards the mouth, clearing of the vegetation was inevitably needed. The clearing did not disturb the birds as only grasses and sometimes a few trees which were in the site had to be removed where necessary. The whole process of erecting the trap was very laborious and needed more than ten people. Some people were lifting and holding the poles while others pulled the ropes joined to the baffles and tightened to the stakes in the ground. The whole process of erecting the net with 10 people took about one hour.

Plate 5.3. The “Tunisian” trap erected in *Typha* sp. grass.

The Tunisian-style trap was tested for capturing quelea three times in 2007. The net was erected and tested on two consecutive nights at a quelea roost in *Acacia* spp. bushes at 4° 24', 25.2" S, 35° 08' 8.6"E near Basuto. The first attempt was made on 13 June 2007 and the second on the following day. The roost was in thorn trees that were impossible to walk through and difficult to walk around in the dark. Attempts quietly to scare the birds towards the net seemed to cause them simply to flutter upwards in the trees and then settle down again almost in the same place.

On the night of 22 June near Kawawa village (5° 58' 12.4"S, 36° 01' 16.7"E), the third trial was conducted in a *Typha* reed bed (Plate 5.3). All three attempts involved roosting quelea, probably several tens of thousands of birds. Birds were driven into the trap 30 minutes after dark and when the birds were settled. On the third trial a head-torch shone at the tube was used. A person holding it shone into the entrance, which helped to guide the birds into it.

5.3.1.3. RESULTS

5.3.1.3.1. Tunisian trap

During the first trial, only a few birds (<10) entered the trap but they bounced out before they had entered the catching tube. The second trial also produced a zero catch because the birds, having been disturbed on the first night and again in the early morning by guards posted to look after the net, abandoned the roost. In the third trial 42 birds were caught.

5.3.1.4. Discussion on results of the Tunisian trapping attempts

The net was not successful in this study as compared to the results obtained in Tunisia for catching Starlings *S. vulgaris*. A number of factors contributed to the poor results, including the design of the trap and the trapping habitat. In Tunisia the trap was funnel-shaped, about 25m across its mouth and 8-10m high. The funnel narrowed into a tube about 1m in diameter at its end and 8m long. The birds were chased into the tube, the trap end of which was then closed off. But in the design used during this study, the net narrowed to 10m wide at the end where the funnel tube was attached. Although the tube was big enough for the birds to escape through, the net was big enough to allow birds to fly in, turn around and get back out through the mouth.

In Tunisia, the starlings roosted in eucalyptus trees through which the trappers could walk using minimal torch light. Minimal noise was used and the birds were quietly chivvied into the trap. During this study, roosts were found in thorn bush of *Acacia* spp. and *Typha* spp. The first area had dense bush of *Acacia* spp. which was difficult to penetrate for driving the birds towards the mouth of the trap. Also, the area with *Typha* spp was partially flooded in areas surrounding where the net was erected. Generally quelea choose vegetation in which to roost and breed which is dense and thorny (*Acacia* trees) or has sharp leaves (*Typha*) and / or is in flooded terrain, areas which are difficult for predators, including trappers, to penetrate.

Driving of the birds directly towards the net was not possible and it was necessary in some instances to throw sticks into the middle of the roost to frighten the birds towards the net. If better areas had been located perhaps the results would have been better. Also, the habit of quelea to leave areas after much disturbance made it difficult to achieve good results.

More trials were not possible in 2007 as the Government was carrying out bird control operations to protect crops from bird damage. Many areas with quelea were already sprayed and some were continuously being sprayed. In later years, no further opportunities to test the traps arose as other activities took precedence.

5.3.2. Funnel trap (modified Tunisian trap)

5.3.2.1. Introduction

A funnel trap, with a catching box of the type used in Heligoland traps at bird-ringing stations in Europe (Brownlow, 1952), was designed and constructed. It was also decided to add a bright lamp shining through the transparent window, in the manner employed successfully in the United States of America in winter roosts to catch Red-winged Blackbirds *A. phoeniceus*, Grackles *Quiscalus quiscula*, Starlings *S. vulgaris* and Cowbirds *Molothrus ater* (Mitchell, 1963). The so-called ‘Floodlight Trap’ caught 672,000 birds over 101 operations with the best single catch being 120,000 birds. A small version of the American floodlight trap was tested by E. A. Bashir (pers. comm. to C. C. H. Elliott) in South Africa for catching quelea, but the best catch was only 80 birds. Nevertheless Bashir felt that, with some modifications and further testing, catches of 10,000 quelea in a single operation, could be expected. Such traps are set up over places where birds collect to feed, rest and roost. The trap was a small version of a modified Tunisian trap made into a funnel shape.

Following reports to the Plant Health Services office, suitable colonies were located at Chidilo (6° 25’ 04.2” S, 35° 25’ 32.3” E) and Zejele (6° 24’ 53.0” S, 35° 24’ 34.7” E), villages in Dodoma rural district about 50 to 60km SW of Dodoma town. The areas were accessible to vehicles and were near the villages. The sites were suitable for the new trap as the trees with nests had gaps between them, which would allow erecting the trap with minimal clearing of the bush.

All the villages were near extensive areas of cultivation, mainly of millet and sorghum, which are vulnerable to quelea and it was clear that the birds were posing a threat to the crops. This had the advantage that it was thus unlikely that the quelea would abandon the place as they could easily get food for themselves and their chicks near the colony.

It was decided to do a trapping trial at Chidilo, where the site was big enough. It was spread over about 200ha and could have contained 20 to 50ha with nests. A figure often used for quelea colonies in East Africa is that each hectare containing nests can contain about 30,000 nests or 60,000 adults (Elliott, 1989). On this basis, the Chidilo colony was estimated to have contained 1.2-3.0 million quelea, which had the potential to produce 1.8-4.5 million fledglings.

5.3.2.2. Materials and Methods

A 100 x 6m knotted nylon netting material with a mesh size of 15 x 19mm was used for construction of the trap. The net was brown and merged with the background better than the “Tunisian” funnel net (C.C.H. Elliott, pers. com.). Two pieces of different sizes were joined by sewing by hand. One piece was 19m long and the other was 6.5m long (Fig. 5.2). The two pieces were joined along their lengths before the combined pieces were fashioned into a funnel-shaped net. The end of the funnel was attached to a Heligoland-type catching box with a window of transparent acrylic plastic about 50 x 60cm square, and an opening to the funnel. It had provided a hole of about 15cm in diameter, closed by a sliding shutter, and through which birds could be taken out by hand. The box was placed on a metal platform or stand 2m above the ground. The box into which the birds were expected to fall was about 60cm square (Plate 5.4).

The trap was erected supported by cast-iron poles. The poles supporting the trap were like series of soccer goal posts of different heights, and spaced at decreasing widths. The net was supported at its mouth with two poles of 6m in height and 3.75cm in diameter. To have its funnel shape, the trap was supported at its mouth with two poles 3m long, at the middle by two poles 2m long with 2.5cm diameter, 4m from the mouth, and at the catching box by 2m high poles 7m from the mouth. At the mouth, the trap was about 6.1m wide, and then converged in the middle to 2m wide and at the catching box was funnelled to being about 60cm wide.

The last two poles were fixed to the catching box which was fixed to a 2m high platform (Plate 5.5). Each pole was supported by 3 nylon ropes of 5mm diameter and 15m long each to the stake driven into the ground. When erected, the total length of the funnel was about 11m and its mouth was placed as close as possible to the edge of the quelea roost or near a tree with nests in a breeding colony. A powerful floodlight (1,000 Watts, Jones Lite with 15 million candlepower) was placed on the platform behind the catching box directed towards the roost or trees with nests, through the mouth of the trap.

Figure. 5.2. Diagram illustrating how pieces of netting material were joined to form the funnel trap.

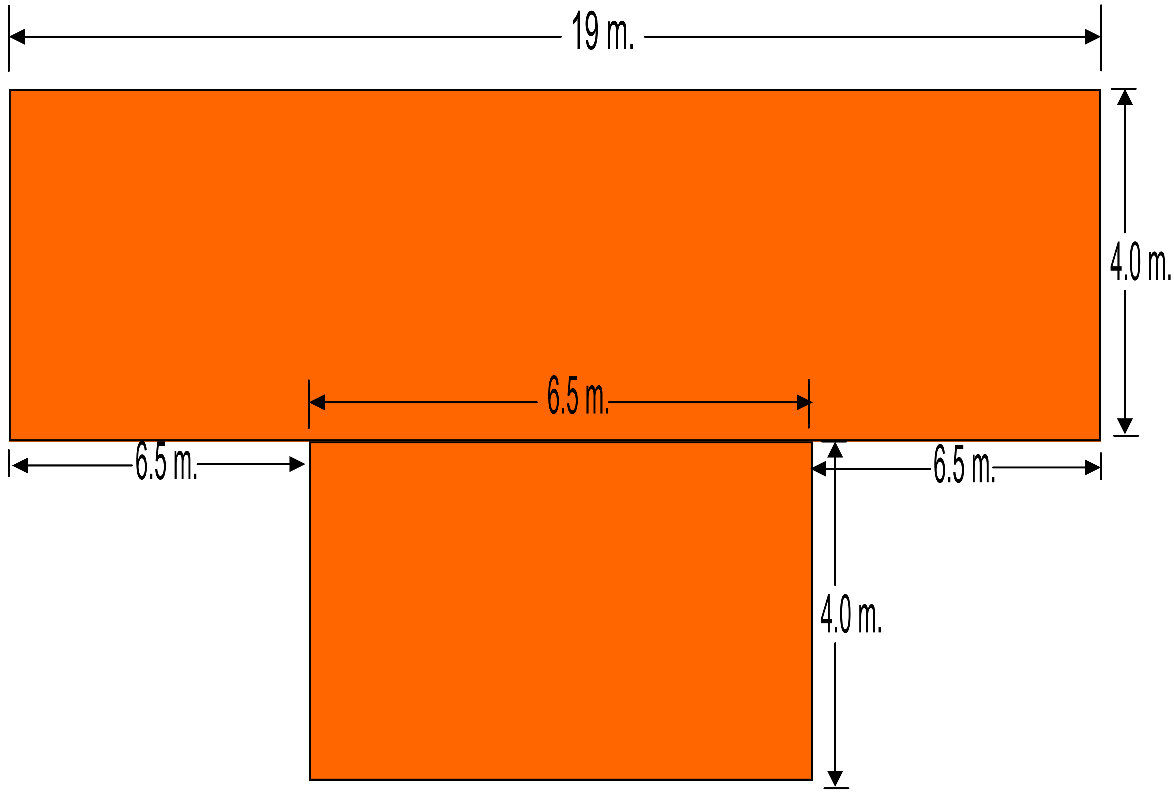


Plate 5.4. The Funnel trap in position in front of quelea nests (Photo: R. A. Cheke).

Plate 5.5. The Funnel trap, with a Heligoland trap style catching box, in the field with the floodlight in position (Photo: R. A. Cheke).

The funnel trap net and its catching box were erected near a dense concentration of quelea nests in acacia thorn trees (300 nests in the immediate vicinity) at the Chidilo colony. The completed erected net cost about Tshs 720,000 and was re-usable. The erection took about 1.5 hours with 10 people. Five trials were done after which the colony was sprayed.

Trial 1

At the first site, the net was erected by about 1630 hrs with sunset occurring at 1855 hrs on 4 March 2008. Having erected the net, the first attempt to chase birds into the net took place at 1925hrs, half an hour after sunset. Ten people were organized to make a drive of the birds towards the net, starting from about 70m away. On the blast of a whistle the drivers made various forms of noise, clapping and shouting, and hurled stones or branches into the trees. Two people were positioned concealed in the mouth of the trap, one of them equipped with a powerful torch (15 million candlepower). Their expected role was to try to chase any birds that went into the funnel into the catching box, using the lamp to frighten them. The chasing did not seem to move many of the birds very far although it was difficult to see what was happening in the dark.

Trial 2

It was decided to leave the net in place and try to drive the birds into it the following evening of 5 March 2008, but starting a little earlier than the previous night. The powerful floodlight was placed on a platform on the catching box so that its beam shone through the transparent window into the funnel trap. The drive towards the net was carried out at 1920hrs by 6 people. Two others were again concealed near the net with torches ready to chase any birds in the trap into the catching box.

Trial 3

It was thought that the first site had suffered too much disturbance for further catches and quelea adjacent to the net had abandoned their nests, but there was still plenty of activity in other parts of the colony only a few tens of metres away. On 6 March 2008 the net was moved to a new site about 300m away and re-erected near a concentration of nests. From sunset onwards many flocks of between 50 and 100 birds flew in the direction of the net. It was difficult to see where they settled. Again the floodlight was placed to shine through the catching box window into the funnel. Only four people were available for the drive towards the net which was carried out at 1920 hrs.

Trial 4

On 7 March 2008 in the afternoon the area to the south of the net site was searched for signs that it was being used as a roost. If a roost has been active for several days an accumulation of droppings occurs like a whitish carpet under the trees. Although some trees had more droppings than usual beneath them, there were no clear signs that a roost had been formed for long enough for droppings to accumulate. Possibly the roost had only recently been formed. Nevertheless it was decided to move the net to a new site next to a tree with substantial droppings under it. From dusk onwards, several flocks of 50-100 birds flew into the trees immediately in front of the trap, indicating that in addition to the birds occupying the nests in front of the trap, other birds were roosting there. The floodlight was placed on the catching box as before and turned on at 1915 hrs. At about 1920 hrs a drive of the bushes and trees by 7 people was carried out.

Trial 5

A fifth trial was conducted on the evening of 8 March 2008 when an attempt was made without use of the floodlight.

5.3.2.3. Results

Trial 1.

A total of 14 birds was caught, all of them female quelea in breeding condition. No non-target birds were caught and none were seen during the drive. It was thought that the males belonging to the nests in the immediate vicinity of the tree had left the trees to roost separately, a behaviour that has been observed before (Allan and Jackson, 1974).

Trial 2

No birds flew into the trap, giving a catch of zero.

Trial 3

Three birds were caught, all of them females in breeding plumage. While the birds were being removed from the catching box, the typical noise of a quelea roost was heard within 500m of the net site to the south.

Trial 4

Two large flocks of several hundred birds were seen to swerve away from the entrance to the funnel, missing the net by a few metres. Only six birds flew into the catching box, of which three were male and three female.

Trial 5

After a whistle was blown at 1920hrs and the beating team of 4 people moved towards the trap, observers positioned near its entrance saw about 30 quelea fly into the netted area, but without light they seemed not to perceive the "exit" at the end. When a light was then shone at the exit to illuminate the birds' path into the catching box, this proved to be counter-productive as the birds were dazzled, turned around and flew back towards the light and thence out of the trap. Nine quelea were caught (7 males and 2 females).

5.2.2.4. Discussion

Although the floodlight traps in America and South Africa were used in roosts (Mitchell, 1964), it was decided to test the trap in breeding colonies of quelea. This was mainly because colonies were available in the study area. Normally in March every year, quelea breed in the Dodoma region. Although there were roosts reported, the one roost visited was found to have too few birds to make it suitable for a trial.

The advantage of working in breeding colonies was two-fold: first, nests would be less likely to be abandoned because of netting trials than roost sites, and, second, that as a crop protection target, the colonies represented a serious threat to nearby crops. Several other breeding colonies which were reported to the Plant Health Services (PHS) office were visited; two sites were at Mwitikila and one at Chunyu in Dodoma rural. When reached, these sites were rejected as suitable trial sites for various reasons. Firstly, it was found that the birds were in the process of abandoning the place due to a lot of disturbance from local people. Secondly, the trees at the site were considered to be too high for the trap. Thirdly, the area was not accessible to vehicles and the vegetation was very dense thorn bush. Some rivers which were crossing the Chunyu site were flooded and the site was very far from the village. Thus it would have been very difficult to get local people to help in different activities involved in the quelea trapping. These activities include erecting the trap, carrying the net and other materials, clearing the site and driving the birds towards the trap.

Although the Chidilo site was good for the trials, the results were not good. The reasons may include the following:

- It appeared that placing the floodlight behind the transparent window of the catching box had the effect of showing the birds where the net was. Once the birds were close to the catching box, they appeared to be dazzled by the floodlight, but when they were further away it did not seem to cause them to fly into the trap. Birds were flying away from the trap into the nearer vegetation illuminated by the light. It seems that the behaviour of quelea is substantially different from the behaviour of starlings as caught successfully in the Tunisian trap and of starlings / blackbirds / cowbirds caught in the American trap. This behaviour was not expected, thus more studies with quelea are needed. Both field and aviary studies need to be carried out to investigate the effect of light on quelea.

- Unlike starlings in Tunisia which roosted in eucalyptus and which moved away from danger by fluttering away, quelea in the dark seemed to flutter only up and down within the thorn trees and move the minimum distance. This makes them difficult to chivvy into the trap in big numbers when driven towards it.

- On the 5^{th} day of the trial it was raining before getting to the site. It then transpired that one reason that the birds had failed to see the "exit" was that rain earlier during the day had led to the clear plexi-glass becoming "steamed-up" with rain drops rendering it opaque. Without this misfortune it is possible that more birds would have been caught.

5.3.3. Traditional basket traps

5.3.3.1. Introduction

On 16 June 2007 the town of Kelema (05° 06' 36.3"S, 35° 49' 25.3"E), about 35 km south of Kondoa, was visited to interview people who catch quelea there for food, using traditional methods. At the village there were both Ward (constitutes several villages) and village officials. Thomas Mazai, the Ward executive officer, the Chairman of the village and 21 villagers including trappers were interviewed at a meeting using a questionnaire (Appendix 1). A bowl of about 100 quelea prepared as food was presented at the meeting. This belonged to the retailers who buy trapped quelea from the trappers and prepare them for selling. It was reported that more than five people sell prepared quelea at the centre of the village every day during quelea outbreaks. It was also reported that people throughout Kelema Ward, consisting of about 15,000 people in six villages within 950 km^2, ate quelea. Birds were usually sold in triplicate for 100 Tanzanian Shillings (about 4p), but at the end of the season, or when Rift Valley fever outbreaks prevented the slaughter of cattle, the price could rise to 50 TSh per bird.

The main trapping technique employed utilised torus-shaped baskets woven from star grass *Cynodon nlemfuensis*. Traditional basket traps are increasingly becoming very popular among the trappers in Dodoma region. The traps have been used by farmers and trappers in Kondoa district, Dodoma region, for more than 60 years. Thus they are common, well known and acceptable in the area. Substantial numbers of quelea have been trapped for years. It was reported at the meeting by a Ward Executive officer that a trapper deploys 5-10 traps from which 500-1000 birds can be caught per day. Quelea were used as a food source and for income generation.

Trapping was done at Pongai village, Kondoa district. The site was a traditional drinking site for quelea in a location with a river running through it, leaving stagnant water. Fortunately, in the dry season these places retain water for a long time, sometimes until as late as the early rains. The sites were near a site where quelea were roosting beside a river about 2-3km from the trapping sites. The roosting places had thick vegetation mixed with reeds, ideal for quelea roosting.

The trapping was planned to be used only at drinking sites in the dry season when drinking sites are limited to allow quelea to concentrate in a few areas. During the rainy season water is available in many places which might make trapping difficult and hence affect the results. Two trials were conducted, one using traditional baskets alone and the second by mixing the traditional and the wire mesh versions.

5.3.3.2. Materials and Methods

Trials were conducted using the improved traditional baskets (wire mesh version, see below) and the traditional type. Fifteen wire-mesh baskets were made; five with each of one, two or three inlet openings. These were tested in comparison with each other and with the grass-made traps. Removing of trapped birds was carried out after every hour to observe the most effective time to do trapping.

The torus-shaped traps, both the traditional and improved versions, were made in the same shape and size. The basket traps are about 60cm in diameter, 20cm deep, 2m in circumference and with two central holes, one hole on top and another hole on the bottom (Plate 5.6). During the research period one grass made trap was costing Tshs 4,000. The improved version was made of white-coated aluminium wire-mesh, with mesh size of 1cm square. They were non-reflecting and some were made with more holes on top (one, two or three) than the basket versions (Plate 5.7). A complete trap was costing about Tshs 7,000. The top holes were 5cm in diameter and tapering inwards, serving as the entrances for the birds but out of which they have difficulty escaping. The bigger hole, 15cm in diameter on the bottom, served as a removal hole through which birds could be taken by hand. The holes underneath the trap were blocked with bulrush panicles which also acted as bait. The first birds to get into the trap are attracted by bait not by a decoy bird. Usually a bird in a trap makes a noise which attracts other birds that, perhaps, assume that its presence indicates a likelihood of food or drinking water being available.

Where cereal panicles are used, undeveloped or damaged panicles are placed on top of the trap while the developed ones are placed inside the trap. The damaged panicles are used to attract birds. When reaching the trap they will find no seeds on the top panicle while those inside the trap have seeds. The birds will easily find the small entrance hole and enter for food, but have difficulty in leaving. Removing of trapped birds by hand was carried out every hour, during trapping sessions lasting from 0700hrs in the morning to 1800hrs in the evening.

The first trial was done from 21-25 July 2008 when food for quelea was available in the farms (when harvesting). The second trial was done from 3-15 September 2008 (to allow participation at the farmers' show in August) after harvesting.

The design of the experiment with traps was as follows:

(i) 5 grass baskets were compared with 5 baskets made of wire-mesh all of them with single inlet holes.

(ii) 5 grass baskets with one hole each were compared with 5 baskets made of wire-mesh with two inlet holes.

(iii) 5 grass baskets with one hole each were compared with 5 baskets made of wire-mesh with three inlet holes.

(iv) A mixture of 3 grass baskets (with one hole each) were compared with 3 each of the wire-mesh baskets with 1, 2 or 3 inlet holes.

As food for quelea was not available near the trapping site, food was provided to attract them not to go very far to search of it. 200 kgs of bulrush millet was bought and used to feed the birds during the trapping period together with un-threshed panicles of bulrush millet for placing in the traps as bait. The bulrush millet was distributed about 100m from the trapping areas for the whole trapping period. This encouraged the birds to feed near the trapping areas and catching was thus easier.

5.3.3.3. Results

Trial 1.

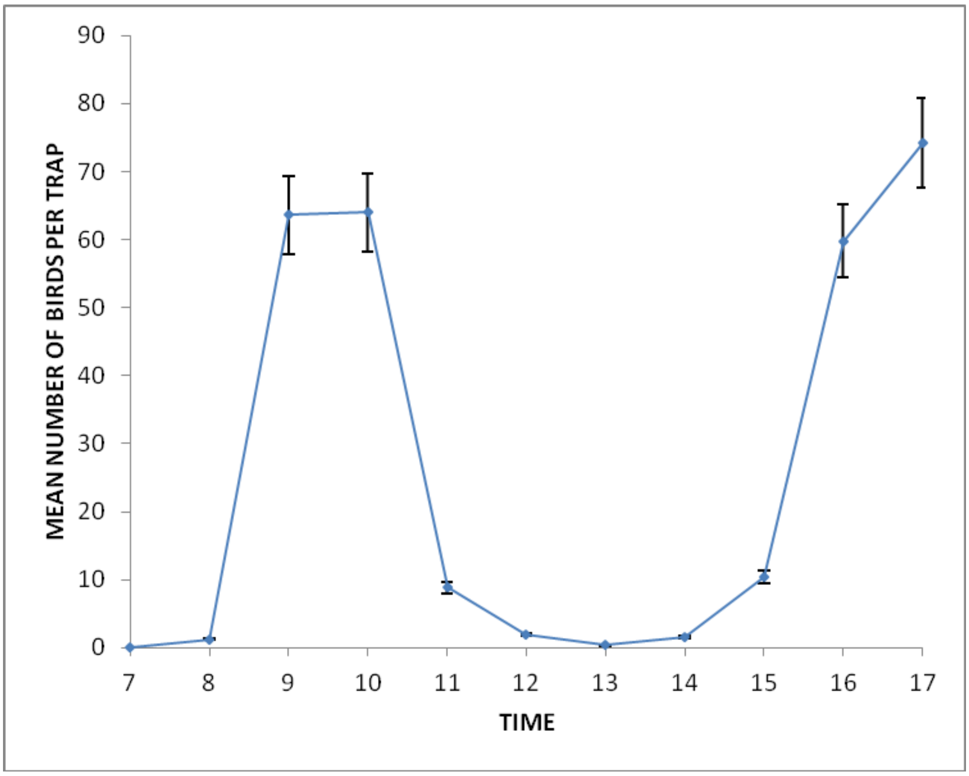
A total of 35,766 birds was caught at a rate of 285.9 birds / trap / day. Fig. 5.3 shows means of the data plotted according to time of capture. There was a clear temporal trend with more birds caught in the mornings between 0900 and 1100 and in the evenings between 1600 and 1800 than during other times of the day. The differences between catches at the various times was highly significant when tested using a Friedman non-parametric repeated measures analysis of variance (ANOVA), with the data analysed being the total catches for each time category for each trap over the 5-day period (Friedman chi-squared = 228.98, df = 10, p-value < $2.2e^{-16}$).

Plate 5.6. Traditional torus-shaped traps made from grass at a trapping site, placed at a *Quelea* drinking site.

Plate 5.7. Improved basket trap made from wire mesh (Photo: R. A. Cheke).

Plate 5.8. Both traditional and wire mesh baskets at a trapping site, placed at a *Quelea* drinking site.

Figure 5.3. Mean numbers of quelea caught per trap at different times of the day during 5 days of trapping with 25 traditional basket traps at Pongai village in Kondoa district from 21-25 July 2008. Error bars are standard errors of the means. Time denoted as 7 refers to the period 0700-0800 and 8 refers to 0800-0900 etc.



Trial 2.

A total of 221,703 birds was caught (see Appendix 5. 1 - 4).

First of all, the data comparing the performances of one-holed basket traps with wire mesh equivalents with only one entrance hole were examined. From Fig. 5.4, it is clear that more birds were caught in the wire mesh traps (Statistical analyses conducted using R). The mean percentage caught in basket traps using the grand total as the denominator was 6.83 (S.E. = 0.21) while the mean percentage for the wire traps was 13.17 (S.E. = 0.21). The differences were highly significant (ANOVA; $F = 443.98$, $df = 1$, $P < 2.2e^{-16}$), using a linear model with Gaussian errors that passed tests for its applicability (Q-Q plot of residuals versus theoretical quantiles for a standard normal distribution).

Next the diurnal variation in trapping rates in the two trap types was examined. Fig. 5.5 shows the results for each trap type. Analysis of variance using the mean data over the three days for each time category from Fig. 5.3 showed highly significant effects of trap type ($F = 303.31$, $df = 1$, $P < 2.2e^{-16}$), time ($F = 178.57$, $df = 10$, $P < 2.2e^{-16}$) and the interaction between trap type and time ($F = 15.45$, $df = 10$, $P = 2.32e^{-11}$). The latter result was surprising but may be accounted for by the relatively greater proportions of birds caught in the wire traps in the 0800-0900 and 1500-1600 periods.

In the experiment with basket traps being compared with wire mesh traps with 1, 2 or 3 holes, the same diurnal variation as described above was recorded (Fig. 5.6). As with the earlier results, trap type ($F = 1821.93$, $df = 3$, $P = 2.32e^{-11}$), time ($F = 1402.08$, $df = 10$, $P = 2.32e^{-11}$) and the interaction between trap type and time ($F = 45.53$, $df = 30$, $P = 2.32e^{-11}$) were significant when tested by ANOVA using a Generalised Linear model with a quasipoisson log link.

Analysis of the results of the trials comparing basket traps with wire mesh traps with 1, 2 or 3 holes also revealed significant differences with the 3-holed wire mesh traps catching the most birds (Figs. 5.6 and 5.7). Catches of basket traps with one hole (gh1), wire mesh traps with 1 hole (w1h), 2 holes (w2h) and with 3 holes (w3h) were compared by first calculating the difference between the actual percent share of a given day's catch and the expected catch (DELTA) (with expected values set at 10% when there were 10 traps out and 8.33 when there were 12, i.e. the data were normalised for the day and for the number of traps out that day). Then the DELTA values were tested by ANOVA which revealed a significant effect of trap type ($F = 241.66$, $df = 3$, $P < 2.2e^{-16}$). Next a Tukey multiple comparisons of means test was applied to the mean DELTA values which showed, with 95% family-wise confidence intervals, that wire mesh traps with 1, 2 or 3 holes caught more birds than basket traps ($P < 0.00000001$, in each case). Furthermore wire mesh traps with 2 holes caught more than those with 1 hole ($P = 0.02$), those with 3 caught more than those with 1 hole (($P < 0.00000001$) and more than those with 2 holes ($P = 0.0000001$).

Figure 5.4 Comparison of percentages of daily total catches in traditional basket traps with one entrance hole and in wire mesh traps with one entrance hole. Data used were from 3 dates, with the grand total of catches for both basket (grass) and wire traps for each date used as the denominator for percentage catch for individual traps. The box-and-whisker plots show median (50th percentile, thick dark bar) and ranges. Upper part of box denotes upper quartile [75th percentile] and lower part of box shows lower quartile [25th percentile]) of catches of quelea in traditional basket traps averaged over 5 days and 25 traps according to time of capture.

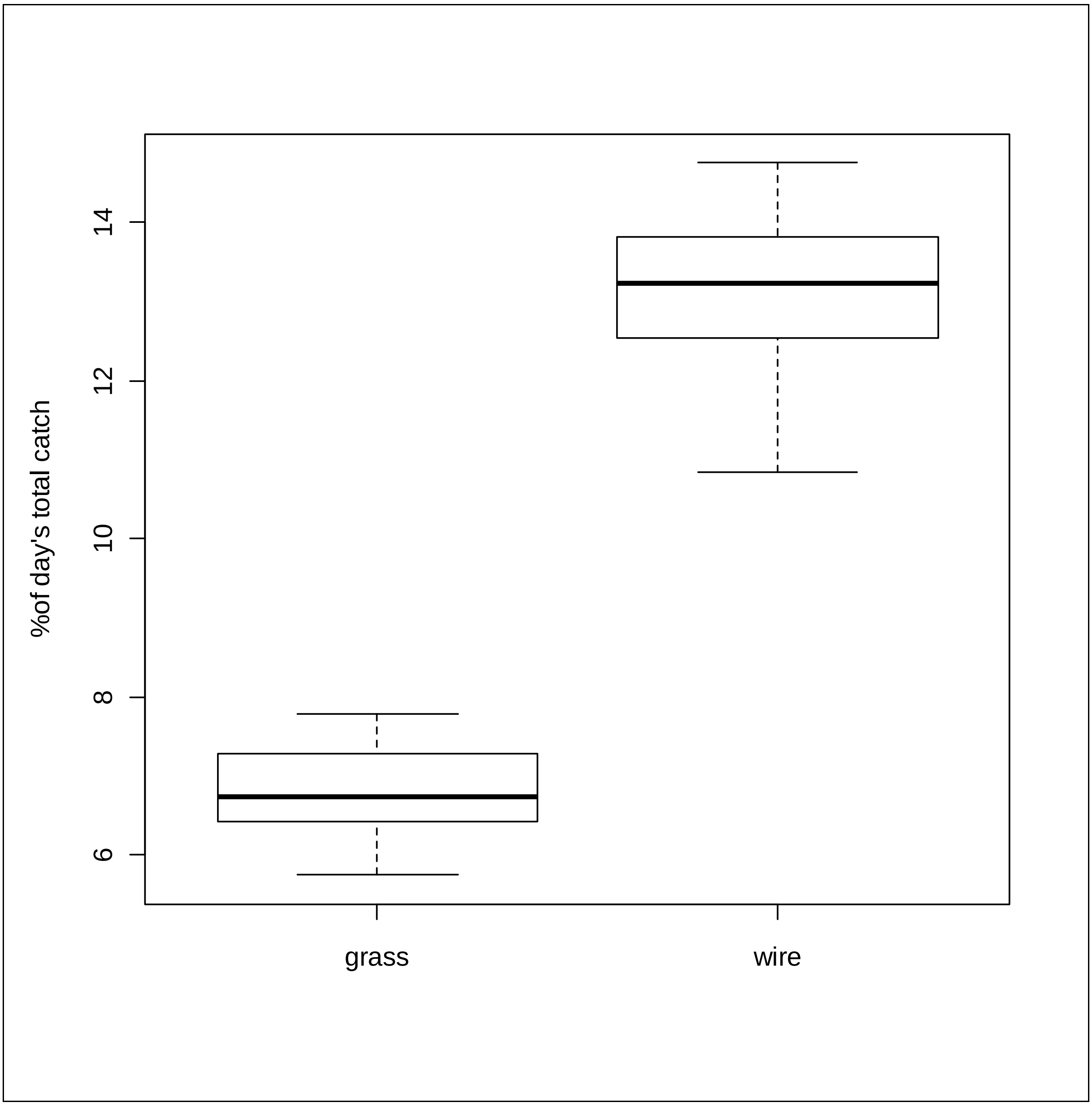


Figure 5.5 Mean percentages of total catches of quelea in basket (grass, blue bars) and wire-mesh traps (red bars), each with single entrance holes. Error bars are standard errors of the means.

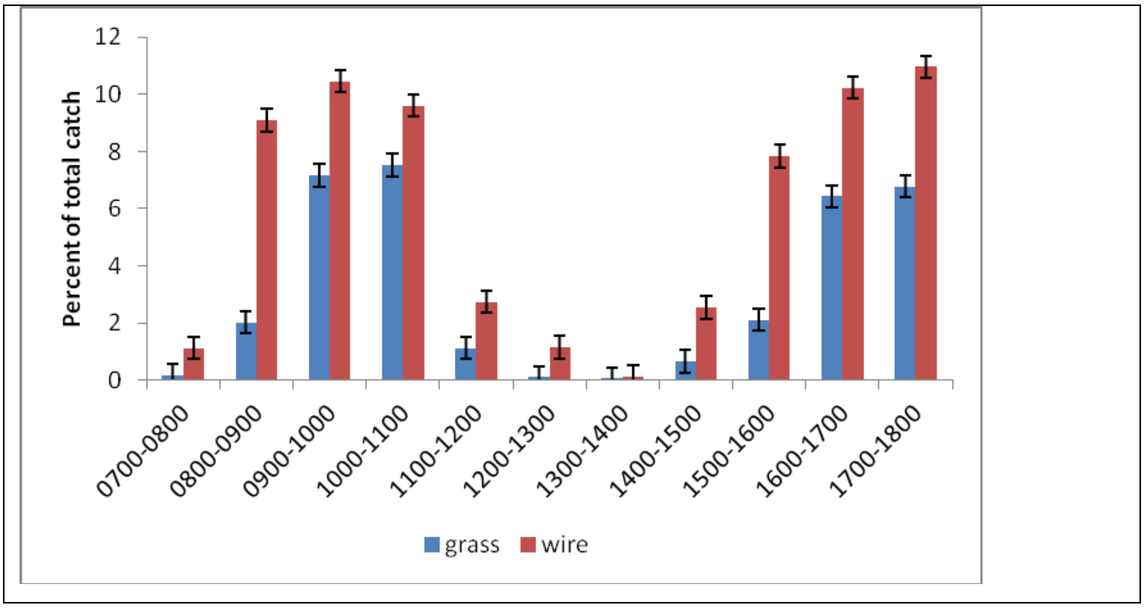


Figure 5.6. Variation with time of day in average catches in basket traps (blue lines, g1h), wire mesh traps with 1 hole (red line, w1h), wire mesh traps with 2 holes (green line, w2h) and wire mesh traps with 3 holes (grey line, w3h). Error bars denote standard errors of the mean.

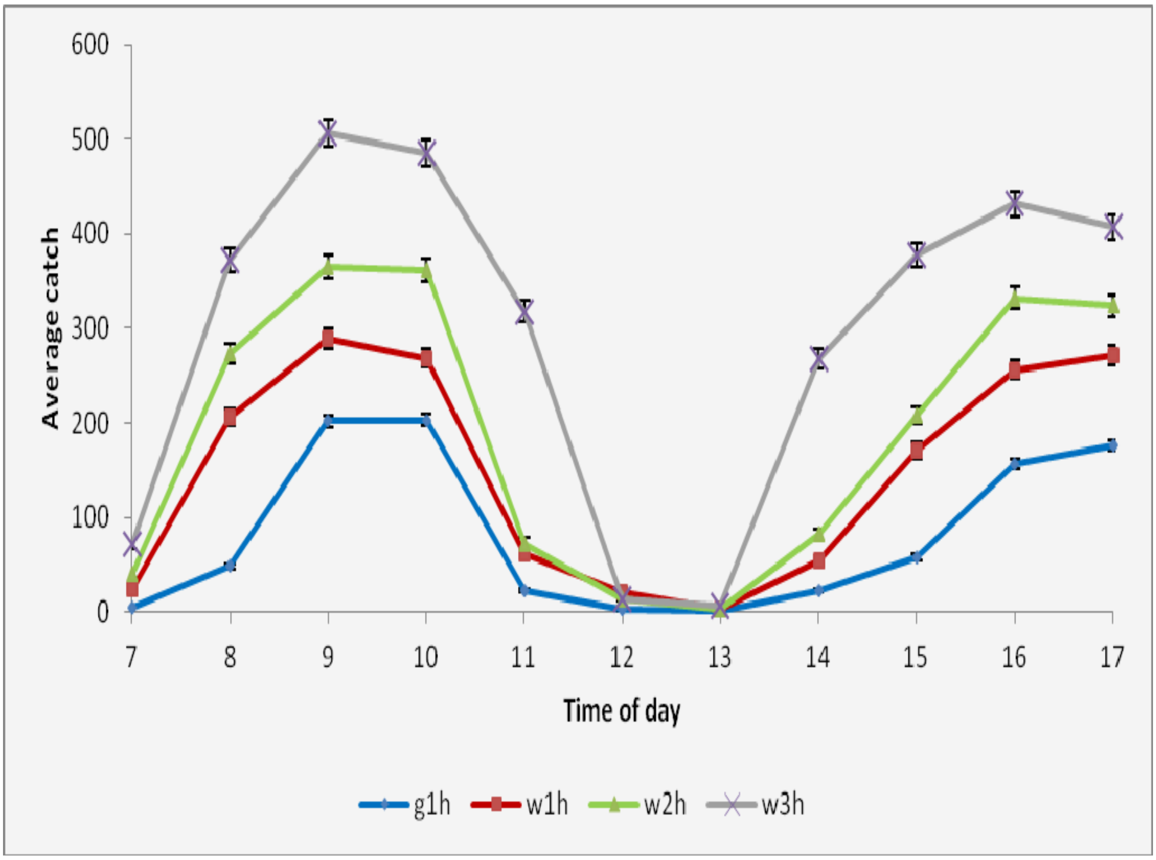
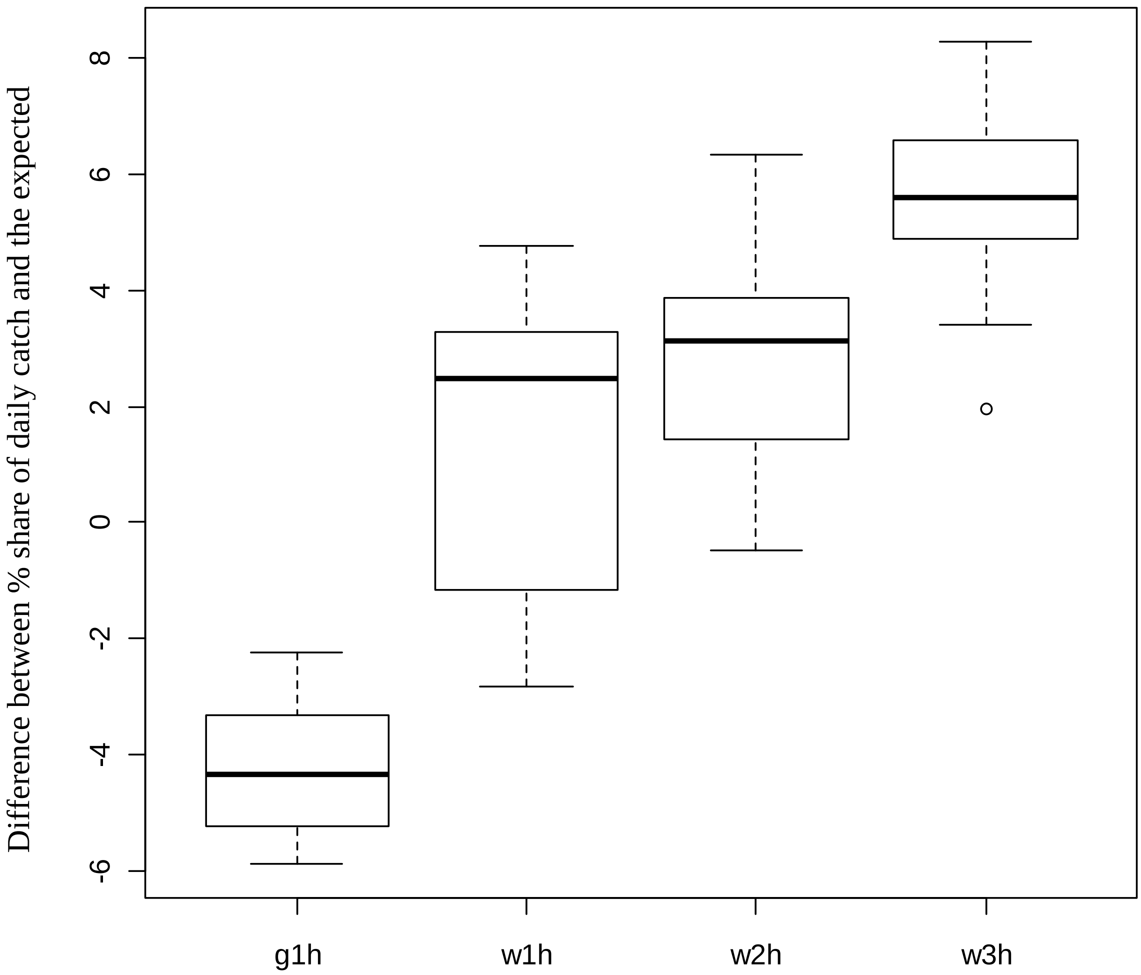


Figure 5.7. Box-and-whisker plots comparing catches of basket traps with one hole (gh1), wire mesh traps with 1 hole (w1h), 2 holes (w2h) and with 3 holes (w3h). The y axis denotes the difference between the actual percent share of a given day's catch and the expected (DELTA) (with expected values set at 10% when there were 10 traps out and 8.33 when there were 12, i.e. the data were normalised for the day and for the number of traps out that day). For explanation of box-and-whisker plots see legend for Fig. 5.4. Additionally, the whiskers give the range, unless this exceeds 1.5 times the interquartile range from the top or bottom of the box, when outlying points are shown as circles.



5.3.3.4. Discussion

Performances of the traps depended on different factors including selection of the trapping site, time, appropriate baiting and minimum disturbance at the trapping site. Open dry land habitats were suitable capture sites. Although the time for emptying was after one hour, when birds were coming in a large number for drinking, it showed that traps can be checked even before the time set. This allows taking the trapped birds out of the trap allowing for many others to enter before the bait is finished. Also it showed that traps were effective if bait was always replaced inside the trap and lightly spread around the traps.

The results showed that there were significant differences in the times of catches in the traps during the day (diurnal variation). Many birds were caught from 0900 to 1100 hours in the morning and 1600 to 1800 hours in the evening (see Figure 5.1). Also, the wire-mesh traps caught more than grass traps when each had one entrance hole (see Fig. 5.2) and successively more when they had 2 or 3 entrance holes (Figs. 5.4 and 5.5). When it is hot, quelea drink at least twice a day. They drink in the morning after feeding and in the evening before they go for a night rest (Bruggers *et al*., 1989; pers. obs.).

The results may have been affected by different factors. The optimum times for trapping quelea using basket or wire mesh traps vary depending on the weather conditions. During the rainy season or when there is cloud, trapping may be less effective as quelea may not get as thirsty as they do in hot weather. Particularly during the dry season, when food and water are less abundant or there is hot weather, birds are forming large flocks at drinking and feeding places and many birds can be caught. When trapping quelea with basket traps, the use of water as an attractant has been successfully demonstrated in different places where quelea congregate (pers. obs). Water is very important to quelea as they never spend a day without drinking water (Bruggers *et al*., 1989).

For good catches trapping sites and traps should be prepared and placed well in advance, at least one hour ahead, of the expected arrival of the birds. Traps should be placed near drinking water, and loosely covered with dry tree branches driven firmly into the ground. These help the birds to settle on them before getting into the trap. The funnel entrances of the baskets should be just wide enough to allow a quelea to pass through the opening, or push inside the opening if the material is slightly flexible; the larger the entrance, the greater the likelihood of birds escaping. Baits are very important in bird trapping. When trapping quelea it is important to bait heavily with panicles of bulrush millet, sorghum or other food inside the trap but lightly on top of the trap, using damaged or underdeveloped panicles, and around the funnel entrance to entice birds into the trap. During normal trapping regular checking of traps is very important. The traps need to be checked at least after one hour or less. The frequency of trap monitoring will depend on a number of factors including trap success, mortality due to congestion etc. The frequency should increase when many birds are being captured. There is no risk of injury or mortality to captured birds when using both of these traps, even when deployed by inexperienced trappers.

5.3.4. Roost trap for use in "trap roost" vegetation

5.3.4.1. Introduction

The concept of the "trap roost" was first developed in Zimbabwe to lure quelea to an artificially grown roost of Napier Grass *Pennisetum purpureum* where they can then be controlled (Jarvis and La Grange, 1989). The roost trap described here is derived from that idea but existing planted areas were used for the trap deployments rather than involving the deliberate planting of sugar cane *Saccharum officinurum* or Napier grass *P. purpureum* by the author specifically to catch quelea.

Quelea are selective in their choice of roost, preferring vegetation that enables them to crowd as close together as possible. A survey of 29 known roosts in Zimbabwe indicated that, provided water was close by, quelea selected dense and homogenous vegetation rather than widely spaced plants (La Grange, 1978), including stands of sugar cane or Napier fodder, vegetation in which quelea have also been found roosting in all areas of Tanzania. In northern Tanzania, farmers grow Napier grass for fodder and sugar cane for sugar processing. The birds travel more than 10km from feeding grounds to sugar cane plantations or Napier grass for roosting (pers. obs.), roosting in such habitat in preference to the natural vegetation.

In Zimbabwe, "trap roosts" were especially significant since a control method had been developed whereby roosting quelea could be sprayed by a tractor mounted with a mist-blower (La Grange and Jarvis, 1977). The "trap roosts" were much more accessible for this method of control rather than were roosts in natural reed beds. The advantage of the mist-blower method was its cheapness compared with aerial spraying operations. A second advantage of the “trap roost” was that far fewer non-target species used the same sites for roosting (La Grange and Jarvis, 1977). Therefore, control or trapping operations against quelea in those situations caused less damage to other wild birds. Due to the economic advantage resulting from cheaper control methods and the conservation advantage of these trap roosts, legislation has been mooted to encourage all small-grain farmers to plant a “trap roost” near their lands. Legislation was proposed in Zimbabwe so that farmers who did not follow this recommendation might find that they would have to carry the cost of any quelea control undertaken on their land. This gave rise to publicity about the “trap roost” concept (Jarvis and La Grange, 1989).

“Trap roosts” are intentionally planted to attract quelea into situations facilitating trapping activities. Different trapping methods can be used. Napier grass and sugar cane are probably good and are the most high-yielding of all the perennial tropical grasses. After 50 days of growth Napier grass has a digestible nutrient content of about 60% and is useful as a stock feed supplement and provides dense vegetation suitable for quelea birds to roost. Depending on the variety involved, sugar cane can have dense vegetation 120–150 days after planting, when the vegetation becomes suitable for quelea to roost in (Acland, 1971; Williams and Chew, 1980). For suitable quelea roosts, plants should be left to grow up to 2m high or more. At this height the roost has good and dense vegetation for quelea to roost in.

Typha spp. is also used by quelea for roosting. Where these plants are available and not in marshy areas they can be used as good vegetation for a “trap roost”. In Tanzania, many places where soils have been excavated for road construction hold water and become occupied by *Typha* spp., where quelea have been found roosting (pers. obs). Such places can also be maintained for quelea trapping activities.

The plan for the trap to be described was that a net was to be laid out around a small roost or part of a roost and that, when the birds had settled down for the night, the net would be rapidly pulled over the site to trap the birds within an enclosed space. The ideal dimensions for a trap to be deployed at a “trap roost” site for mass trapping of quelea birds depends on the type of netting material to be used but the ideal size is 10 x 20 m square. These dimensions will depend on the strength of the netting material (fine or coarse strand) to be used. A very important consideration is the top sheet which is used to cover the roost, which should not be very heavy. If the sheet becomes heavy then unrolling and rolling it up on top of the roost will be difficult. Light material may be necessary although this also depends on the type of vegetation and the strength of the strand. More experience using different materials is needed. Only three trials were conducted due to availability of suitable trapping sites during the study.

5.3.4.2. Materials and Methods

A brown knotted nylon netting (100 x 6 m square) material with mesh size 15 x 19mm with coarse strands of 1mm thickness (in diameter) or size 9 was used to construct a trap of a rectangular shape. The size of the trap was 15m wide, 25m long and 6m high. This was made up from 5 pieces, of which two pieces were 6m wide and 15m long, two others were 6m wide and 25m long and the last sheet, the cover sheet, was 15 m wide and 25 m long. A funnel of 2m in diameter and 10m long was made. This was fixed at the top of the width of the rectangular trap. This was fixed at the centre. The door was opened joining together the upper and the lower sheets. This allowed the birds to fly out of the trap along the funnel. A complete trap cost about Tshs 650,000.

When setting the net before a trapping exercise, it was found that for a successful set-up the targeted trap roost should be smaller than the construction with netting material. This was to allow flexibility during pulling and fixing the sheets to each other to cover the top of the roost. The size of the "trap roosts" which were maintained during trapping trials was 12m wide and 20m long, with an area 3m wide and 2m long left around it to allow flexibility during set-up.

During trapping, the trap roost was surrounded by poles. The hollow iron poles were firmly driven into the ground and spaced 5.2m apart along the net's length and 3m apart along its width. Six poles were spaced along the length and 4 poles along the width of the net. The poles were 3m long and other poles of 2m long were inserted into the bigger poles. The 3m long poles had diameters of 3.75cm (1.5 inches) and the 2m long poles had diameters of 2.54cm (1 inch). The poles had hooks to hold the sheets on the sides and the top cover. The poles had holes of 1 cm in diameter spaced 1m apart. The intention for the holes was to lift and fix the poles inserted into them according to the height of the vegetation; most of the vegetation was expected to be 3–4 m high.

Another factor for consideration was the need to lift the net (the top sheet) above the vegetation during the removal of the birds. This was to provide a way for the trapped birds to fly out towards the outlet funnel. The tops of the poles were joined with ropes across and along their lengths and widths (Plate 5.9).

This made an ideal layout for smooth rolling of the top cover sheet. The ropes were adjusted on top of the vegetation such that they were not clearly visible to the birds. The trapping site, the trap roost, was surrounded by the net sheets on its sides. The upper part was left uncovered (see Plate 5.10).

Plate 5.9. Set-up of the roost trap on the ground: ropes on top of the poles with the net ready to be pulled over.

Plate 5.10. The sides of the roost trap being surrounded by net sheets.

The setting of the trap was done in day-light before the birds began arriving to roost. Specific places where birds were concentrating were located, where the net was set. The rest of the places in the roost were destroyed by cutting some of the vegetation, leaving only a few places left attractive for the birds to roost in.

They settled and became quiet at about 2000 hrs. At 2100 hrs all the birds were silent. Three trials were conducted on 4, 11 and 19 November 2009 at Rundugai, Kilimanjaro region and at Madiira and Rongorongo villages in Arusha region. The quelea population was first estimated as the birds were entering the roost before the trapping exercise. A method of estimating the number of birds entering the roost by observing carefully the bands of the flock size was employed. The quelea numbers were estimated in the following way (see Figure 5.8):-

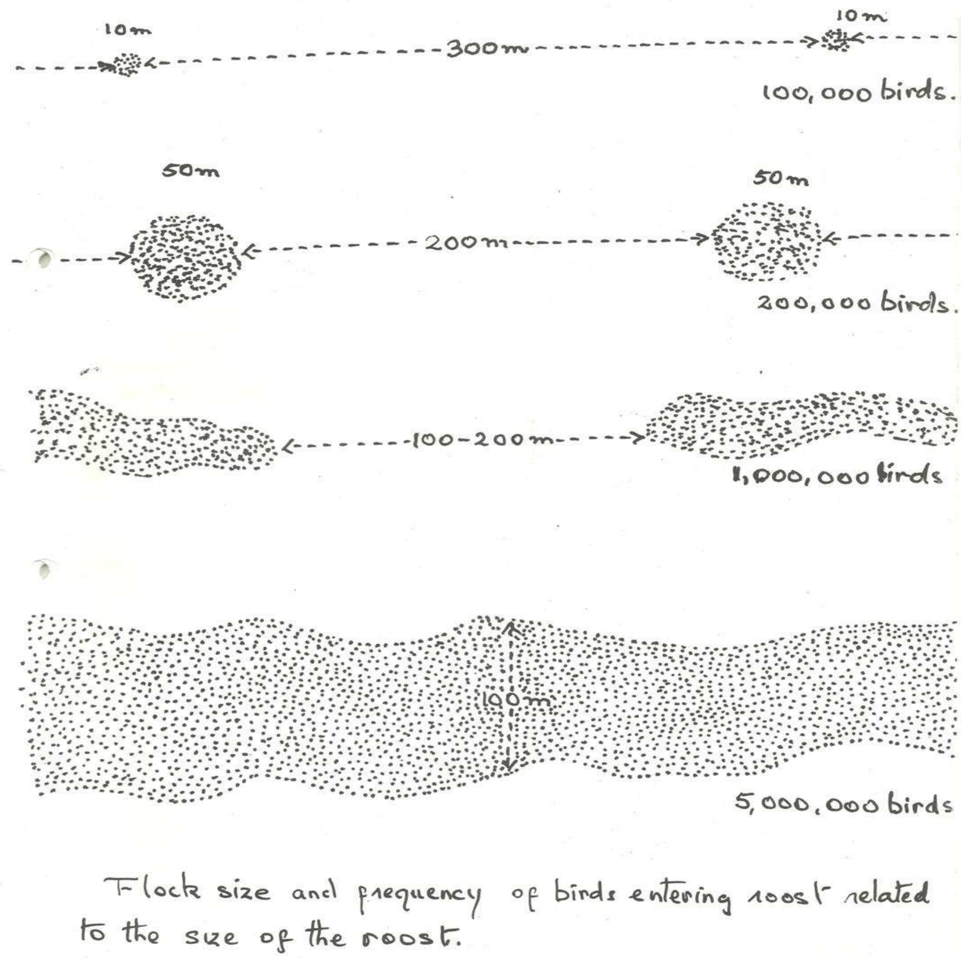
i) Small flocks less than 10 metres in diameter spaced 300 metres apart were estimated to have 100,000 birds.
ii) Larger flocks of up to 50 metres in diameter spaced 200 metres apart were estimated to have 200,00 birds

iii) Larger snake-like flocks spaced 100 metres apart were estimated to have 1,000,000 birds

iv) A continuous stream of birds 100 metres wide was estimated to have 5,000,000 birds (La Grange 1989).

The top sheet was covered by unrolling it on top of the rectangle-shaped trap. Seven ropes, about 20m long, so reaching away from the roost, were tied onto the net along the length of the piece of the net and each was manipulated by one person. Thus seven people were used to pull and unroll the sheet on top of the rectangular trap. A sign was made to alert all the people to start pulling the sheet at the same time. The roosts were covered in about 3 seconds (see Plate 5.11).

Figure 5.8. A method of estimating the number of quelea entering the roost (see text for explanation).



Source: Training manual, Migratory Pest Management; Quelea Survey. Regional Training Course, 22 March to 2 April 1993. Swaziland. International Red Locust Control Organisation for Central and Southern Africa.

Plate 5.11. The whole roost being enclosed with the birds inside – upper part is covered.

The birds were collected at the end of the funnel into a bag and removed through the funnel (Plates 5.12 and 5.13). It was possible to get the non-targets out before they died. At the time of the year when the trapping was done, weaver birds *Ploceus* spp. were treated as pests because there was much complaining from farmers as their crops were being damaged by them. Weaver birds were destroying irrigated crops such as maize, rice and red-fruited nightshade (*Solanum villosum* Miller).

Plate 5.12. A funnel being attached to the roost trap (covering the "trap roost") for collecting the birds.

Plate 5.13. A funnel attached to the roost trap, for collecting the birds from the trap.

5.3.4.3. Results

Three trials were conducted in *Typha* spp. The bands of the flying flocks were used to estimate the size of the quelea population, as described above. When birds were coming for roosting they were scared by the net. The net was placed into the vegetation. When they were coming, the birds were flying over the roost for about 15 minutes before settling. Some tried to go to the destroyed areas, but when it was becoming too dark, they then moved to the "trap roost".

First trial

The first trial was conducted at Rundugai village, where a roost had about 20,000 birds. The birds settled at the roost at 2000 hours and at 2100 hours an attempt was made to cover the roost which was successful for one part of the area while elsewhere the net became stuck on the hook of the pole, thus the roost was not fully covered instantly. The birds flew out of the trap through the uncovered part. It was very difficult to rectify the problem before the birds got out. After managing to unhook the net, the area was then covered quickly but few birds remained. From this trial 5,089 birds were trapped. These included:

- Quelea 3,097
- Weaver birds 1,981
  - African Golden Weavers (*Ploceus subaureus*) 1,314
  - Chestnut Weaver (*Ploceus rubiginosus*) 457
  - Black-headed Weaver (*Ploceus cucullatus*) 210

- Others (non-targets) 11
  - Common Waxbill (*Estrilda astrild*) 4
  - Green-winged Pytilia (*Pytilia melba*) 3
  - Winding Cisticola (*Cisticola galactotes*) 1
  - Red-billed Firefinch (*Lagonosticta senegala*) 1
  - Desert Cisticola (*Cisticola andulus*) 2

Second Trial

The second trial was conducted at Rongorongo village. The roost was in *Typha* spp. and was estimated to have about 20,000 birds, which entered the roost from 1830 hrs and settled at 2000 hrs. This time the roost was covered without problems. 17,137 birds were trapped.

These included:

• Quelea	10,826
• Weaver birds	6,306
- African Golden Weaver (*Ploceus subaureus*)	948
- Chestnut Weaver (*Ploceus rubiginosus*)	4,873
- Black-headed Weaver (*Ploceus cucullatus*)	485
• Others (non-targets) 5	
- Rattling Cisticola (*Cisticola chiniana*)	2
- Banded Parisoma (*Parisoma boehmi*)	1
- Tawny-flanked Prinia (*Prinia subflava*)	2

Third Trial

The third trial was conducted at Madiira village in an area which was estimated to have 15,000 birds. The birds settled at 2000 hrs, the trial was done at 2130 hrs and the roost was successfully covered. 13,371 birds were trapped. These included:

• Quelea birds	9,478
• Weaver birds	3,886
- African Golden Weaver (*Ploceus subaureus*)	628
- Black-headed Weaver (*Ploceus cucullatus*)	181
- Chestnut Weaver (*Ploceus rubiginosus*)	3,078
• Others (non–targets)	7
- Green-winged Pytilia (*Pytilia melba*)	3
- Red-billed Firefinch (*Lagonosticta senegala*)	2
- Winding Cisticola (*Cisticola galactotes*)	1

5.3.4.4. Discussion

The bird catches during the last two trials were good in relation to the estimated population. The results in the first trial were not good due to the problem encountered when trying to cover the trap. These results may be due to the following reasons:

The "trap roosts" were well prepared and were in places and vegetation favoured by quelea for roosting. Experiments showed that well placed and preferred "trap roost" vegetation can be used by quelea in preference to reed beds and thorn scrub (La Grange and Jarvis, 1977). Aviary experiments with roost perches indicated that quelea preferred to use designs that best enabled them to crowd, suggesting that the vegetation was important mainly as regards the density of perches it provided (La Grange, 1989). Aviary experiments also indicated that where the perch length of a favoured roosting perch was decreased below the length that could accommodate all the birds in the aviary, they abandoned it for a less favoured perch that could accommodate all of them (La Grange, 1989). Therefore, vegetation such as sugar cane, Napier grass and *Typha* spp. all seemed to be suitable for roosting.

Although the quelea select particular vegetation to roost in, it seems that the site of the roost is more important than the vegetation type. The birds also prefer situations in close proximity to water and to the feeding grounds. Another important factor is disturbance, as quelea do not like noises and other disturbances. "Trap roosts" should not be planted near roads or houses, but should be sited in open land away from other canopy vegetation into which quelea could move if they were disturbed.

During roosting, quelea move deeper into roosting vegetation when danger threatens (pers. obs.). Also quelea react instantly to any approaching threat or danger and when disturbed in a roost they move readily within the vegetation, but they are reluctant to move out of the roost, especially if it is too dark for them to see alternative destinations, which acts in favour of the success of trapping activities.

Destruction of the areas around the trap roost helped the birds to concentrate in the target area. It was also observed that, even where there is a large expanse of homogeneous vegetation, quelea were choosing to occupy only a small part of it (pers. obs.). The habit of occupying a small area during roosting resulted in successful catches.

Quelea react to alterations of the roosting vegetation or if part of the vegetation is removed when cutting paths (pers. obs.) and will move to other suitable roosting places if these are available but, as there was no other roost nearby in the experiments, the birds continued to enter the target roost.

Therefore, the intended "trap roosts" should ideally be situated somewhere between the crop lands and the areas of natural vegetation formerly used by quelea for roosting. Where possible, the plots should also be within a few hundred metres of a drinking place since quelea drink just before roosting for the night. "Trap roosts" should be some distance from other suitable roosting vegetation and the thicker the "trap roost" is grown the better it is for a trapping exercise.

From the results, a large proportion of the estimated number of quelea in the roost were trapped. More trials are needed on this trapping method, as it shows promise in reducing crop damage, as does the mass harvesting technique (see below), for collecting a large quantity of quelea for food and income generation if done in many places of the country. Also more research is needed on the proper netting materials suitable for different vegetation covers as well as the size of the trap roost suitable for the trapping exercise.

5.3.5. Quelea Chick harvesting

5.3.5.1. Introduction

Chick harvesting is done in parts of Tanzania where the breeding colonies are found. In areas in Dodoma, Singida and Shinyanga regions, chicks are harvested and used for food (pers. obs). Chick harvesting at breeding colonies is the easiest way for villagers to obtain large numbers of uncontaminated quelea for food. Thus chick harvesting provides a quantity of nutritious food for local people (Plate 5.14). Chicks are collected at almost any age, some people prefer young chicks while others old chicks. Thus, chicks are harvested from 6 to 14 days old, just before they leave the nest. Chicks are easier to eat than adults as they have softer bones.

Chick harvesting has been associated with nest destruction. Destroying nests is a traditional co-operative activity carried out collectively by hundreds of villagers directly affected by pest birds (Jaeger and Elliott, 1989). Nests are destroyed normally using hooked wooden poles or poles equipped with a hooked device. Nests are pulled down and the chicks collected from the nests. The whole or part of the nest can be pulled down. Sometimes, when the nests were pulled, they were damaged and the chicks fell down on the ground and were collected.

When there are many villagers competing in chick harvesting at a small colony (pers. obs.), many trees and especially tall trees with many nests are cut down to ease chick collection (Plate 5.15).

When trees have been felled, chicks are collected easily. If large scale tree-cutting is involved it might have adverse consequences on the environment and intensify desertification (Bashir, 1989). In Western Sudan, where villagers can easily be encouraged to group, manual nest destruction is widely used and is effective under the supervision of the crop protection unit (Jaeger and Elliott, 1989). Only one site was possible for the trial as many located breeding sites had eggs or were inaccessible.

Plate 5.14. About of 20kg of harvested naked chicks in a bucket.

Plate 5.15. Trees with nests cut down for ease of chick collection.

5.3.5.2. Materials and Methods.

During the research both wooden hooked sticks of 2–3 m length owned by local people and hooked iron sticks 4m long and 6mm in diameter were used. The hooked iron sticks were provided by the researcher. The aim was to compare the effectiveness of these devices. Fifteen farmers were involved in two trials at Iyoli village, Kondoa district before starting trials with mist nets. Farmers were found in a colony harvesting chicks on 7 May 2009. In collaboration with village leaders, farmers were asked to be checked on the next day, on 8 May 2009, with their harvest when more than 50 farmers gathered at a meeting point with their harvests. Leaving their harvest aside, 15 farmers were selected randomly. Thereafter they were asked to get their harvests which were measured with the weighing scale and recorded (see Table 5.1). When farmers were asked how long they did the harvesting for, they replied about six hours. It was decided to do the trial for six hours from 0700hrs to 1300hrs.

The same farmers were asked to continue with the trial on the following day (9 May 2009) by being given an iron hooked stick each. The farmers were asked not to involve another person in the exercise. The time given for the work was six hours from 0700 to

1300 hrs as people would be tired if expected to work much longer. On the following day early in the morning at about 0600 hrs, the farmers were given the hooked iron sticks. After six hours all of them gathered at a meeting point and their harvests were weighed and recorded (see Table 5.2).

5.3.5.3. Results

It was found that one person can collect about 7-15kg of chicks per day (mean 11.3) using the local wooden sticks with hooked device. These were not uniform. After using iron hooked sticks, farmers were able to harvest 18-25kg of chicks per day (mean 21.7) (Table 5.1). The differences in harvests were highly significant ($t = 12.73$, $df = 28$, $P < 1.83e^{-13}$).

Table 5. 1. Chick harvest at Iyoli by farmers at a breeding colony

Farmer number	Weight Harvested (kg) using hooked wooden sticks on 8/5/2009	Weight Harvested (kg) using hooked iron Sticks on 9/5/2009
1	13.5	21.2
2	12.6	19.6
3	7.2	24.3
4	9.8	20.7
5	15.1	21.5
6	8.7	23.4
7	11.5	21.5
8	9.8	18.8
9	10.2	25.1
10	13.4	24.4
11	14.5	22.3
12	12.3	20.2
13	8.4	19.3
14	13.3	23.5
15	9.6	19.7
Mean (S.D.)	11.33 (2.41)	21.70 (2.04)

5.3.5.4. Discussion

Successful chick harvesting may depend on a number of factors. These include the number of people and their persistence relative to colony size and status, its vegetation type, height, density and accessibility. The area was 2 km from the village and easily accessed by people. The bush with nests was not dense, but easy to penetrate. Trees with nests were estimated to be 4-5 m high. Using iron sticks was easier than using wooden sticks as these were uniform and long enough to reach tall trees.

Short trees with nests were easier for chick harvesting than tall trees. Sparse trees were more easily accessible than dense trees, so successful chick harvesting and a large number of quelea have been harvested from sparse vegetation with short nest trees (Jaeger and Elliott, 1989; pers. obs.). Using the iron sticks, farmers were able to harvest a large quantity of quelea for food and also make it unnecessary for them to cut trees down. This means if farmers are using long enough and strong hooked devices, they may be able to harvest a substantial amount of quelea without cutting trees which may damage the environment.

Chicks under 14 days old were easy to harvest as they did not get outside their nests, but once outside the nests, chicks were difficult to harvest as they moved quickly from branch to branch. With good hooked sticks, large numbers of these birds can easily be harvested. In one colony in southern Tanzania, villagers collected piles of naked chicks about 6 days old (Jaeger and Elliott, 1989; Plate 5.17). In Zimbabwe, villagers often wait until the chicks are almost ready to fledge before raiding the colony (Jarvis and Vernon, 1989b). When the chicks are outside the nests, nest pulling is never done, villagers collect them with sticks and catapults, but few are collected per day.

Distance of the colony from the village is also an important factor. The colony was not far from the village. If the colony is far from the village, it may discourage old people to do chick harvesting and, also, very few people are able to reach the site.

Sometimes quelea breed in marshy and thick thorn bush areas, which are very difficult for chick harvesting as they may not be accessible easily, unlike dry and sparse tree areas. The farmers involved in the trial were happy as they obtained larger quantities of chicks than expected. Many farmers asked for assistance in getting such iron hooked sticks, which they were prepared to buy if available for sale. Each piece of iron hooked stick cost Tshs 4,000 and can be used for a long time. With such a cost, it is possible for a farmer to buy one if he or she manages to sell the harvested chicks to other consumers. One kilogram of chicks (about 70 chicks) was sold at Tshs 1,000 before processing. Assuming each farmer was able to harvest an average of 18 kg and sell 15 kg per day and remain with 3 kg for home consumption, he was able to get Tshs 15,000. With this amount of money a farmer was able to buy his iron hooked stick.

5.2.6. Mist nets

5.2.6.1 Introduction

Mist netting is the most widely used method for catching small to medium-sized wild birds for research and ringing (McClure, 1984). Catching birds using mist netting in principle is simple; an inconspicuous mesh net is used. The net is erected vertically on poles and deployed in areas of high activity to intercept birds as they go about their normal daily routines such as feeding, drinking, roosting and nesting (Bub, 1991). Mist nets are available in many different measures, materials, mesh sizes, colours and strand thicknesses. Dark-coloured nylon nets are commonly used, but the optional features for a mist net will depend on the target species and habitat characteristics at the netting site. Short nets are more practical in heavy cover, while longer nets can be used in more open habitats (Inglis, 1985). Mesh size of the net is directly related to the size of the target species; smaller mesh for smaller species, and larger mesh for larger species. Nets with finer strands are less visible but more fragile than nets with coarser strands, although the more durable coarse nets may be adequate for species netted at night or in other low light conditions (Schemnitz, 2005).

When the nets are properly positioned, they are inconspicuous even to the birds' keen vision, and unsuspecting birds may strike the net at a considerable speed. Mist nets are made with a series of 3-4 shelves or pockets running horizontally along their lengths into which the bird drops when it strikes the net, a design which decelerates the bird when impacting the net (Plate 5.16).

Trapping of quelea was carried out in the study area of Dodoma region and in Singida region depending on the availability of sites where quelea were congregating for feeding, drinking, roosting or breeding. The following villages were involved in the exercise: Mahata, Swaswa and Mamba in Dodoma Urban, Kawawa East, Msanga and Chamwino in Dodoma Rural, Chidilo Dodoma Rural, Piho and Iyoli in Kondoa district and Solya Manyoni district, Singida region. Locally made mist nets were used.

5.3.6.2. Materials and Methods

Locally-made mist nets, constructed by a team of trappers based near Dodoma, were made from white nylon fishing nets 45 x 1m each, with 1.5cm mesh size, sown together and dyed black with waste from batteries or with hair dye mixed with kerosene. Two such nets were needed to construct a 20 x 4m long mist net. The nets were made up into four shelves with thicker thread acting as shelf strings which were also dyed black. At the ends of each shelf, loops made of about 7cm lengths of thicker acrylic rope were tied. When made-up and erected on wooden poles, the effective catching area of each net was about 12 x 3m. The poles were about 4m high. Wooden, aluminium and cast iron poles were used. Wooden poles were cut from bushes and were strong enough to hold the nets with catches. Although cheap and light, the aluminium poles that were used were found not to be strong enough, especially if there was any wind, and by the end of the trials more than 50% of such poles were broken or bent. Their cost-benefit ratio was undermined by their lack of durability and it would have been better to continue buying cast iron poles that were more or less indestructible, albeit that they were heavier and more expensive.

Plate 5.16. Locally made mist nets showing a series of shelves allowing formation of pockets to trap birds. (Photo: R. A. Cheke).

The wooden poles cut from a bush were prepared in a way that they were very strong to hold the nets and such that they would not snag on them. The pole surface was smooth enough to allow the net attachment loops to slide cleanly on and off the pole. Nets were properly erected which is important for successful catches (Schemnitz, 2005) (Plate 5.17 and 5.18).

Each 45 x 1m net cost 780 Tsh (when bought in Dar-es-Salaam in February 2009) and a completed 20 x 4m long mist net required 4000 Tsh in labour costs. Thus, together with sundries for making shelf lines and pockets and loops at the ends for attachments to poles, each 20 x 2m net cost about 6000Tsh at 2009 prices (equivalent to about £3, as opposed to the £100 or more for a commercial 18 x 2m net; R.A. Cheke, pers. comm.).

In the breeding colonies the nets were erected in the gaps between the patches of thorn trees in which the quelea were nesting. In roosting sites paths were made to erect the nets. Very little clearing of the path was made so as not to destroy the vegetation. In other sites nets were erected following the birds' routes to drinking or feeding sites.

The number of nets used varied from one trapping site to another depending on the size, type of trapping sites, people involved and time of the day. The nets were taken down at the end of the trapping exercise. Erecting the nets was done early in the morning before the birds came to or left the trapping sites. In the night roosts nets were erected early in the morning and late evening and kept up until midnight. Birds were extracted at hourly intervals and the numbers caught recorded. Trappers and other local people helped in trapping and extraction exercises as they were given trapped quelea for food. Non-target birds were removed and released.

The birds caught were mainly killed following normal and religious attitudes. In other areas birds were killed by crushing the head, which was thought to be the quickest and most humane method available. The local people sometimes killed the birds by throwing them at patches of hard ground. But in other places especially in Kondoa district, where Muslims are predominating, birds were killed by cutting their throats with a sharp knife. Sometimes the birds were killed by crushing or cutting their heads while they were still in the nets. The mass of the individual birds was between about 18 and 20g (weighing using PESOLA Spring Balance), thus an average of 110 birds provided about 2kg of food for the local people.

Plate 5.17. Trapped birds in a mist net (Photo: R. A. Cheke).

Plate 5.18. Entangled Red-billed Quelea birds in a mist net (Photo: R. A. Cheke).

5.3.6.3. Results

On 17 June 2007, 201 quelea were caught at a “day-roost” at a drinking place amongst *Sesbania* sp. in a marshy area at Mahata village (06° 06’ 54.6”S, 35°42’ 55.8” E) 15km from Dodoma town. The following non-target species were also caught and released (unless otherwise stated): 1 Black-eyed Bulbul *Pycnonotus tricolor,* 4 Lesser Swamp Warbler *Acrocephalus gracilirostris* (3 died), 2 Rattling Cisticola *Cisticola chiniana*, 3 Jameson’s Firefinch *Lagonosticta rhodopareia* (1 died), 1 Red-billed Firefinch *L. senegala*, 19 Blue-capped Cordon Bleu *Uraeginthus cyanocephalus*, 2 Green-winged Pytilia *Pytilia melba* and 3 Southern Masked Weaver *Ploceus velatus* (2 died).

On 18 June 2007, at a drinking place at Mahata village, 504 quelea were caught when using 21 nets. The following non-target species were also caught and released: 4 Lesser Swamp Warbler *A. gracilirostris*, 2 Rattling Cisticola *C. chiniana* and 15 Bishops *Euplectes* sp.

On 21 June 2007, 1841 quelea were caught during the evening at Kawawa (05 58’ 12.4”S, 36° 01’ 16.7” E) in a *Typha* spp. roost when using 21 nets. The following non-target species were also caught and released: 2 Laughing Doves *Streptopelia senegalensis*, 1 Malachite Kingfisher *Alcedo cristata*, 2 Crimson-rumped Waxbills *Estrilda rhodopyga*, 1 weaver *Ploceus* sp. and 1 Bishop *Euplectes* sp.

On 17 July 2007 at Swaswa–Dodoma Urban, 1766 quelea were caught in *Typha* spp. The following non-target species were caught and released 1 Green-winged Pytilia (*Pytilia melba*), 1 Village Weaver (*Ploceus cucullatus*), 2 Red-cheeked Cordon-bleu (*Uraeginthus bengalus*) and 1 African Firefinch (*Lagonosticta senegala*). 10 mist nets were used as the site was only about 1 hectare in area. It was used by the birds for drinking during the day and roosting in the night.

On 18 July 2007 at Swaswa, 1724 quelea were caught feeding on bushes at the edges of a rice field. This was a resting place of quelea when they were threatened in the farm. 10 mist nets were used according to the length of the bush which was about 160m long. The following non-targets were caught and released: 1 Green-winged Pytilia (*Pytilia melba*), 1 Red-cheeked Cordon-bleu (*Uraeginthus bengalus*) and 1 African Firefinch (*Lagonosticta senegala*).

On 19 July 2007 at Swaswa, 1033 quelea were caught at a night roost in *Typha* spp. Three Village Weaver (*Ploceus cucullatus*) were caught and released. 10 mist nets were used due to the size of the roost.

On 20 August 2007 at Msanga Village, 237 quelea were caught using 5 mist nets at a threshing ground. No non-target bird was caught.

On 21 August 2007 at Msanga Village, 1059 quelea were caught using 7 mist nets at a drinking site. No non-target was caught. This was not a permanent drinking place. Birds were threatened and moved to another place.

On 22 August 2007 at Msanga village, 2373 quelea were caught using 7 mist nets in a night roost. 2 Village Weaver (*P. cucullatus*) and 2 Southern Masked Weaver (*P. velatus*) were caught and released.

On 23 August 2007 at Msanga village, 4153 quelea were caught using 7 mist nets in a night roost. 5 Southern Masked Weaver (*P. velatus*) and 4 Village Weaver (*P. cucullatus*) were caught and released.

On 24, 25 and 26 August 2007 at Chamwino village in a sugarcane roost, 574, 621 and 519 quelea were caught, respectively. No non-target species was caught. Seven mist nets were used. The plot occupied by quelea was estimated to be 10 hectares. The area had thick vegetation which made it difficult to penetrate. Nets were erected only one metre inside the sugarcane and quelea were driven from the middle.

On 1 August 2008 at Kawawa East in a night roost, 1285 quelea were caught and 2 Village Weaver (*P. cucullatus*) and 1 Southern Masked Weaver (*P. velatus*) were caught and released. Seven mist nets were used.

On 2 August 2008 at Kawawa East in a night roost, 872 quelea were caught and 1 Village Weaver (*P. cucullatus*) was caught and released. Seven mist nets were used.

On 5 August 2008 at Kawawa East in a night roost, 1164 quelea were caught and 1 Village Weaver (*P. cucullatus*) and 1 Speckled Mousebird (*Colius striatus*) was caught and released. Seven mist nets were used.

On 6 August 2008 at Kawawa East in a night roost, 723 quelea were caught and 1 Speckled Mousebird (*Colius striatus*) was caught and released. Seven mist nets were used.

On 21 August 2008 at Kawawa East in a night roost, 1635 quelea were caught and 1 Village Weaver (*P. cucullatus*) was caught and released. Seven mist nets were used.

On 22 August 2008 at Kawawa East in a night roost, 663 quelea were caught and 2 Southern Masked Weaver (*P. velatus*) were caught and released. Ten mist nets were used.

On 30 March up to 4 April 2009 at Solya village in a breeding colony 457, 690, 825, and 805 quelea were caught, respectively. Ten mist nets were used. Fourteen non-target species were caught, of which 12 were released but 2 died in the net.

On 6 and 7 April 2009 at Mamba village in a breeding colony 2066 and 1536 quelea were caught, respectively. Sixteen non-target birds were caught and released except one was harmed. Ten mist nets were used every day.

On 10 – 19 May 2009 at Iyoli village, 158,113 quelea were caught in a breeding colony using 50 mist nets every day. Fifty-six non-target birds were also caught, 4 were killed and the rest were released.

On 25 – 29 May 2009 at Piho village, 20,815 quelea and 23 non-target birds were caught in a night roost. 15 non-targets were released and 8 were seriously harmed. 24 mist nets were used every day. During the same days, 2503 quelea were caught on the edges of the rice field in the same village using 4 nets every day.

A summary of the results of mist netting in different habitats are presented in Fig. 5.9. The data were analysed by ANOVA according to locality, habitat type and year. The latter was not significant ($F = 0.29$, $df = 1$, $P = 0.59$) and so data for all years were pooled. It was then found that habitat type was significant ($F = 13.66$, $df = 4$, $P = 1.874e^{-6}$), as was locality ($F = 15.85$, $df = 7$, $P = 1.645e^{-8}$), but the interaction between habitat type and locality was not ($f = 2.25$, $df = 3$, $P = 0.10$) so it was concluded that the pattern of catches was the same at different localities. Mean catches per net per day (with standard errors in parentheses) for the different habitat types were as follows: breeding sites 226.29 (18.59), drinking sites 80.80 (40.95), edges of rice fields 133.00 (25.02), night roosts 163.62 (24.99) and threshing grounds 47.00 (46.39). Tukey tests for differences between these means showed the following significant differences. Breeding site > drinking sites ($P = 0.0000083$), Breeding site > edges of rice fields ($P = 0.0017$), Breeding site > roosts ($P = 0.0045$), Breeding site > threshing grounds ($P = 0.0062$), and drinking sites > roosts ($P = 0.012$).

Diurnal variation using different netting systems are depicted in Fig. 5.10. Excluding the data for the night roosts, the patterns were found to be significantly different when tested with a Friedman non-parametric 2-way ANOVA ($P < 0.0001$).

Figure 5.9. Histogram showing average catches per net in different habitats. Breeding = breeding sites; drinksite = drinking sites; feededge = edges of rice fields; roost = night roosts and thresh = threshing grounds. Error bars are standard errors of the means.

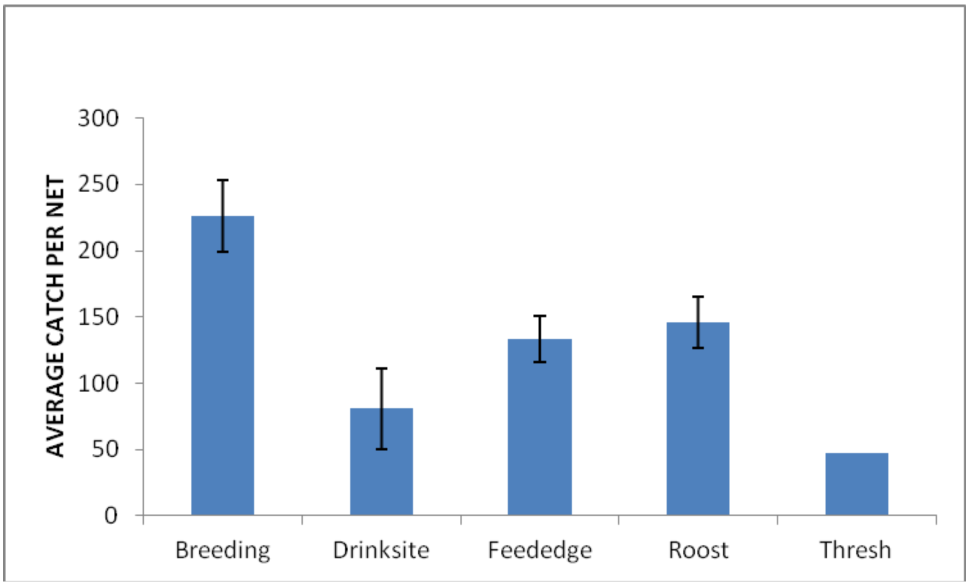
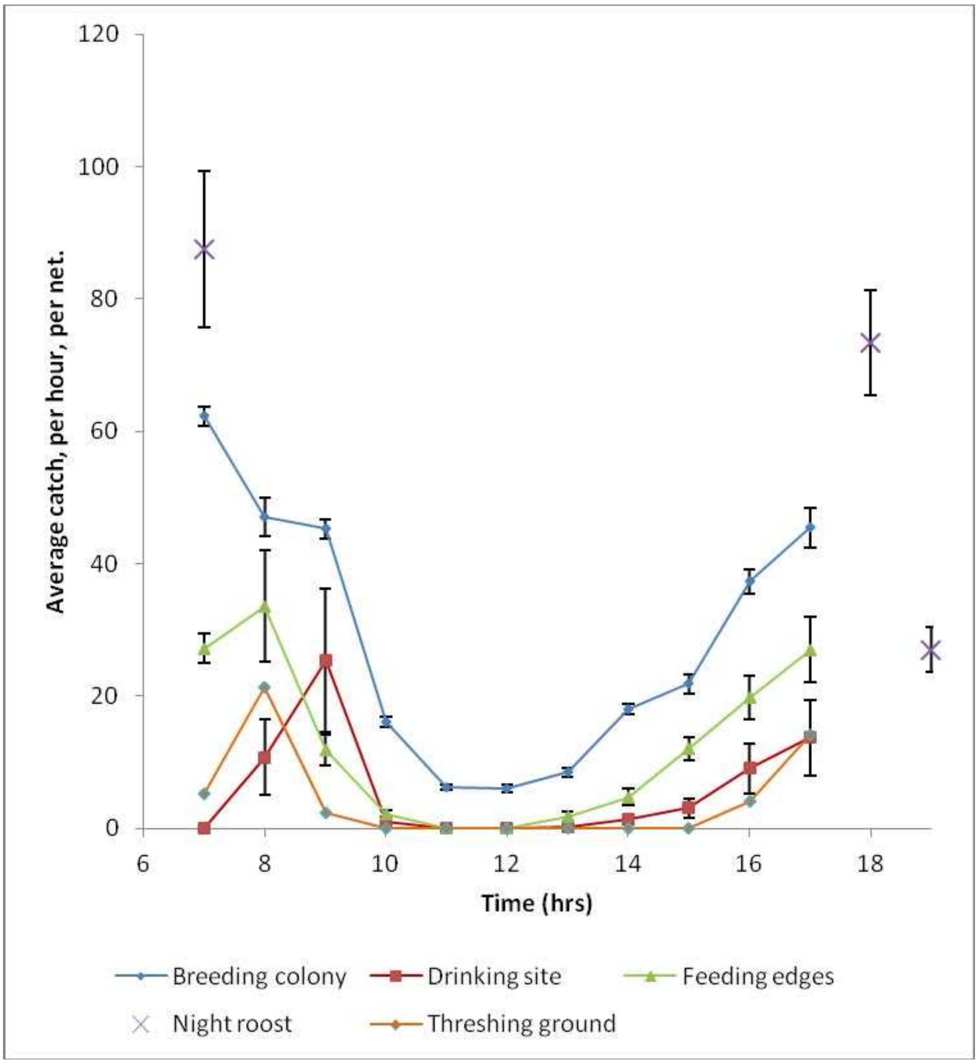


Figure 5.10. Diurnal catch patterns between habitat types. Average catches per net per hour for breeding colonies, drinking sites, edges of rice fields, threshing grounds and night roosts at different times (0700-0800 – data above 7 on the x axis; 0800-0900 – data above 8 on the x axis etc.). Error bars denote standard errors of the means.



5.3.6.4. Discussion

It was observed that the periods and trapping site when and where mist netting was carried out were very important for a successful catch. Quelea are active at dawn and dusk, as they feed intensively early in the morning and in the late afternoon. Both in roosts and in colonies, flocks leave at dawn for feeding sites where they typically feed for 2 or 3 hours (Erickson, 1989). Adult quelea with chicks, when fed enough themselves, bring food to their chicks throughout much of the day, leaving feeding flocks in small groups to return to the colony. These groups gather more birds as they fly by other feeding flocks (Jarvis and Vernon, 1989a). Thus, when in breeding colonies quelea are active most of the time. When incubating, male and female quelea regularly change places and therefore some are active almost all of the time, looking for food.

When food is abundant, such as wild grass seeds or cereal grains in milky stage near the colony, adults make many movements to and fro in the morning and evening feeding the chicks. Fewer movements are made when it is hot or after the adults have enough food themselves and for their chicks, when they rest. In the evening from 17:00 hrs adult quelea are busy looking for food which will sustain themselves and their chicks for the following night. During these hectic movements more birds are caught in the mist nets.

From the analysis above it was shown that morning hours and evening hours are ideal times for trapping. These indicate that early setting-up of the nets and late evening trapping could improve catches. Fortunately this was not a problem with the trappers as they were doing this already: they were erecting the nets early in the morning before the birds began leaving the colony or roost but this was difficult with inexperienced local people who wanted to practice. They also left the colony or roost after 2000hrs in the night. They were using torches to extract birds from the nets. From this experience, catching was very successful.

At drinking sites and threshing grounds, for example, nets need to be erected some metres away from the source of water. Nets had to be moved to adjust the distance at which birds headed for the drinking site. This also depended on the site where the birds were resting before they went to drink. Twelve metres between the erected nets and the water source seemed to be an ideal distance.

Accessibility to the site also contributed to the results. Other sites were too bushy and flooded with water that made it impossible for easy erection of the nets. In the sugarcane it was not possible to do any alteration like cutting paths for nets. This also limits the results.

During mist netting, shifting of the nets after two days was observed to be very important. It was observed that trapping in one area for more than two days makes the birds change their routes. Sometimes a few birds were seen to fly within the same area or direction thus resulting in low catches. The catches were found to be higher where the nets were first put up. Continuous catching at the same place showed that few catches were experienced, and hence it was good to change to another place. Through experience the numbers dropped, probably due to many birds having been caught or deserting the area.

CHAPTER SIX

GENERAL DISCUSSION

6.1. INTRODUCTION

Bird trapping has been a part of the ancient hunting behaviour of mankind in many parts of the world. Apart from other uses, birds were mainly caught for food. Thus, many bird species were caught and their habitats were continuously eroded. Considering these consequences, many countries enacted laws to protect the majority of their bird species (Bub, 1991), with the result that mass trapping of birds for food was banned and only a few bird species were caught for scientific research.

With the rise of agriculture, and especially the growing of small grain crops, some bird species which destroy crops like the Red-billed quelea (*Quelea quelea*) needed intervention (Mineau, 2002). For effective control this species has been killed with chemicals which pose negative impacts on non-target species and the environment. Quelea killed with the chemical are contaminated and not recommended for human consumption. Thus it became important to investigate environmentally friendly methods of mass capture that could provide uncontaminated quelea and income generation to local people and, if possible, reduce bird numbers in order to minimize the damage done to crops. However, trapping methods are often labour intensive, opportunistic and may have limited value in bird control (Jaeger and Elliott, 1989).

This chapter discusses the main findings of the research. Further research is needed for testing some of the mass trapping methods tried, and others which were not tried, to see which will be feasible for successful mass-trapping of quelea in Tanzanian situations. Some recommendations are given following the findings associated with the communities' interactions.

6.2. DISCUSSION OF THE MAIN FINDINGS OF THE RESEARCH

Trapping quelea has been customary mostly in the central regions of Tanzania using local traditional basket traps for trapping adult quelea. Some local people in the central regions of Tanzania are trapping quelea and harvesting chicks, sometimes as an alternative means of control that was investigated in detail (Chapter 5). It was also noted that many people in the country where quelea are a problem were using them for food as well as for income generation, although only a few were trapped using local trapping methods, partly because of regulations in force at the outset of this study that banned wild bird trapping irrespective of their pest status. The interest amongst the population of eating quelea was shown at the Farmers' Shows where many people from all over the country attended and were interested in tasting cooked quelea meat.

In other parts of the country where quelea are a problem chick harvesting is done as well as in the central zone by both men and women. Only boys in these areas are trapping adult quelea for food, using other local trapping methods. Such methods include throwing sticks about 0.5 m long into dense feeding flocks, using baited drop traps to catch quelea alive as well as for the cage-bird trade, catapults and bird lime, an entangling glue. Sticky twigs covered with bird lime are placed in resting or drinking sites, and a catch can be made every few minutes at the right time of day. Such methods are generally used only by small boys supplementing their personal diet while occupied in other activities like herding livestock (Jaeger and Elliott, 1989).

Baseline data on the people involved in such quelea trapping, the number of birds trapped, the trapping system and trapping techniques used by local people, were obtained before embarking on the practical parts of the research through meetings and interviews.

Little quantitative information was available, however, on the quantity trapped by the trappers, but since many people in the research area were using quelea for food and for income generation, the research was welcomed by local farmers. Traditional basket traps which were being used by local people were among the traps tested and they showed positive results in terms of catches of quelea and especially their replicas. Traditional knowledge was highly regarded in this research and trap techniques developed were to be environmentally friendly, easy to carry and effective for trapping quelea. Finally the public, through mass media, was kindly advised to assist and support what the government was working on in trying to control these pest birds by participating in the areas tested.

Before starting the study, it was reported in the meetings that local people were able to trap a reasonable number of birds applying local methods. The development of large traps and particularly of special nets and an improvement on the traditional basket trap (the wire-mesh version) constituted a great step forward. A number of techniques were tested. The first of these special nets included the use of big nets, the Tunisian trap and the Funnel trap. These were constructed and used as described in Chapter 5. These nets were conspicuous to the extent that the birds would fly around or over them rather than into them. Traditional basket traps and its wire-mesh versions, mist nets and a roost trap in trap roost vegetation were also used. Although the big nets (Tunisian trap and Funnel trap) did not work effectively, other methods performed well (Chapter 5). Some trapping techniques used methods to lure birds to areas where the traps were set. Food, water, and decoys in the form of captive birds are effective to attract birds (Gadd, 1996, Lowe, 1989) and both use of food (supplies of supplementary grain spread near the traps) and water were used successfully in this study.

The three methods, the mist nest, traditional baskets (and the wire-mesh versions) and the roost-trap proved to be much more successful in mass capture of quelea than the Tunisian and funnel traps. The reasons for these are discussed below.

6.2.1. The big nets (Tunisian trap and Funnel trap).

The big nets, the Tunisian trap and Funnel trap which were tried in 2007 and 2008 were designed following the general plan of the Floodlight trap or the Heligoland trap used in the United States of America (USA) and Tunisia for catching large numbers of Red-winged Blackbirds and Starlings at roosts. The traps have been used in many places with great success. The experience gained (during the study period 2007 and 2008) with the effort to carry out mass-trapping of quelea using the two types of funnel traps suggested that the trapping sites, the behaviour of quelea and the breeding habitat made this method unlikely to succeed.

6.2.1.1. Trapping sites

For the trapping site (for all the traps) there should be adequate cover (bushes or trees) leading into the trap. It is very important that this be somewhat lower than the entry, perhaps 2/3 of its height, otherwise some birds are likely to fly up and over the trap (Woodford and Hussell, 1961). For example at Long Point, Ontario, the top of the trees in front of the trap were cut off so that they were about 0.5m below the trap's roof level with the result that fewer birds flew over it (Hussell and Woodford, 1961). Sometimes, the mouth should, if possible, face the direction of migrants' local movements at the season when it is likely to be the most productive. For example, 'double' traps along stone walls have been built at Fair Isle, the two mouths facing in opposite directions (Woodford and Hussell, 1961). Unlike starlings, quelea do not enter a roost or a breeding colony in a single direction. This made it impossible to direct the mouth of the traps in the direction of their movement.

Another important factor is the density of the cover at the trapping site. It is suggested that the cover at the trapping site should not be too dense; otherwise it may lead the trappers to miss the trap when driving birds. Any cover at the side of the entry which might lead birds away from the trap was removed.

In principle, mass trapping needs a site where birds are congregating in large numbers. Such sites are breeding, roosting and feeding places. In U.S.A. and Tunisia most of the traps have been used at roosting sites and baits were provided, but during this research the Funnel trap trials were conducted at breeding sites where no baits were provided. These factors might have been affecting the results. More trials are needed to ensure that all important factors are observed and, where necessary, improvements made.

Most of the big traps designed from the plan provided by the Patuxent Wildlife Research centre which were used in different places had different shapes and sizes (Mitchell, 1963). The importance of these may be to make them efficient, portable and even cost effective according to the users. Very heavy and expensive traps may not be feasible for many farmers or trappers in Tanzania as they may require vehicles to carry the traps, which may not be possible. Also farmers may not be able to afford expensive traps, like the ones used in this study, which were also heavy and required a vehicle for their transportation.

It is clear that successful trapping using the big nets depends on many factors besides the structures of the traps. Regardless of the structure of the trap and its costs the most important factor is that the trap should be constructed so that it presents the birds driven into it with a ‘point of no return’ (Brownlow, 1952, 1955), beyond which the transparent back of the catching-box or the funnel tube appears as the only, or at least the most obvious, way of escape. This is made possible if the last section leading to the catching box or funnel tube is made into a narrow passageway and should slope slightly upwards towards the catching-box or funnel tube. This creates the illusion of a ‘point of no return’ as the birds fly naturally upwards (Woodford and Hussell, 1961). Also the side walls should be such that they guide the birds into the trap and prevent them from by-passing the entry. For example, at Point Pelee, Ontario, the long side walls were built at the same height as at the entrance of the trap and have proved to be very effective in guiding birds into the trap entrance (Hussell and Woodford, 1961; Gunn, 1954). Thus, traps can vary in their design to capture birds and are adapted according to the habitat and behaviour of the birds. More trials using such big nets need to be carried out for mass-capture of quelea.

Although there was little success with the big nets (the Tunisian and Funnel traps), if many trappers and farmers were available, more trials at roosting sites and threshing grounds should be conducted, with provision of baits and water at the trapping sites, particularly during threshing when many flocks come to the threshing grounds looking for food. Also, when coming for night roosting quelea usually make a stopover about 500m away from the roosting place. If a trap were to be constructed at such a place and provided with water and baits, it might produce good catches.

6.2.1.2. The behaviour of the target species.

The behaviour of bird species is an important factor when considering mass capture. It was observed that the behaviour of quelea is substantially different from the behaviour of starlings, as caught successfully in the Tunisian trap, and of starlings / blackbirds / cowbirds caught in the American trap. Quelea generally choose vegetation in which to roost and breed which is dense and thorny (*Acacia* trees) or has sharp leaves (*Typha* spp.) and is in flooded terrain, both of which are difficult for predators, including trappers, to penetrate. For those choosing trees, their defence against attack is to retreat into the thorns. In the Chidilo colony, incoming flocks were occasionally chased by falcons and they reacted by swerving away and settling into the thorn trees. The thorns are a very good protection against almost all predators. Unlike starlings in Tunisia which roosted in eucalyptus and which moved away from danger by fluttering away, quelea in the dark seem to flutter only up and down within the thorn trees and move minimal distances. Both quelea and starlings have the capacity to react to disturbance by abandoning the roosting site altogether. The Tunisian trapping technique involves carrying it out with the minimal use of noise and torches. Roost sites are worked only for three or four nights and then are left to settle down. If a starling roost is worked too much, the birds abandon the site and go somewhere else to roost (Tunisian trap, C. C. H. Elliott, pers.com.). Since the finding of roosts is a laborious process and it can take several days to pin-point a roost, it is inefficient to trap too much and cause the birds to move elsewhere.

The capacity for quelea to abandon a roost when disturbed was demonstrated by the experience in June 2007 when a roost was abandoned after being disturbed only twice. Quelea also abandon colonies as they had done at Mwitikira in 2008 when 200 local people had reportedly invaded the colony to collect birds with catapults. Also, in the Chidilo colony, the area of nests nearest the funnel trap's first position was abandoned, although the rest of the colony was functioning normally.

The bird density is also one of the most important factors in mass-trapping. Many migratory species travel, roost, feed or breed in large numbers together. Thus, mass-trapping is most successful when bird densities are high. In U.S.A. and Tunisia mass-trapping traps were used where birds were roosting especially in winter when they roost in compact masses (Mitchell, 1963). At a few areas, especially at bird-ringing stations, birds were baited with grain at the entrance to the trap. Thus, few birds were caught automatically entering the traps, but the great majority were caught by driving them into the mouth of the traps from some distance away. The driving techniques may vary with every trap, and with the species of bird being caught. Thus, the driving techniques must be worked out for each trap and species targeted (Hussell and Woodford, 1961). Birds should be driven into the trap with the minimum possible noise. Too much disturbance tends to make most of the birds to fly up and move out of the trapping range (Woodford, 1959). Due to the birds' behaviour some can be gently driven almost all the way into the trap, but others require rather more forceful driving into the trap's mouth. When birds are approaching the mouth of the trap, the quieter should be the driving. When necessary, a final rush can be done when birds are at the mouth of the trap.

Proper management during driving is needed. The trappers need to keep in touch with each other and coordinate their efforts. When birds are reaching the mouth of the trap, it is necessary for the trappers to keep in line with each other. Sometimes, if this is not done, birds break back much more easily and fly away from the trap (Woodford, 1959; Brownlow, 1952). Driving can be easily done by clapping hands, shouting, or pounding on the roost or nesting trees with sticks (Seubert, 1963). Quelea are sensitive to noise, thus readily move out of trapping areas when too much noise is made during the driving. But also they may need a forceful driving just at the mouth of the trap. More studies are needed in aviary and field studies to observe the effect of noise on driving quelea to the traps.

The nature of the USA-designed trap was based on the attraction of the birds to light and provision of baits together with live decoys. These funnel traps are characterized by narrow entrances leading to the catching-boxes or chambers into which birds may be lured or driven. Food, water and live decoys were provided to attract the trapped birds. Starlings, Grackles, Red-winged Blackbirds and Cowbirds were more easily attracted by the light than quelea. Quelea are not easily attracted by the light, but can easily see objects illuminated by the light and move to them. More experiments using light at night when trapping quelea need to be studied in aviary and field studies. Quelea, like other birds, are also attracted to baits and live decoys.

6.2.1.3. The trapping habitat

Trapping habitat is an important factor when considering mass-trapping of quelea. Mass-trapping can be successful regardless of adverse weather or other unfavourable conditions when the trap can be placed at a proper site immediately higher than the vegetation and immediately beside a very dense concentration of birds (Mitchell, 1963). Quelea will fly towards the trap when placed at a good site regardless of weather conditions. A good site should be near the end of an isolated, narrow, line of low cover. The best cover consists of bushes, with some small trees, but with no big trees in front or behind the trap as these will encourage some birds to fly over the trap (Woodford and Hussell, 1961).

Where there is strong wind, it is good to protect the trap from wind (Brownlow, 1952). The amount and position of cover is a very important factor in the number of birds caught. At most sites, it is always necessary to remove some trees or bushes near the trap. Tall trees in the area of the trap, both behind and in front of it, may have to either be topped or removed. For convenience, bushes or trees at either side of the entry may have to be removed. Such favourable cover and that near the roost may induce the birds to by-pass the trap and fly into it. It is necessary to ensure that bushes or trees in the entry area need to be lower than the height of the entry area (Woodford and Hussell, 1961). It is better to ensure that the cover at the entry area should not be so dense to prohibit the movements of the trappers when driving quelea into the trap. When necessary, selective thinning may be needed to allow trappers driving the birds to pass through easily to the catchment area (Woodford and Hussell, 1961). Therefore, suitable trapping habitat is important for successful mass trapping of quelea.

6.2.2. Traditional traps

Traditional traps were also observed to be an effective method for mass capturing of quelea. Although the traditional traps have been used for a long time, more than 60 years in the Kondoa district, they are used under restricted conditions. The traps are used only in the dry season when water and food are limited. Traps are placed at traditional or artificially made drinking sites with baits. With artificial water sites, traps can also be placed near roosts and along the route to the roosting area (McClure, 1984; Sharp and Saunders, 2004).

The trap size of 60cm in diameter, 20cm deep, 2m in circumference for both types of trap, grass and wire-mesh versions, seems to be ideal. This is because the traps have to be taken back to their owners' homes after trapping sessions. A trapper sometimes deploys more than 10 traps depending on the market and availability of the birds. Traps of bigger size than these have not been used, but might also be effective when quelea invade in high numbers, although such traps would not be easy to carry.

Areas with standing water like ponds or swamps are preferred by quelea for drinking. These are the best sites for trapping. It is better when the sky is clear and very hot rather than when it is cool and cloudy. Quelea drink water at least once each day. When it is hot and water is available, quelea can drink twice a day during the hot midday when congregating in day-roosts (Erickson, 1989). For successful catching of quelea it is essential to provide food and / or water inside and outside the trap as bait. An artificial drinking water supply can be provided at places where natural water is not available. Water and food may be provided at the same trapping place. When birds are coming for drinking they will easily find the food placed in the trap, find the small entrance hole and enter for food, but have difficulty in leaving. When birds are coming in a large numbers for drinking, traps should be checked regularly at least once every half an hour. This allows taking the trapped birds out of the trap allowing for many others to enter before the bait is finished. The traps are effective if bait is always replaced inside the trap and lightly spread around the traps.

It is necessary to identify suitable capture sites where quelea drink water in open dry land habitats. The site and traps are prepared and placed well in advance of the expected arrival of the birds. The site should be prepared and traps placed at least two hours before the capture effort.

The optimum times for trapping quelea using basket traps vary depending on the weather conditions. During the rainy season or when there is cloud, trapping may be less effective as birds may not get as thirsty as they do in hot weather. At other times of the year, particularly during the dry season, when food and water are less abundant or there is hot weather, birds are forming large flocks at drinking and feeding places and many birds can be caught. When trapping quelea with basket traps, the use of water as an attractant has been successfully demonstrated in different places where quelea congregate.

During this study, both the traditional basket traps made of grass and improved versions made of wire-mesh were tested to see which worked efficiently. The results showed that the traditional basket trap caught an average of 800 birds per day while the improved wire-mesh version with one entrance hole captured an average of 1600 birds per day. Others with two and three entrance holes caught averages of 2200 and 3300 birds per day, respectively (see Appendices 5.1 to 5.4). Thus, the wire-mesh versions were superior to traps made of grass. Some factors contributing to this result were that: (1) the food and birds in the wire-mesh versions were more visible than in the grass traps. Quelea birds outside the baskets can see other birds and / or the bait more clearly in the wire mesh versions. Those feeding in the trap can attract the rest outside towards the food bait, acting as extra decoys. (2) The wire-mesh version is more durable than the grass traps as the latter are destroyed easily when they get into contact with water. Thus, wire-mesh versions could be used for longer times in water than the grass-made ones without being damaged. However, these traps have other advantages in relation to the grass-made ones, as they are easy to make. Their construction is less time consuming than the making of grass traps that requires skilled basket weavers.

The improved version caught more than twice as many quelea as did the traditional trap. If these traps can be used widely in all quelea invasion areas, substantial numbers of quelea can be captured which can contribute a substantial amount of protein-rich food for local people and hence generate income.

The appearance of quelea in many areas is seasonal, which limits the times when they can be caught. Large flocks of quelea invade an area when there is food, water and suitable roosting or breeding vegetation available for them. These are the considerations to be taken into account when choosing appropriate sites for successful trapping. When necessary, a supplementary food supply may help the birds to feed near the trapping site. Good results were obtained when the traps were baited heavily inside the trap and lightly around or on top of the trap.

As indicated above, when birds were feeding near the trapping site, regular checking was necessary. Sometimes, and especially when it was hot in the morning hours (from 0900 – 1100 hrs) more birds came to drink than at other times. In the evening, from 1500 – 1800 hrs quelea need to feed to build up reserves for surviving the night, rather than spend time drinking (Bruggers and Elliott, 1989). These times were ideal for regular checking as many birds got into the traps. During the study the traps were visited every one hour, although sometimes emptying was done twice in an hour as many birds entered the traps. This sometimes happened in the wire-mesh version when many birds entered the traps and required an urgent emptying. Half an hour or an hour are ideal intervals for regular checking when many flocks are coming for drinking especially during the above mentioned hours. A higher visiting rate, however, probably increases the total number of captures. There is no risk of injury or mortality to captured birds when using both of these traps, even when deployed by inexperienced trappers.

The presence of juveniles at the trapping site can also contribute to a large number being caught. This is because, when properly baited, the juveniles drive themselves into the traps to seek food. It was reported by Agricultural Officers in the district that about 4 – 6 million quelea are caught in the Kondoa district using the traditional basket traps during the peak season, although this number may be somewhat optimistic.

Potentially, traditional traps and especially the improved version are an effective technique for capturing quelea. Thus, locally adapted research based on farmers' skills and experience in quelea mass-trapping is needed to increase the potential uptake of the methods throughout quelea-infested zones of Africa.

The trapped quelea were sold by trappers to various people including women, men, young boys and girls in the village and outside the village. Quelea were bought for food at home or for selling after processing (fried in cooking oil). The price of trapped quelea during the study period demonstrated little elasticity. The trappers always obtained a premium price for quelea as there is a huge demand for them. Quelea prices went up in periods when animal and chicken meat was scarce or when few quelea were trapped. Sometimes the prices went up to Tshs. 100 for 3 – 5 fresh birds (equivalent to 30 – 50 birds per US$ 1). The women, young boys and girls then sold the fried quelea at roadsides or in local pubs for cash, usually single pieces for Tshs. 50 or dried birds packed in lots of 20 birds for Tshs. 1,000 (equivalent to US$ 1).

6.2.3. Roost trap for use in "trap roost" vegetation

From the results, trapping quelea using a trap at "trap roosts" may be an ideal method which can help to minimize the number of quelea birds damaging crops. In Tanzania damage to crops is mainly caused by roosting concentrations of birds during May to December. Breeding is mainly in the central regions of Dodoma and Singida from February to April. When looking for a breeding area, quelea first roost for 3 to 5 days before securing a suitable breeding area (pers. obs.). Suitable roosting areas are near water and sometimes feeding grounds. Also quelea tend to roost in traditional roosting areas, where they commonly roost at least once every year. These traditional roosting areas are suitable sites to establish "trap roosts" in.

Large congregations of quelea at the roosting site contributed to good results during the trapping activity. In the central regions of the country quelea start arriving one to two months after the first rains in mid-February to mid-March, when the cereal crops sorghum and bulrush millet are near to their booting stage. Quelea during this time feed on natural grass seeds. It is not known why they concentrate before seeds begin to form in the crops.

However, it is probable that they recognize early crop growth that resembles natural grass such as they would find when flying behind the rain front in search of breeding areas and food (Ward, 1971). It is also possible that quelea surviving from previous seasons are able to recall areas of food concentration and return to them, possibly attracting other birds with them (Ward and Zahavi, 1973). As crops mature, bird numbers increase. Small roosts are then abandoned in favour of large ones that are better able to accommodate large numbers (La Grange, 1978). When grouped in large numbers, they start breeding. Before starting to breed, quelea usually roost in suitable vegetation which, if planted intentionally, would attract birds for a while before they move to breeding areas. Before they move for breeding, quelea in “trap roosts” could then be trapped. If “trap roosts” work effectively, they may minimize breeding by quelea as they would be trapped before they start breeding. If this can be done in many places in the country, large numbers of birds could be trapped before the breeding period and provide large quantities of food to local people.

Quelea quickly detect any modifications to their roost, when they may then keep away from it. Where serious interference is made, either by introducing foreign objects, or by removing a substantial part of the vegetation, the birds may vacate the roost completely. This behaviour was observed during the trapping activity. Birds were flying over the cut areas for some time until it was becoming dark, but eventually they joined others which were roosting in the undisturbed area with much concentration of birds. After an hour all the birds were settled into the trapped area. This behaviour contributed to the good results. Experience shows that any disturbance or alteration in the roosting area can force the birds to move to another suitable roosting place (pers. obs.). After every trial the trap was not placed on the second day as very few of the remaining birds returned to the roost.

The ideal period and place to plant the “trap roost” are important factors to consider for mass-trapping of quelea. If “trap roosts” are to be maintained in the dry season when quelea depend mostly on irrigated crops, they can be attracted to the greenness of the “trap roosts” when looking for roosting areas. The concentrations of birds that cause damage during this period can be trapped. Also if the “trap roosts” are to be maintained and found by quelea during their arrival in the area during the breeding season they would also be attracted to these areas before locating suitable breeding areas.

“Trap roosts” should ideally be situated somewhere between the crop lands and the areas of natural vegetation formerly used by quelea for roosting. Where possible, the plots should also be within a few hundred metres of a drinking place since quelea drink just before roosting for the night. “Trap roosts” should be some distance from other suitable roosting vegetation and the thicker the “trap roost” is grown the better it is for a trapping activity. Although the birds select particular roost vegetation, it seems that the site of the roost is more important than vegetation type. The birds also prefer situations in close proximity to water and to the feeding grounds.

Another important factor is disturbance as quelea do not like noises and other disturbances. “Trap roosts” should not be planted near roads or houses. Therefore, “trap roosts” should be sited in open lands away from roads, houses and other canopy vegetation into which quelea could move if they were disturbed.

6.2.3.1. Roost preferences of quelea

For a successful trapping exercise using a roost trap, the size of the “trap roost” and type of vegetation cover most preferred by quelea were the important factors. Dense vegetation cover enabled them to form crowds and an area big enough to accommodate them contributed to good results (La Grange and Jarvis, 1977; La Grange, 1989).

During this research, *Typha* spp. and an area of 20m long and 12m wide of the “trap roosts” were used. The areas were able to accommodate all the roosting birds. More research is still needed to determine what sizes of areas can accommodate a certain number of birds.

Napier grass and sugar cane have proved to have potential and be attractive to quelea and these crops can also be used by farmers as multipurpose crops (pers. obs.). The crops can be used for fodder and, when mature, sugar cane can be sold for income generation as well as for fodder. To have "trap roosts" available throughout the year, it is preferred that two trap crops or more plots of each crop of different age can be planted so that one patch can be cut and harvested in rotation with the other. At least one patch should be fully grown at any one time, especially during the first rains when quelea start coming into the area. Such a condition of the "trap roost" can contribute to good results as it will attract many birds into it. *Typha* spp. have also proved to be favoured by quelea for roosting. If these crops are maintained properly they can provide good cover for the "trap roost". The three trials were conducted in this type of cover and the activity was successful. If "trap roosts" are to be maintained in the dry season when quelea depend mostly on irrigated crops, they can be attracted to such areas for roosting. This can contribute to successful mass-trapping of quelea. The size of the area of the "trap roost" is entirely dependent on the type of netting material to be used to cover the top of the roost trap. Strong and lighter material to cover the top can be feasible for a big area, with heavy material only feasible for small areas.

6.2.4. Mist netting

Mist netting of quelea at different trial sites using locally made mist nets was a learning process for participants in the study area as no one had been using the nets for quelea trapping. The netting was performed in various types of vegetation such as sugar cane, rice fields, *Typha* spp. and *Acacia* spp. where quelea were feeding, roosting or nesting.

The author, who had been using the nets for other purposes, had to train the local people who assisted in the research before and during the netting exercise. Local people were first trained to make the nets from the normal fish netting materials. Also the people were trained in the use of the nets for quelea trapping and extracting. Improvements were made as experience was gained allowing more nets to be put up and larger numbers of birds to be caught. In a trial at Iyoli the highest total achieved was >19,000 birds per day and a catch of 395 per net compared to 46 per net when the trapping activity was started in the breeding colony. Local people made an important contribution to the work, helping to carry the equipment to the sites, putting up the nets and extracting the birds. In some places people helping changed and the new ones had to be shown what to do. But in other places people were maintained for the whole exercise. This is because teams of people were formed to monitor certain nets while supervised by the researcher. On one occasion, a local team was left in charge of the nets and they managed to extract over 500 birds on their own. The work of extracting the birds was quite demanding physically in that it required the person extracting birds to be standing in the sun for six or seven hours per day, plus the exertion required to reach the site on foot and to erect the nets. The achieved results were made with the contribution of the local people who assisted to the end of the exercises. The highest catches were made when the catching continued until dusk. The catching was higher in the morning, from 0900 to 1100 hours. The catching was also higher in the evening from 1500 to 1800 hours as the birds were coming into the catching area to roost as well as those returning to their nests. It is essential that the number of the nets be limited to that which can be effectively managed with trappers or supervised with field officers as a large number of birds can be caught.

Mist nets, like fishnets, consist of fine, thin, nylon threads (see Plate 5.19). To be effective, the shelf strings must be tight. The key to effective use of mist nets is proper installation and when they are erected attention to the nets is needed (McClure, 1984).
Qualified personnel are needed to attend the nets and to quickly untangle and release the birds (Bub, 1991; Sharp and Saunders, 2004). Thus, during the research, local people were trained to be able to release the caught birds where possible, without injuries to them.

Successful results were obtained, eventually, through keen observation of the location and direction of flight paths. These are the best important factors to observe prior to trapping quelea in their roosting sites or breeding colonies. Before setting the net, it is best to note the flight path or paths that the quelea use to enter and exit the breeding colony or night roost. The best location to install the mist net is where it will intersect the path taken by the majority of the birds. When quelea are flying into the mist net, they seldom hit the net perpendicular to it (90 degree angle), but usually hit it at a lesser angle and lose air speed almost immediately. They fall down the net and into the shelves where they remain until removed (McClure, 1984).

Poles are also very important elements in installing the mist net. Strong and long enough poles are important to erect and support the mist net directly in the observed flight path in all types of conditions. The poles should be light enough to be portable. This is because sometimes trapping equipment needs to be carried a long distance from the end of the road where a vehicle is parked to the trapping site. It is better to use a set-up that allows raising and lowering the mist net quickly and repeatedly after extraction of the birds. Strong wooden poles or cast iron bars of maximum diameter of 2 to 2.5cm are preferred. The height of the poles can range from 3-4 m long. Where mist nets need to be raised higher than the available cast iron bars, posts can be added by using simple end-to-end couplers (Bub, 1991; Sharp and Saunders, 2004). Such poles will be useful in different places where vegetation heights differ.

A total of 10 nets was about the maximum that could be handled by one responsible leader with four trappers in one day, if the nets were to be taken down again at night and there was a large number of birds being caught.

Trapping areas, especially colonies far from villages, were most efficient if a camp was set up in the vicinity of each colony or roost and catches were made all day, with perhaps longer periods for rest in between extracting the birds. This would require more logistic support but could allow catches to increase to perhaps 4,000 or 5,000 birds per day for one team with 10 nets in the first few days before the population is reduced. The efficiency of the nets would also improve if the nets were tethered, reducing their tendency to billow to one end if there was a wind blowing and causing substantial numbers of birds to bounce out. The nets would also be easier to handle if they were dyed with a permanent dye that did not come off when touched. Further trials need to be done using parallel lanes of nets to catch those that may bounce out. The parallel lanes were tried in one trial and seemed to be effective. Those birds which bounced out of the nets were caught in the parallel lane. More research is needed to observe the effect of this practice on mass capture of quelea.

At the Mamba/Makutupora colony, an area of about 1.5ha, the two days of catching were insufficient to show a strong impact on numbers although some of the nests nearest the nets were deserted. If it had been possible to continue with trapping for another three or four days of all day catching, it might have succeeded in controlling the colony. However, there was another patch of the colony, about 0.5ha in area, a few hundred metres to the east and this would also have needed several days of catching in order to have an impact on the population and to reduce the number of birds attacking the crops.

More research is needed to observe the impact of both trapping and disturbance which can cause birds to desert the trapping sites in relation to protection of crops from bird damage.

Generally, the environmental impact of the netting was limited to the catching of non-target birds. Throughout the catching period the number caught was very low compared with the total number of birds extracted from the nets. Most of them were released unharmed. Even if all the birds caught had been killed, the number affected would probably have been very much lower than if the sites had been treated with organophosphate aerial spraying. The types of birds affected by the spray would also be greater and would probably include raptors and scavengers, as well as predatory or scavenging mammals. It is believed that with a little training of agricultural staff and other trappers they would soon learn to extract non-target birds without harming them. On the other hand local people would be likely to kill them and use them as food whatever species was caught in the nets, or, alternatively, would injure the birds sufficiently that they would not survive. To avoid this it is suggested that the nets should only be used for quelea and that the Government permit only quelea to be killed. It is considered that this edict was likely to be followed mainly because catching quelea in a breeding colony was an effective way to achieve good catches and the local people were used to eating the birds. It would be difficult to police the use of the nets if they were left in the possession of the villagers. If they were left with the village chairman, it would be more likely that the nets would only be released to villagers during the quelea season.

Fine mesh mist nets are relatively inconspicuous when deployed, but choice of a netting site that helps conceal the net is very important. Erecting mist nets on sites where the outline of the net is clearly revealed against a monotonous background such as the sky, open water or uniformly coloured fields, should be avoided. Shaded sites are always preferable to sunlit areas.

A clearing in a vegetated area with a dark but variegated background is an important netting site. As quelea are most active at dawn and dusk, therefore, these are important mist netting periods as shown by the results in section 5.3.6.3.

The number of nets needed depends on the size of the colony to be targeted. About 100 nets can make an impact on a breeding colony of about 20ha for 10-15 days of trapping. It will be necessary to use 20 nets per supervisor and to have at least 5 supervisors with 10 teams each with a leader. Where colonies are far from the village ideally a comfortable camp should be established nearby so that advantage can be taken of peak catching times in the early morning and around sunset. The larger the colony, the more days will be needed to make an impact and local people also need to be encouraged to collect the chicks.

At a cost of about 6,000TzShs/net (equivalent to about £3) during the research, it seems unlikely that villages will be willing to invest in 100 nets which can be used effectively in the village. A procedure needs to be established that the village chairman notifies the local agricultural officer that a colony has been found and that catching is about to start. This would allow the Agricultural officer to visit the area and check that correct procedures are being followed. Where necessary officers from the Ministry of the Environment would also be able to check that only quelea are being caught and, in theory, non-target birds are being released. Alternatively the nets could remain the property of the local District Agricultural Office and could be provided to farmers on notification that a colony has been found. Both local people and agricultural staff involved in quelea trapping need training in the proper use of the nets and especially in extracting non-target birds without harming them.

6.2.5. Evaluation of different methods used in mass-trapping of quelea

To evaluate the relative merits of traps and nets it was necessary to consider various factors including the design or type of the trap, the trapping site, the trapping habitat, the ideal trapping time, the experience of trappers who were involved in all of the techniques, the cost of each trap and their efficiency in operation (Woodford and Hussell, 1961). All the factors mentioned differ from one method to another during the operation. Thus, it is difficult to say which method is best as each method had its own operational optimum and merits in the context of mass capture of quelea. Although some of the methods were not successful, the successful methods contributed to the successful achievement of the objectives of the research.

Although after several trials with the big traps only a few birds were caught, some good catches were obtained with the “trap roost”. Although there were good catches in USA and Tunisia for Starlings, Grackles, Cowbirds and Red-winged Blackbirds, the birds were easily attracted by the light. In contrast, when quelea were flushed by the light they flew away from the light, although on one occasion when light was used there was a catch of 42 birds. Due to difficulty of locating feasible areas for trials, only few were possible which were not enough to conclude whether the traps are feasible or not for mass-trapping of quelea. Therefore, more research in aviary and field studies are needed to observe the reaction of quelea towards lights. Also more research is needed on the use of Funnel traps which can be constructed in the design of the Heligoland trap with minor changes to suit local conditions. The trap can be constructed at the threshing grounds where quelea congregate during feeding or near the roosting sites at their last stop over before they enter into their roosting site. Baits will be provided to attract them into the trap. In the U.S.A. baits (food and water) and live decoys were used. No such elements were used during this research with big nets. More research is needed to observe the reaction of quelea with such elements with big nets. The trap should be constructed in such a way that it can be easily moved to other places as the trapping sites will be changed.

During the study, it was observed that quelea, like starlings, are attracted to baits, water and live decoys, as these were used successfully with the traditional basket traps and with the wire-mesh versions.

As the big traps were not used in the study area before, people who assisted in driving birds into the traps were not experienced with such traps. Also a variety people were used at every trial and so there was poor coordination with trappers being trained on an *ad hoc* basis. When driving quelea towards the trap with too much disturbance, especially noise, it can easily scare them away from the trap. Sometimes this can cause quelea to desert an area in favour of another and hence protect the crops in the first area.

The traditional basket traps and the improved wire-mesh versions were so successful that they can make a valuable contribution to the livelihoods of people, providing useful proteinaceous food and generating income. The wire-mesh versions caught more than the grass made ones. These traps, if employed in various areas where quelea are a problem, can help in catching many birds which can contribute to the provision of food and generate income for local people. The wire-mesh version can be used at almost every place where quelea are available as the material can be found in many shops, whereas the grass for making the basket traps is only found in certain areas. Also as mentioned before, making of the grass traps needs an expert while the wire-mesh version needs little expertise. The traditional traps are also good as many bird problems occur after the main rainy period in many parts of the country. This is from June to December, including the irrigated crops. Such a trap is recommended to be used in many parts of the country wherever quelea are pests.

The mist nets also provided good catches. The nets can be used all year round, but are most successful in breeding colonies. The nets were used in daylight as well as at night. Also the nets were able to be used at feeding, drinking, roosting and nesting sites (Schmidt *et al*., 1986).

Mist nets are very effective at different sites and under many different conditions compared with the traditional traps which work only in the dry season when drinking water is very scarce and conditions are hot. But the traditional trap has an advantage over the mist net in that extracting the birds from the traps is much easier than from the mist net. For example, extracting 100 birds from a mist net can take about 30 minutes for a professional trapper, while the same number of birds can be removed from a trap in about 10 minutes. Sometimes this time for extraction can vary depending on the way the birds are entangled in the net.

A mist net at a breeding colony at Iyoli was able to catch an average of 400 birds per day. When employing about 100 mist nets at each trapping site, a very good catch could be obtained. The reactions from farmers indicated a relief from bird pests in their farms and reduced bird activity at the trapping sites. This implied reductions in bird populations at the sites, indicating that at least small colonies could be controlled by a combination of netting and chick collection. It should be borne in mind that quelea with chicks are very difficult to induce to desert their colony through disturbance, in contrast to quelea with new nests or nests with one or two eggs. As observed in Mwitikila, quelea in a 5 day old colony with at least two eggs were forced into desertion by local people's disturbances, while the colony at Iyoli remained for the whole period of trapping as it had chicks from the outset of the netting operation. From the results obtained, with the permission given by the Ministry of Natural Resources, trappers and many farmers have established a thriving commercial trapping enterprise.

Mist nets have the advantage of being portable and easy to set up, can cover a wide trapping area, and are easily movable from place to place to take advantage of local movements of birds, which is not the case with the big nets (Williamson, 1957). The initial cost of the nets was lower than that for the big nets and they can be easily operated by few people, as even amongst high density populations, two people can manage five mist nets. Some disadvantages of mist nets are that they need regular checking and experienced bird trappers to operate them (Woodford, 1959, Woodford and Hussell, 1961).

The roost-trap was aimed at covering small roosting sites of about 12 x 25m. The three trials done showed good catches of 5,000, 17,000 and 13,000 birds per trial, respectively. The trapping was done in the dark after the birds had settled for roosting. The first trial was not so successful as the net stuck on some poles, and the covering was not done quickly enough. The next two trials were more successful after adjusting for some problems experienced in the first trial. This trap showed promising achievements in reducing bird populations as well as providing food and income for local people.

Generally, traps used for bird trapping cannot be used successfully under all circumstances. Some areas are inaccessible, others have insufficient open areas in which to operate and some places have almost impenetrable vegetation where thinning may be necessary. Sometimes during the rainy seasons some areas can be flooded with water thus making it difficult to work in them, whilst in some areas birds may cover large areas, through which the birds are spread too thinly where the birds are apt to by-pass the traps (Mitchell, 1963). Traps used in mass-trapping also differ in shape and design. This allows them to be used in different situations, seasons or times and conditions. This provides some advantages of using a variety of different traps in different situations, times and conditions.

Improvements to traps and improving operational methods are always necessary depending on different factors involved in trapping activities. Small, portable, and less expensive traps have to be modified and are satisfactory and more convenient to use. The objective is to adapt traps for better use in different trapping situations and to improve their usefulness in catching large numbers of birds for food and for income generation (Mitchell, 1961), and where necessary as a device for bird control.

Emphasis is now being placed on improving catches and processing of quelea meat by local trappers to improve supplies for domestic markets and when possible to take advantage of high prices for quelea meat products in overseas markets. This is currently prohibited by most countries because of fear of importing avian influenza (H5N1 virus).

However, if substantial numbers of quelea can be caught locally, then there is the potential for a substantial number of people to benefit from any establishment of a long-term mass-capture programme in Tanzania.

Interviews conducted with trappers and farmers in the study areas disclosed that the trapping trials became very productive after deployment. Trappers and farmers were willing to continue trapping if they were allowed to and given trapping equipment. Formerly, quelea trapping was conducted illegally by local trappers but this project obtained permission for the activity from the Ministry of Natural Resources. Subsequently, some trappers and farmers were willing to buy mist nets (locally made from fishing nets) and began their own quelea trapping activities. To maintain this momentum, trapping techniques need to be improved and continued as part of an intensive programme. The methods tried during the research can be used by the trappers as well as other farmers. As not all the methods were possible for all conditions and situations, some were good during the rainy season and some in the dry season, as described above. Also some methods were good in breeding colonies while others in roosting sites. Other methods were costly while others were cheaper to be managed by farmers themselves. Therefore, different factors can guide which method should be employed under different conditions.

Although the catches with various mass-trapping methods were substantial, they may have amounted to far too little to affect the overall quelea population present in Tanzania. Even though the methods were not suited for bird control, they provided a good source of food and income to local communities, thereby achieving the study objectives:

- To assess potential mass-trapping methods for quelea and the potential use of quelea for food and for income generation
  and
- To determine the feasibility of mass-trapping techniques using nets for controlling quelea birds.

Finally, further investigations need to be carried out on how best the methods should be implemented, regulated and where necessary operated by trained personnel. If the methods are to be used as bird control methods, more research and use of these methods needs to be carried out throughout the country where quelea are a problem to evaluate whether the methods can serve as an alternative to or merely supplementary to existing bird pest control methods such as spraying with avicides.

6.3. Forecasting breeding opportunities for the Red-billed Quelea (*Quelea quelea*) in Tanzania

This topic was discussed in Chapter 3 (see section 3.5.2.)

6.4. Training of farmers, trappers and extension service personnel in mass-trapping and use of quelea as a resource.

Training of farmers, trappers and extension service personnel who assisted during the execution of the research was very important. The aim was to sensitise them to the objectives of the research and eventually to promote the quelea mass-trapping technology to the villagers or farmers who will be able to utilize it for their economic benefit. The objective of the training was to integrate stakeholders' input at all levels of technology development and transfer. The stakeholders needed to have knowledge of the trapping methods as well the trapping devices to be used. This also will aid in the transfer of information to reach the wider producers and consumers throughout Tanzania. The learning was aimed at assisting the stakeholders to acquire the knowledge and skills with the intention that they might then contribute towards the achievement of some of the main activities of the research and disseminate the information to other people. During the training the knowledge, concepts and skills to be acquired were communicated in various ways such as joint participation, technical meetings, trade shows, and information dissemination (Greenhalgh *et al*., 2004).

During the training it was expected that everyone involved should gain a shared understanding of the needs and interests of the different people who use quelea within the community and an accurate picture of the existing and potential uses of quelea and their products. It was expected that the interpretation and application of training results will depend on the experience of the community members have on quelea. By showing an interest in new ideas and asking for peoples' opinions and suggestions, it was possible to uncover a whole new range of knowledge not available to them before. The training also provided an opportunity to meet groups that had not previously participated in quelea trapping activities.

During the Farmers' Show informal training was conducted for people who attended the quelea stand. Issues on quelea trapping, processing and use were addressed and were very interesting issues which even attracted media people, who started to advertise the demonstration. From their advertisement many additional people were attracted to the shows. Journalists from print and electronic media joined the visit of Ministers at the show. Print media such as *Mwananchi*, *Mtanzania* and *Nipashe* published some pictures and articles on quelea activities. Electronic media like *Tanzania Broadcasting Co-operation Ltd* provided some Radio and Television coverage. They also had short programmes on quelea trapping, processing and use. The programmes were presented in different styles, both during the News and in special programmes of 2, 5, 15 and 40 minutes (see Appendix 3). The mass-media programmes were aimed at large populations and were intended to catch people's attention and arouse their interest in quelea trapping, processing and use. The programmes created general awareness of quelea trapping through mass-capture methods as well as effectively increasing the public's knowledge of the processing and use of quelea as a source of food and income generation.

Involvement of different people in the research helped to achieve the goals. Some provided the relevant information required, while others engaged themselves to almost every kind of work that was initiated. Some assisted in carrying equipment to the site, putting up the nets or traditional basket traps and the wire-mesh versions and extraction of the birds from nets and traps. In some places, like Solya and Mamba, most of the people participating changed each day and new people had to be trained in the activities. On several occasions, local people were left by themselves carrying out the trapping activities under the researcher's supervision. More practice and experience resulted in good catching of quelea. The efficiency of the nets and basket traps also improved as trappers learned proper ways of putting up the nets and setting the basket traps.

The training stimulated and enhanced the capacity of the trappers of quelea through linking quelea products with market channels to process the birds and to sell them as value added products. Also, it strengthened the research–extension and local marketing linkages, dissemination capacity of the trappers and users of quelea. Empowering the stakeholders (involved in quelea business) in respect of their initiatives was undertaken for the technology transfer mechanisms.

6.5. Conclusions

Substantial numbers of quelea could be caught, providing useful proteinaceous food to local people, using mist nets, traditional baskets and the improved wire-mesh versions, the roost trap and chick harvesting. At least small colonies in accessible areas could be controlled by a combination of netting and collecting the chicks when many people could be organized with a sufficient number of nets. When many people could be involved in the trapping activities, especially when using mist nets, 100 nets can make substantial catches and hence reduce the number of birds which could destroy crops in a circumscribed area.

The research established catching quelea as an alternative method of small breeding colony or night roost management. If the methods were carried out in different parts of the country where quelea pose a problem it is anticipated that they will contribute substantially to bird pest control programmes.

The mass-capture techniques have allowed substantial numbers of birds to be eaten by local people as healthy uncontaminated food. The methods could also make an important contribution to people's well-being as they provide quelea as a good proteinaceous food to local people and to some limited extent can compensate farmers for the losses to their crops. The mass-capture methods are an alternative to aerial spraying of pesticides at small colonies or roosts which could limit the use of pesticides and reduce their negative side-effects on human health and the environment. Mass-trapping of quelea for providing residue-free birds for protein supply and income generation could contribute to economic growth and poverty alleviation of resource-poor small holders. The results of this research have opened up grounds for future research work, outlined in the next section.

6.6. Future Research

Further research needs to be carried out to develop clear methodologies, to decide how best to train agricultural staff and other stakeholders and on regulation of the procedures to ensure that the traps are used exclusively for quelea, avoiding their use for non-target birds.

Further research needs to be carried out to determine how best to use the birds caught as human food for local people and, when and where possible for foreign markets, and to delineate the areas where the cultural tradition would favour such an approach.

As some colonies were deserted through human disturbance, this needs to be studied as a potential means of protecting crops from quelea damage. Although it is likely only to move quelea from one area to another, it might serve to save the crop from damage in the first area.

Future research is required for an in-depth and critical review of world-wide mass-trapping methods, the selection from them of a wide range of potential candidate methods for quelea under the conditions prevailing in Tanzania, and the testing of these in both aviary and field.

Further development of the techniques is needed and further experience to establish the limitations of the techniques as means of controlling quelea colonies and roosts.

6.7. Recommendations

1. Given that substantial numbers of quelea could be caught using mist nets, traditional basket traps, improved wire-mesh versions of these, a roost trap and chick harvesting, these operations should be encouraged to provide proteinaceous food and income for local people.
2. The trapping methods should be considered as potential control measures for small colonies in accessible areas that could be controlled by a combination of netting and collecting the chicks, provided that enough people can be organized with a sufficient number of nets and under supervision of Ministry of Agriculture personnel.
3. With further refinement, practice and experience, the number of colonies or roosts that can be controlled by catching without recourse to aerial spraying could be gradually increased. Perhaps in the future, more than 50% of all colonies and roosts, mainly small ones, could be controlled with the methods tried and others which need to be investigated; but large colonies and roosts will still have to be controlled by aerial spraying.
4. Capacity building is needed to enhance quelea mass-trapping, processing and preservation of quelea meat. Capacity building of agricultural staff in the Zonal Plant Health Services Offices and Districts' Plant Protection Staff is very important as this will increase the number of staff with knowledge of the use of mass-trapping methods. This will also aid in the promotion of mass-trapping methods in the villages, particularly among the younger generation. A recommendation is made for training of these staff with shared knowledge and practices in the making and use of the traps. These staff need to know how to make mist nets, wire-mesh basket traps and the roost trap, locally. Processing and preservation of quelea meat methods need to be learnt by the staff to promote the marketing of quelea meat.
5. Building and forming networks both internally and externally is also important in sustaining quelea mass-trapping and its use as a resource. In most of the communities, there are village institutions (e.g. community development

committees) which could act as linkages for entry into the community for implementing mass-trapping activities.

6. For sustainability of the activity, the Government of Tanzania needs to include it in their development programmes. As many people are willing to eat quelea and some methods have shown promising results then efforts should be made to approach donors for support for follow-up work, more capacity building of the stakeholders and more research. The sustainability of mass trapping will only be achieved if many Tanzanians become involved in the activity. This means trapping, use and marketing (Kotler and Armstrong, 2007). Farmers or trappers involved in the activity should be provided with the appropriate technology required. Where necessary, assistance should be given to all stakeholders to be able to implement their activities.

REFERENCES

Acland, J. D. (1971) *East African Crops. An introduction to the production of field and plantation crops in Kenya, Tanzania and Uganda*. Longman Group Limited, London.

Adolph, B. (1999) People's participation in natural resource management: experience from watershed management project in India. Margraf, Dirk Hanstein, Weikersheim, Germany.

Allan, R. G. (1996) *Grain-eating birds of sub-Saharan Africa: identification, biology, and management*. Natural Resources Institute, Chatham, U.K.

Allan, R. G. and Jackson, J. J. (1974) Notes on the behaviour of male *Quelea* in nesting colonies with implications for control. Unpubl. Rep., Food and Agriculture Organisation of the United Nations (FAO) Regional Project RAF/73/055, Rome, Italy.

Anthes N. (2004) Long-distance migration timing of *Tringa* sandpipers adjusted to recent climate change. *Bird study* 51: 203-211.

Babbie, E. (1997) *Survey methods.* Second edition. Wadsworth, California, U. S. A.

Bashir, E. A. (1989) Traditional African practices for preventing bird damage. Pp 248-261 in Bruggers, R. L. and Elliott, C. C. H. (eds.) *Quelea quelea: Africa's bird pest.* Oxford University Press, Oxford, U.K.

Beentje, H. J., Adams, B. and Davis, S. D. (1994) Region overview: Africa. Pp 101-118 in S. Davis, V.H. Heywood and A.C. Hamilton (eds.) *Centres of Plant Diversity: A Guide and Strategy for their Conservation* Vol. 1. WWF and International Union for Conservation of Natural Resources, Gland, Switzerland.

Berman, D., Eldridge, S., Adams, N., Schwartkopft, S. and Bryan, R. (1996) Feral pigeon eradication program. Alice Springs, 1993 – 1995. Northern Territory Parks and Wildlife Commission, Australia.

Bridges, E. M. (1990) *World Geomorphology*. Cambridge University Press, Cambridge, U.K.

Brooke, C. (1967) The heritage of famine in central Tanzania. *Tanzanian Notes and Records* 67: 15-22.

Brown, L. H. and Britton, P. L. (1980). *The breeding seasons of East African birds*. East African Natural History Society, Nairobi.

Brown, L. H., Urban, E. K. and Newman, K. (1982). *The birds of Africa,* Vol. 1. Academic Press, London, U. K.

Brownlow, H. G. (1952) The design, construction and operation of Heligoland traps. *British Birds* 65: 387-399.

Brownlow, H. G. (1955) Reconstruction of Heligoland traps. *Bird Study* 2: 86-87.

Bruggers, R. L. (1989) Assessment of bird-repellent chemicals in Africa. Pp 262-280 in: Bruggers, R. L. and Elliott, C. C. H. (eds.) *Quelea quelea: Africa's Bird Pest,* Oxford University Press, Oxford, U.K.

Bruggers, R.L., Jaeger, M.M., Keith, J.O., Hegdal, P.L., Bourassa, J.A., Latigo, A.A. and Gillis, J.N. (1989) Impact of fenthion on nontarget birds during Quelea control in Kenya. *Wildlife Society Bulletin* 17: 149-160

Bub, S. D. (1991) *Bird trapping and bird banding; a handbook for trapping methods all over the World*. Cornell University Press, Ithaca, New York, U.S.A.

Campbell, B., Frost, P. and Byron, N. (1996) Miombo woodlands and their use: overview and key issues. Pp. 1-10 in Campbell, B. (ed.) *The Miombo in transition: woodlands and welfare in Africa*. CFIOR, Bogor, Indonesia.

Cheke, R. A. (2003) Forecasting movements and breeding of the Red-billed Quelea bird in southern Africa and improved control strategies. DFID Crop Protection Programme, Final Technical Report, Project R7967. Natural Resources Institute, University of Greenwich, U.K.

Cheke, R. A. and Tratalos, J. A. (2007) Migration, patchiness, and population processes illustrated by two migrant pests. *Bioscience* 57: 145-154.

Cheke, R. A., Venn, J. F. and Jones, P. J. (2007) Forecasting suitable breeding conditions for the Red-billed Quelea *Quelea quelea* in southern Africa. *Journal of Applied Ecology* 44: 523-533.

Cotton P. A. (2003) Avian migration phenology and climate change. *Proceedings of the National Academy of Sciences U.S.A.* 100: 12219-12222.

Creswell, J. W. (2003) *Research design: qualitative, quantitative and mixed methods approaches*. Second Edition. Sage Publications, Thousand Oaks, California, U.S.A.

Crook, J. H. (1957) Bird damage and crop protection in west Africa. CSA Symposium on Quelea. Livingstone 1957. Bukavu CCTA/CSA Joint Secretariat. QB4. 13pp.

Dallimer, M. and Jones, P. J. (2002) Migration orientation behaviour of the red-billed quelea *Quelea quelea. Journal of Avian Biology* 33: 89-94.

Dallimer, M., Blackburn, C., Jones, P. J. and Pemberton, J. M. (2002) Genetic evidence for male biased dispersal in the red-billed quelea *Quelea quelea. Molecular Ecology* 11: 529-533.

De Grazio, J. W. (1989) Pest birds: an international perspective. Pp. 1-8 in Bruggers R. L. and Elliott C. C. H. (eds.) *Quelea quelea. Africa's Bird Pest*. Oxford University Press, Oxford, U.K.

Disney, H. J. d. S. and Haylock, J.W. (1956) The distribution and breeding behaviour of the Sudan dioch, (*Quelea quelea aethiopica*) in Tanganyika. *East African Agricultural Journal* 21: 141-147.

Dyer, M. I. and Ward, P. (1977) Management of pest situations. Pp. 267-300 in Pinowski, J. and Kendeigh, S. C. (eds.) *Granivorous birds in ecosystems.* Cambridge University Press, Cambridge, U.K.

Easterby-Smith M., Thorpe, R. and Lowe, A. (2002) *Management research, an introduction*. Second edition, Sage, London.

Edmondson, A. and McManus, S. (2007) Methodological fit in management field research. *Academy of Management Review* 32: 1155-1179.

Elliott, C.C. H. (1979) The harvest time method as a means of avoiding quelea damage to irrigated rice in Chad/Cameroon. *Journal of Applied Ecology* 16: 23-35.

Elliott, C. C. H. (1989a). The pest status of Quelea. Pp. 17-34 in Bruggers R. L. and Elliott C. C. H. (eds.) *Quelea quelea. Africa's Bird Pest*. Oxford University Press, Oxford, U.K.

Elliott, C.C.H. (1989b) The quelea as a major problem in a food-deficient continent. Pp. 90-99 in: Mundy P.J. and Jarvis M.J.F. (eds.) *Africa's Feathered Locust*. Baobab Books, Harare, Zimbabwe.

Elliott, C. C. H. (1990). The migrations of the red-billed quelea *Quelea quelea* and their relation to crop damage. *Ibis* 132**:** 232-237.

Elliott, C. C. H. (2006) Bird population explosions in agroecosystems – the quelea, *Quelea quelea*, case history. *Acta zoologica Sinica* 52 (Supplement): 554-560.

Elliott, C. C. H. and Allan, R. G. (1989) Quelea control strategies in practice. Pp. 317-326 in Bruggers R. L. and Elliott C. C. H. (eds.) *Quelea quelea. Africa's Bird Pest*. Oxford University Press, Oxford, U.K.

Elliott, C. C. H. and Bruggers, R. L. (1989) Conclusions and future perspectives. Pp. 252-256 in: Bruggers R. L. and Elliott, C. C. H. (eds.) *Quelea quelea Africa's Bird Pest*. Oxford University Press. Oxford, UK.

Ellis, F. (2000) Determinants of rural livelihood diversification in developing countries. *Journal of Agricultural Economics* 51: 259-302.

Erickson, W.A. (1989) Feeding Ecology of quelea Pp 230-247 in: Bruggers R. L. and Elliott, C. C. H. (eds.) *Quelea quelea Africa's Bird Pest*. Oxford University Press. Oxford, UK.

Erickson, W. A. and Damena, A. (1982) Breeding of red-billed queleas (*Quelea quelea*) in relation to rainfall patterns in Ethiopia. FAO/UNDP Regional Quelea Project ETH 77/022, Food and Agriculture Organisation of the United Nations (FAO), Rome, Italy.

Frost, P. (1996) The Ecology of Miombo woodlands. Pp. 299-326 in B. Campell, (ed.) *The Miombo in transition; woodlands and welfare in Africa*. CFIOR, Bogor, Indonesia.

Gadd, P. J. (1996) Use of the modified Australian crow (Mac) trap for the control of depredating birds in Sonoma county. *Proceedings of the 17th Vertebrate Pest Conference,* 103-107. California, U.S.A.

Gunn, W. W. H. (1954). The bird-banding project at Point Pelee National Park. *Bulletin of the Federation of Ontario Naturalists* 66: 24-28.

Hamilton, A. C. and Bensted Smith, R. (1989) *Forest conservation in the east Usambara mountains, Tanzania*. Pp. 1–392. in Hamilton, A.C. and Bensted-Smith, R. (eds.) International Union for Conservation of Nature and Natural Resources, Gland, Switzerland.

Haylock, J. W. (1959) *Investigation on the habits of Quelea quelea and their control.* Department of Agriculture. Nairobi, Kenya.

Holt, J., Mushobozi, W. L. and Tucker, M. R. (2000) Modelling armyworm population dynamics to forecast outbreaks. Pp. 151-163 in Cheke R.A., Rosenberg, L.J. and Kieser, M. (eds.) *Workshop on research priorities for migrant pests of agriculture in southern Africa*. Plant Protection Research Institute, Pretoria, South Africa, 24-26 March 1999. Natural Resources Institute, Chatham, U.K.

Hussell, D. J. T and Woodford, J. (1961) The use of a Heligoland trap and mist-nets at Long Point, Ontario. *Bird-Banding* 32: 115-125.

Inglis, I. R. (1985) Humane control of rural birds. In Britt, D.P. (ed.) *Humane control of land mammals and birds*. Proceedings of a symposium held at the Univ. of Surrey, Guildford, Surrey, 17-19 September 1984. Universities Federation for Animal Welfare (UFAW). Potters Bar, England. Hyperion Books, New York, U.S.A.

Jackson, J. and Park, P.O. (1973) The toxic effects of fenthion on a nesting population of queleas during experimental control by aerial spraying. *Proc. 6th Bird control seminar* Bowling Green, Ohio, 6, 53-73.

Jaeger, M. E. and Jaeger, M. M. (1977) Quelea as a resource. Unpubl. Internal Rep; FAO/UNDP Quelea Project RAF/73/055, FAO, Rome, Italy.

Jaeger, M. M., Bruggers, R. L., Johns, B. E. and Erickson, W. A. (1986) Evidence of itinerant breeding of the red-billed quelea *Quelea quelea* in the Ethiopian Rift Valley. *Ibis* 128: 469-482.

Jaeger, M. M., Elliott, C. C. H., Bruggers, R. L and Allan, R. G. (1989) Distribution, populations, and migration patterns of quelea in eastern Africa. Pp. 113-131 in Bruggers R. L. and Elliott C.C. H. (eds.) *Quelea quelea. Africa's Bird Pest.* Oxford University Press, Oxford, U.K.

Jaeger, M. E. and Elliott, C. C. H. (1989). Quelea as a resource. Pp. 327-338 in Bruggers R. L. and Elliott C.C. H. (eds.) Quelea quelea. *Africa's Bird Pest.* Oxford University Press, Oxford, U.K.

Jaeger, M.M. and Erickson, W. A. (1980) Levels of bird damage to sorghum in the Awash Basin of Ethiopia and the effect of control of quelea nesting colonies (1976 – 1979). Proc.9th Vertebrate Pest Conference, Fresno, California, 9, 21-28.

Jaeger, M. M., Erickson, W. A. and Jaeger, M. E. (1979) Sexual segregation of red-billed quelea *(Quelea quelea*) in the Awash River Basin of Ethiopia. *Auk* 96: 516-524.

Jarvis, M. J. F. and La Grange, M. (1989) *Conservation, Quelea control and the trap roost concept*. Pp. 130-134 in Mundy, P. J. and Jarvis M. J. F (eds.) *Africa's Feathered Locust*. Baobab Books, Harare, Zimbabwe.

Jarvis, M. J. F. and Vernon, C.J. (1989a) Notes on quelea ecology in southern Africa. Pp. 50-68 in Mundy, P. J. and Jarvis, M. J. F (eds.) *Africa's Feathered Locust*. Baobab Books, Harare, Zimbabwe.

Jarvis, M. J. F. and Vernon, C.J. (1989b) Food and feeding habits of queleas in southern Africa. Pp. 24-35 in Mundy, P. J. and Jarvis, M. J. F (eds.) *Africa's Feathered Locust*. Baobab Books, Harare Zimbabwe.

Jenni, L. and Kéry, M. (2003) Timing of autumn bird migration under climate change: advances in long-distance migrants, delays in short-distance migrants. *Proceedings of the Royal Society of London* series B270: 1467-1471.

Johnson, R. B., Onwuegbuzie, A. J. and Turner, L.A. (2007) Toward a definition of mixed methods Research. *Journal of mixed methods Research* 1: 112-133.

Johnson, R. W. and Burrows, W. H. (1994) Acacia forests, woodlands and shrublands. Pp. 257-290 in Groves, R.H. (ed.) *Australian vegetation.* Cambridge University Press. Cambridge, U.K..

Jones, P. J. (1972) The status of *Quelea quelea* in Botswana and recommendations for its control. Unpublished report. Ministry of Agriculture, Botswana Government, Gaborone, Botswana.

Jones, P. J. (1989a) General aspects of quelea migration. Pp. 102-112 in Bruggers, R. L. and Elliott, C. C. H. (eds.) *Quelea quelea. Africa's Bird Pest.* Oxford University Press, Oxford, U.K.

Jones, P. J. (1989b) Distribution, populations, and migration patterns of quelea in southern Africa. Pp. 132-143 in Bruggers, R. L. and Elliott, C. C. H. (eds.) *Quelea quelea. Africa's Bird Pest.* Oxford University Press, Oxford, U.K.

Jones, P. J. (1989c) Factors determining the breeding season and clutch size. Pp. 158-180 in Bruggers, R. L. and Elliott, C. C. H. (eds.) *Quelea quelea. Africa's Bird Pest.* Oxford University Press, Oxford, U.K.

Jones, P. (1989d) The breeding cycle of quelea and factors initiating breeding. Pp. 36-49 in Mundy, P. J. and Jarvis, M. J. F. (eds.) *Africa's Feathered Locust*. Baobab Books, Harare, Zimbabwe.

Jones, P. J., Cheke, R. A. and Bousfield, N. (2007) Flexibility in the timing of post nuptial moult among red-billed quelea *Quelea quelea* in Botswana in relation to the timing of breeding. *Ostrich* 78: 555-559.

Jones, P. J., Cheke, R. A., Mundy, P. J., Dallimer, M. and Venn, J. F. (2000) Quelea Populations and Forecasting in Southern Africa. Pp. 139-150 in Cheke, R. A., Rosenberg, L.J. and Kieser, M. E. (eds.) *Workshop on research priorities for migrant pests of agriculture in southern Africa*. Plant Protection Research Institute, Pretoria, South Africa, 24-26 March 1999. Natural Resources Institute, Chatham, U.K.

Jones, P. J. and Ward, P. (1976) The level of reserve protein as the proximate factor controlling the timing of breeding and clutch-size in the red-billed quelea *Quelea_quelea*. *Ibis* 118: 547-574.

Kideghesho, J. R. (2001) The status of wildlife habitats in Tanzania and its implications to biodiversity. *Kakakuona: Tanzania Wildlife Magazine on Nature, Conservation and Environment* 21: 9-17.

Kinnear, T. C. and Root, A. R. (1988) *Survey of Marketing Research*. American Marketing Association, Chicago, U.S.A.

Kotler, P. and Armstrong, G. (2007) *Principles of Marketing.* Pearson Education, Prentice Hall Inc., New Jersey, U.S.A.

La Grange, M. (1978) *The study of vegetation structures used by quelea in Rhodesia.* Unpublished Certificate in Field Ecology thesis, University of Rhodesia, Salisbury, Zimbabwe.

La Grange, M. (1989) Social behaviour and vegetation preferences of quelea during roosting. Pp. 104-110 in Mundy, P. J. and Jarvis, M. J. F. (eds.) *Africa's feathered locust*, Baobab Books, Harare, Zimbabwe.

La Grange, M. and Jarvis, M. J. F. (1977) *Quelea finch ground control manual*. Dept. of National Parks, Harare, Zimbabwe.

Lowe, K. W. (1989) *The Australian bird banders manual*. Australian National Parks and Wildlife Service, Canberra

Manikowski, S., Bortoli, L. and N'diaye, A. (1989) Distribution, populations, and migration patterns of quelea in western Africa. Pp. 144 - 157 in Bruggers, R. L. and Elliott, C. C. H. (eds.) *Quelea quelea. Africa's Bird Pest.* Oxford University Press, Oxford, U.K.

Matee, J. J. (1999) Is Mkomazi a potential reservoir of avian crop pests? Pp. 455-461 in Coe, M., McWilliam, N., Stone, G. and Pocker, M. (eds.) *Mkomazi ecology, biology and conservation of a Tanzanian savanna*. Royal Geographical Society, London, U.K.

Matee, J. J. (2002) Bird damage and control. Tropical Pesticides Research Institute, Arusha, Tanzania. Pp. 98-100 in: in Pimentel, D. (ed.) *Encyclopaedia of Pest Management*, Cornell University, Ithaca, New York, U.S.A.

Matee, J. J. and Tarimo, T. M. C. (2006) Major bird pests and their management. Pp. 293-310 in Makundi, R. H. (ed.) *Management of selected crop pests in Tanzania*. Management Centre, Tanzania Publishing House Limited, Dar-es-Salaam, Tanzania.

Mbuya, L.P., Msanga, H. P., Ruffo, C. K., Birnie, A. and Tengnas, B. (1994) *Useful trees and shrubs for Tanzania. Identification, propagation and management for agricultural and pastoral communities.* Regional Soil Conservation Unit/SIDA. English Press, Nairobi, Kenya.

McClure, E. (1984) *Bird banding.* The Boxwood Press, Pacific Grove, California, U.S.A.

McLauglin, A. and Mineau, P. (1995) The impact of agricultural practices on Biodiversity. *Agriculture Ecosystems and the Environment* 55: 201-212.

McNiesh, R. P. E. (2007) Site selection for bio-energy project. Harris Group Inc., St. Petersburg, Russia.

McWilliam, A. N. & Cheke, R. A. (2004) A review of the impacts of control operations against the red-billed quelea (*Quelea quelea*) on non-target organisms. *Environmental Conservation* 31: 130-137.

Meinzingen, W. W. (1993). *A guide to migrant pest management in Africa*. FAO, Rome, Italy.

Meinzingen, W. W., Bashir, A. E., Parker, J. D, Heckel, J. and Elliott, C. C. H. (1989) Lethal control of quelea. Pp. 293-316 in Bruggers, R. L. and Elliott, C. C. H. (eds.) *Quelea quelea: Africa's Bird Pest*. Oxford University Press, Oxford, U.K.

Miller, G. T. (2004) *Sustaining the Earth.* Sixth edition. Thompson Learning Inc., Pacific Grove, California, U.S.A.

Miller, G.T. (1998) *Living in the environment: principles, connection, and solution.* Wadsworth Publishing Company, Belmont, Calfornia, USA.

Mineau, P. (2002) Bird Impacts. Pp. 101-104 in Pimentel, D. (ed.) *Encyclopedia of pest management*. Cornell University Press, Ithaca, New York, USA.

Ministry of Agriculture, Food and Co-operatives (MAFSC) (2003) Quelea Control in Tanzania. Operation Reports 1997-2003. Dar-es-Salaam, Tanzania.

Ministry of Agriculture, Food and Co-operatives (MAFSC) (2000) Annual report-Quelea Control Operation in Tanzania. Dar-es-Salaam, Tanzania.

Ministry of Agriculture, Food and Co-operatives (MAFSC) (2002) Annual report-Quelea Control Operation in Tanzania. Dar-es-Salaam, Tanzania.

Ministry of Water and Irrigation (2008) Annual report. Irrigation and Water Management in Tanzania. Dar-es-Salaam, Tanzania.

Mitchell, R. T. (1963) The floodlight trap: a device for capturing large numbers of blackbirds and starlings at roosts. *U.S. Dept. Int. Special. Sci. Rep. Wildl*. 77: 1-14.

Mitchell, R. T. (1964) Assembly and operation of the floodlight trap. *U.S. Fish and Wild Serv. Spec. Sci. Rep. Wildl.report No.* 77 Sup. 7pp.

Morel, G. and Bourlière, F. (1956) Récherches écologiques sur les *Quelea quelea quelea* (L.) de la basse vallée du Sénégal. II. La réproduction. [Ecological research on *Quelea quelea quelea* L. of the lower Senegal valley. II. Reproduction.] *Alauda* 24: 97-122.

Moyo, S., O'Keefe, P. and Sill, M. (1993) *The southern environment: profiles of the SADC Countries*. Earthscan, London, U.K.

Mullié, W.C. (2000) Traditional capture of red-billed quelea *Quelea quelea* in the Lake Chad basin and its possible role in reducing damage levels in cereals. *Ostrich* 71: 15-20.

Mundy, P. J. and Heremans, M. (1997) Red-billed quelea *Quelea quelea*. Pp. 573-575 in Harrison J. A., Allan, D. G., Underhill, L. G., Herremans, M., Tree A. J., Packer, V. and

Brown, C. J. (eds.) *The atlas of southern African birds*. Vol. I. *Non-passerines*. Birdlife South Africa, Johannesburg, South Africa.

National Bureau of Statistics (2007) Analytical report – Agriculture. Ministry of Planning, Economy and Empowerment. Dar-es-Salaam, Tanzania.

National Sample Census of Agriculture (2006) *Gender profile of smallholder rural agriculture population in Tanzania mainland*. Ministryof Agriculture, Food Security and Cooperatives. Dar-es-Salaam, Tanzania.

Ndege, O. J. (2007) *Lecture notes on quelea pest management in eastern Africa*. Desert Locust Control Organisation for eastern and southern Africa (D.L.C.O.- E.A.), Nairobi, Kenya.

Omolo, D. (2004) ‘Mass killings’ of birds, Friends of Kinangop cry foul. *Nature East Africa.* 34 (1):24

Oppenheim, A. (1992) *Questionnaire design, interviewing and attitude measurement.* Continuum, London, U.K.

Oschadleus, H. D. (2000) Red-billed quelea movement in southern Africa shown by ringing recoveries in the SAFRING database. Pp. 125-135 in Cheke, R. A., Rosenberg, L. J. and Kieser, M. E. (eds.) *Workshop on research priorities for migrant pests of agriculture in southern Africa*. Plant Protection Research Institute, Pretoria, South Africa, 24-26 March 1999. Natural Resources Institute, Chatham, U. K.

Otis, D.L. (1984) *A method for Estimating Sorghum Loss to birds Over Large Areas of East Africa.* Mimeograph

Punch, K. F. (2000) *Introduction to social research: qualitative and quantitative approaches*. Sage Publications, London, U.K.

Quelea Control Operation, Tanzania, (2008) Annual report-Quelea Control Operation in Tanzania. Dar-es-Salaam, Tanzania.

Rocheleau, D., Weber, F. and Field-Juma, A. (1988) *Agroforestry in dryland Africa*. Participatory planning: process and methods. Pp. 43-72 ICRAF House. Nairobi, Kenya.

Roming, T. (1998) Behaviour of *Quelea quelea:* invasion of the species in Turkana, north-west Kenya. *Scopus* 2: 96.

Sabates-Wheeler, R. (2002) Farm strategy, self-selection and productivity: can small farming groups offer production benefits to farmers in post-Socialist Romania? *World Development* 30: 1737-1753.

Sæther, B. E., Grotan, V., Tryjanowski, P., Barbaroud, C., Engen, S. and Fulin, M. (2006) Climate and spatio-temporal variation in the population dynamics of a long distance migrant, the white stork. *Journal of Animal Ecology* 75: 80-90.

Schemnitz, S. D. (2005) Capturing and handling wild animals. Pp. 239-285 in Braun, C. E. (ed.) *Techniques for wildlife investigations and management.* The Wildlife Society, Bethesda, U.S.A.

Schmidt, K. H., Jackel, S. and Croon, B. (1986) *Mist netting at bird-feeders – a convenient method to study great tit populations? J. Orn.* 127: 61-67.

Senar, J. C. (1988) Trapping finches with the Yunick platform trap: the residency bias. *J. Field Ornithol.* 59: 381-384.

Seubert, J. L. (1963) Research on methods of trapping the Red-winged Blackbird (*Agelaius phoeniceous*). *Angewandte Ornithologie* 1: 163-170.

Sharp, T. and Saunders, G. (2004) *Trapping of pest birds*. NSW Department of Primary Industry, Natural Heritage Trust, Australia.

Stons, A. E. G. (1995) *Know your trees. Some of the common trees found in Zambia.* Regional Soil Conservation Unit/Sida. Nairobi, Kenya.

Stuart, S. N., Adams, R. J. and Jenkins, M. (1990) *Biodiversity in sub-Saharan Africa and its islands. Conservation, management and sustainable use*. Occasional Papers of the IUCN Species Survival Commission No. 6., IUCN, Gland, Switzerland.

Tarimo, T. M. C. (1994) *Development of bioassay of bird resistant sorghum for bird repellency*. Unpubl. Ph.D, thesis, Purdue University, U.S.A.

Tarimo, T. M. C. (2000). The cyanogenic glycoside dhurrin as a possible cause of bird resistance in Ark – 3048 sorghum. Pp 103-112 in Cheke, R.A, Rosenberg, L. J. and Keiser, M.E. (eds.) *Workshop on Research Priorities for Migrant Pests in Southern Africa*. Plant Protection Research Institute, Pretoria, South Africa, 24 – 26 March 1999, Natural Resources Institute, Chatham, UK.

Tarimo, T. M. C., Kideghesho, J. R., Wambura, J. M., Nsajigwa, E., M. and Silayo, D. S. (2006). The ecology and management aspects of the red-billed quelea: a major avian cereal pest in Tanzania. *Journal of Management and Development Dynamics* 18: 88-112.

Tashkent, S. (1998) *Conditions and provisions for development of a national strategy for diversity conservation. Biodiversity conservation national strategy and action plan of the Republic of Uzbekistan.* Part 1. Prepared by the National Biodiversity strategy project Steering Committee with the financial assistance of the Global Environmental Facility (GEF) and Technical Assistance of United Nations Development Programme (UNDP), Nairobi, Kenya.

The Regional Commissioner’s Office, Dodoma (2002) *Regional development planning programme*. Dodoma, Tanzania.

The Regional Commissioner’s Office, Dodoma region, (2002) *Socio-economic Profile*. Dodoma, Tanzania.

The Regional Commissioner’s Office-Dodoma region (2006). *Socio-economic Profile*. Dodoma, Tanzania.

The United Republic of Tanzania, Dodoma Region (2003) *Socio-economic profile*. Joint publication by National Bureau of Statistics (NBS) and Dodoma Regional Commissioner's Office coordinated by the President's office for planning and privatisation. Second edition. Dar-es-Salaam, Tanzania.

Tucker, M. R. and Holt, J. (1999) Decision tools for managing migrant insect pests. Pp. 97-128 in Grant, I.F. and Sear, C. (eds.) *Decision tools for sustainable development*. Natural Resources Institute, Chatham, U.K.

Ubaidullah, M. (2004) Losses Due to House Sparrow to Wheat Crop in Central Punjab. *International Journal of Agriculture and Biology* 6: 541-543.

Uk, S. and Munks, S. (1984) Fenthion residues in quelea birds from experimental aerial spraying of Queletox at Makuyuni, Tanzania, in June 1983. International Centre for the Application of pesticides. Cranfield Institute of Technology, U.K.

United Republic of Tanzania, (2008) *Agricultural sector development strategy*. Ministry of Agriculture, Food Security and Cooperatives, Dar-es-Salaam, Tanzania.

Venn, J. F, Cheke, R. A. and Jones, P. J. (2002). Forecasting breeding opportunities for the red-billed quelea in southern Africa. Pp. 612-617 in *Proceedings of the* 2003 EUMETSAT *Meteorological Satellite Conference*, Weimar, Germany, 29 September – 3 October 2003, EUMETSAT, Darmstadt, Germany.

Ward, P. (1965a) Feeding ecology of black-faced dioch *Quelea quelea* in Nigeria. *Ibis* 107: 173-214.

Ward, P. (1965b) The breeding biology of the black-faced dioch *Quelea quelea* in Nigeria. *Ibis* 107: 326-349.

Ward, P. (1971) The migration patterns of *Quelea quelea* in Africa. *Ibis* 113: 275-297.

Ward, P. (1973) A new strategy for the control of damage by quelea. *PANS* 19: 97-106.

Ward, P. and Jones, P. J. (1977) Pre-migratory fattening in three races of the red-billed quelea *Quelea quelea* (Aves: Ploceidae) an intra-tropical migrant *J. Zool.* (London) 181: 43-56.

Ward, P. and Zahavi, A. (1973) The importance of certain assemblages of birds as “information centres” for food-finding. *Ibis* 115: 517-534.

.

White, F. (1983) *The vegetation of Africa: a descriptive memoir to accompany the UNESCO/AETFAT/UNSO vegetation map of Africa.* UNESCO, Paris, France.

Williams, J. (1953) The quelea threat to Africa’s grain crops. *E. Africa Agriculture For. J.* 19: 133-136.

Williamson, K. (1957) Mist-nets versus Heligoland traps. *Bird-Banding* 28: 213-222.

Woodford, J. (1959) The use of mist-nets and a Heligoland trap at Point Pelee. *Bird-Banding* 30: 38-46.

Woodford, J. and Hussell, D. J. T. (1961) Construction and use of Heligoland Traps. *Bird-Banding* 32: 1125-1141.

Yahia G. (1957) A note on the occurrence and control of the red-billed weaver (*Quelea quelea aethiopica*) in the Sudan. *CSA Symp. Quelea*, Livingstone, 1957. CCTA/CSA Joint Secretariat, Bukavu, DRC

APPENDICES

Appendix I

QUESTIONNAIRES USED DURING THE STUDY

Summary of the interviews made amongst the different groups of stakeholders involved in quelea control, trapping and use

(A) Interviews were conducted with the Agricultural personnel who attended the workshop on Environmental Impact Assessment of Quelea control and mass – trapping of Quelea from 4 – 8 June 2007 at the Impala Hotel, Arusha, Tanzania. 18 people (17 men and 1 woman) attended the workshop. These were the representatives from Zonal Plant Protection Offices namely Northern Zone, Arusha; Central Zone, Dodoma; Western Zone, Shinyanga; Southern Zone, Mbeya and Eastern Zone, Dar es Salaam.

The responses to the questions were summarized in the notes below:-

Q.1. ***What methods for crop protection from quelea damage are employed in your area?***

The following methods were mentioned.

- Bird scaring methods such as slings and scarecrows and devices such as cloths or plastic flags and a network of movable rattles.
- Farmers guarding their farms by roaming around their farms by shouting and clapping, cracking whips and throwing missiles.
- Covering of crop heads with plant leaves, woven grass sheaths and plastic bags.
- Nest destruction which kills the nestlings.
- Cultivation of less susceptible crop varieties such as sorghum.
- Aerial spraying – using toxic chemicals such as fenthion.

Q.2 ***Do the methods have any adverse impacts?***

- Nest destruction was mentioned as having deleterious effects on trees, as they are sometimes cut down to ease chick collection.

- Aerial spraying using toxic chemicals was said to have an impact on a much wider spectrum of organisms than on the quelea alone. These include the immediate and long-term effects on non-target animals and birds such as foxes, wild cats, kites, eagles, vultures, leguans and storks. Also the method was said to have an effect on the environment such as contamination of water bodies and terrestrial ecosystems.

Q.3. ***What have been the major obstacles in the successful implementation of quelea control operations?***

The following obstacles were mentioned.

(i) Very few knowledgeable personnel, as quelea control requires a good understanding of the behaviour of the bird.

(ii) Timely reporting and control of the quelea attacking the crop.

(iii) Timely availability of control logistics e.g. avicide, aircraft and vehicles for transporting equipment.

(iv) Aerial spraying is very expensive.

(v) Weather conditions such as rain, clouds, temperature and wind have been affecting quelea control operations using aerial spraying.

(vi) Availability of airstrips near the attacked crops. Few airstrips are available in many areas attacked by quelea. It is recommended to have an airstrip within a distance of 5 km from the target area.

Q.4. ***Have quelea breeding seasons and population sizes changed in comparison with the known patterns in the 20th century?***

67 per cent said that the breeding seasons and the population sizes had not changed, although research is needed to justify their statements.

33 per cent said yes, without any justification.

All of them commented that, with climate change and ecological changes which have been happening in many places in the country due to human activities, there has been spread of quelea into areas which had no quelea invasion in the past. The introduction of many new dams, irrigation of big rice paddy farms and sorghum fields in many parts of the country has provided drinking water and food for quelea in new areas.

Q. 5. ***Do people in the area where you work prefer to use quelea for food and for income generation rather than have birds killed by chemical spraying?***

- All of the interviewees said that people prefer the opportunity to harvest them and eat them rather than have them sprayed with chemicals.
- People are concerned about the effects of chemical spraying on non-target species and the environment.
- People are also concerned about the operation being expensive. The money could be used for other development activities if alternative methods would be developed.

An example was given by representatives from the central zone where people have been shifting the markers (flags) used for demarcating the target areas to be sprayed to nearby sites where there were no birds. Their intention was to ensure that the target areas, especially roosts, were not sprayed to allow trapping activities to continue. People in the central zone exploit quelea for food and for income generation more than in other zones.

Representatives from other zones said people prefer to eat quelea but that only a few are caught by small boys, except when chick harvesting is carried out by older people, both men and women. The few quelea that were caught were not sold.

Q.6. ***How do people get quelea for food? Do the methods used for trapping (if any) satisfy the farmers/trappers? Do the methods need improvement?***

4 representatives from the central zone said that people were trapping quelea using traditional basket traps. Other representatives said that old people in their areas harvest chicks. Only young boys catch quelea using lime, drop traps at drinking places and catapults or by throwing knobkerries into dense congregations of quelea.

All representatives said that the methods used by farmers/trappers to catch quelea were not satisfying them as few quelea are caught or harvested. The methods used need improvements or else other new methods which are effective for mass capture need to be developed.

Q.7. ***Is there a potential utilization of quelea for food and income generation in the community leading to poverty alleviation?***

- Yes, if many quelea were caught, many people would be willing to eat quelea.
- In the central zone, both the trappers and retailers (processors) are selling quelea to other people in their communities to generate income which leads to poverty alleviation.
- If mass capture methods of quelea are to be developed many people will be able to do quelea trapping and sell the birds to other people who will eat them and process them for selling to generate income.

Q.8. ***What are your general suggestions on the subjects of quelea control to prevent crop damage and utilization of quelea for food and income generation?***

The replies were summarized as follows:-

- Quelea control methods which can lead to crop protection and produce uncontaminated quelea available to the community for food are needed.
- Trapping methods which lead to mass harvest of quelea and protect crops from quelea damage need to be introduced to the community.
- Research is needed to develop methods of mass capture of quelea for food and income generation. The methods should also be used to alleviate quelea damage to crops.
- If mass trapping methods can be developed, then research should also be done on processing and preservation methods of quelea which will help in future utilization of the processed quelea.

- Farmers/trappers and other users of quelea should be trained in the mass trapping, processing and preservation methods developed.
- If many quelea are to be trapped, more market places than the villages need to be found.

(B) Interviews were conducted with farmers at Kelema Ward on 16 June 2007. 15 men and 10 women were interviewed after the introduction of the objectives of the research. The responses from the interviews were summarized as follows:-

Q.1. ***Is quelea a problem in this area?***

All of them said yes.

Q.2. ***How do quelea affect the peoples' livelihoods?***

- Damaging the crops which leads to food deficiency
- Time consuming during crop production, as farmers concentrate on bird scaring when they could be better occupied
- Many school children and women are involved in crop protection, so attendances at school decline and looking after young children at home becomes neglected.
- Heavy attack of quelea on crops can result in poverty among the people.

Q.3. ***Have quelea breeding seasons and population sizes changed recently, in comparison with previously known patterns in the area?***

25 per cent said Yes

35 per cent said No

40 per cent said they did not know

Q.4. ***What methods are used in the control of crop damage by quelea in the area?***

- Bird scaring methods such as scarecrows, networks of movable rattles, throwing stones, and cracking plastic or cloth flags.

- Field guarding by shouting and clapping
- Aerial spraying by the government

Q.5. ***Are the methods satisfactory or is more assistance needed?***

- Bird scaring methods and field guarding done by farmers themselves were said not to be satisfactory.
- Aerial spraying was said to be satisfactory if conducted in time, just after the observation of quelea flocks in the invaded areas

Q.6. ***Are quelea used for food and income generation in the area?***

All said Yes.

Q.7. ***Were more birds eaten in earlier times?***

- All said Yes. Many people in the area like eating them.
- People have been eating quelea for more than 60 years.

Q. 8. ***Who are collecting or trapping quelea?***

- Both men and women, including young boys and girls are involved in the collecting of quelea during chick harvesting.
- Only men trap quelea using traditional basket traps.

Q. 9. ***Any comments on the possibilities for improved trapping methods of quelea?***

- New mass trapping methods of quelea need to be developed
- Traditional trapping methods need to be improved to be durable and able to catch many quelea
- Develop processing and preservation methods of quelea for future use
- Training of people, farmers/trappers in the use of newly developed mass trapping, processing and preservation methods.

(C) Interviews with quelea trappers at Kelema Ward were conducted on 16 June 2007. 20 people who are involved in quelea trapping activities in the area were interviewed after an introduction to the research.

The following is a summary of the questions and replies.

Q.1. ***How long have you been trapping quelea?***

45 per cent said between 15 – 25 years

35 per cent said between 10 – 15 years

20 per cent said between 5 – 10 years

Q.2. ***Why do you do trapping?***

All said to obtain food and generate income

Q.3. ***If you sell them, how much do you charge?***

How much do you get per day? Who determines the pricing of your product?

- The price varies with the increase in quelea trapped at certain periods. The price varies from 3 – 5 quelea per Tshs. 100

- The amount obtained depends on how many the individual can catch per day. A trapper owning 5 traditional basket traps can catch 700 – 1000 quelea per day. When sold at 5 quelea per Tsh. 100, a trapper can get between Tshs, 14,000 – 20,000 per day. When few quelea are available or they are trapped by one trapper with 5 traps he can get at least Tshs. 5,000 per day.

- The price is determined by the trappers themselves depending on the availability and the market itself.

Q. 4. ***Is the money you make from quelea trapping enough to meet your family needs? How do you use the money?***

- 35 per cent said it depends on the time of year and the population sizes of quelea found in the area
- 65 per cent said – No

People said that they use the money to buy household goods, building materials, bicycles, cows, goats and meet school requirements for their children.

Q. 5. ***What methods do you employ for trapping?***
Are they satisfactory for your business?

- All of them used traditional basket traps
- They were not satisfactory for their business
- Traditional basket traps need to be improved
- Many more improved mass trapping methods need to be developed

Q.6. ***How many traditional traps does one trapper deploy per day?***

One person can deploy about 10-20 traps per day. Sometimes one person can deploy up to 30 traps depending on the market and availability of birds.

Q.7. ***Who are involved in quelea trapping?***

- Only men when using traditional basket traps
- Both sexes are involved during chick harvesting

Q.8. ***Do people fight over areas feasible for trapping such as roosting sites, breeding colonies, drinking places, threshing places and others?***

No. everyone is allowed to do trapping or harvesting at any feasible place. If the area is not big enough, especially a drinking place, artificial drinking places are created by the trappers themselves.

Q.9. ***Can anyone who needs to collect/trap the birds or are there any restrictions on the activity?***

- Everyone who needs to collect/trap the birds is allowed to.

- Trapping using mist nets is not allowed.
- Only quelea are allowed to be trapped.
- Trapping in the national reserved areas is not allowed

Q. 10. ***If there are restrictions, how do these restrictions/laws affect your livelihood activity?***

The restrictions/laws are not affecting our livelihood activity.

Q.11. ***Do you think the restrictions/laws are necessary or should they be removed and, if so, why?***

- 75 percent said that the restrictions/laws are necessary and should not be removed as they protect non-target species which could be killed when using mist nets or trapping in the national reserved areas.
- 25 per cent said that the restrictions/laws are not necessary and should be removed allowing people to use mist nets and get into the national reserved areas for trapping.

Q.12. ***Are there available markets for the trapped quelea within your community or there are problems with selling them?***

- All said that the market is available as many people in the area prefer to eat quelea
- Many people are willing to buy quelea in the area

Q.13. ***Do your activities reduce the population or do the birds still attack your crops?***

- The trapping is done using traditional basket traps. This does not aim at reducing the population that attack crops. The trapping is done off season when the crops are harvested and when drinking water is limited.
- Chick harvesting is aimed at both obtaining food and reducing the population of the chicks that would attack crops.

Q.14. ***Do you prefer to catch and eat quelea or have them controlled?***

- We prefer to catch and eat them.

- Control using aerial spraying has effects on non-target species and the environment. We have seen dogs, kites, foxes and birds of prey dead after spraying.
- Spraying is expensive, we prefer trapping.
- When adults in the early breeding colony are heavily attacked, they can be forced to abandon the colony to move to other places, thus protecting the crop in the vicinity.
-

Q.15. ***Do you have any comments to make about quelea trapping and harvesting?***

- New mass trapping methods of quelea should be developed and introduced to the farmers/trappers.
- Hooked iron bars should be provided to the farmers to assist in quick chick harvesting.
- Mist nets should be allowed for quelea trapping, with a policy to protect non-target birds.
- Traditional baskets traps should be modified to make durable and more efficient versions.
- More market places, inside and outside the country should be secured to enable the sale of all the birds if many can be trapped or harvested.
- Processing and preservation methods of trapped/harvested quelea should be developed to enable use of the processed quelea in the future.
- Farmers/trappers should be trained in mass trapping, processing and preservation methods.

(D) The interviews were conducted with the retailers who buy quelea from trappers and process them for sale. 14 men and 11 women were interviewed on 16 June 2007 at Kelema Ward. The following is the summary of the replies.

Q.1. ***How long have you been selling quelea?***

60 per cent of the people said 15 – 25 years

25 per cent said 10 – 15 years

15 per cent said 5 – 10 years

Q. 2. ***Where do you get them?***

From the trappers

Q. 3. ***Do you get them at all times of the year?***

- Only when there are crops in the fields from May to July
- When drinking water is limited from July to early October, during this time water is available at the river Bubu. The river is a traditional drinking place for quelea in the area.

Q. 4. ***How much do you get per day?***

- It depends on the daily catch from the trappers, on the demand, and on the availability of quelea.

Q. 5. ***What methods do you use for processing the birds for food?***

- Cooking as a relish
- Frying in vegetable oil
- Roasting on charcoal or firewood

The processing is done after plucking and removing the heads and intestines.

Q. 6. ***If a large quantity is collected, is it possible to process them and store them for future use?***

No. Only few are trapped, not enough to require storage for future use.

Q.7. ***Any comments on possibilities for improved processing of the birds?***

- Improved processing, preservation and packaging methods need to be investigated
- Training of trapper/farmers in improved methods of processing and preserving of quelea should be done
- If many quelea can be trapped, more markets need to be found. At the moment quelea are sold to the communities in the villages.

(E) The interviews were conducted with different people who attended the Farmers' Show from 1 – 8 August 2009. 167 men and 233 women were selected randomly as they were coming to the quelea stand. Interviewed people were coming from 136 villages, 53 districts and 15 regions in the country.

The following questions were posed to the people.

Q. 1. ***What is your primary occupation?***

- 81.75 percent were farmers
- 18.25 percent had different occupations such as students, teachers, working in the government and non-governmental organizations.

Q. 2. ***If you are a farmer, what kinds of crops do you grow?***

The following crops were mentioned.

- Bulrush millet, Sorghum, Maize, Paddy, Cotton, Coffee, Sisal, Finger millet and Sunflower.

Q. 3. ***Is there any problem with bird attack to some of your crops? If so, mention the bird that attacks your crops.***

- 89 percent said Yes
- 11 percent said No.

The following birds that attack crops were mentioned.

- 73.5 percent mentioned quelea
- 26.5 percent mentioned Weaver birds (Chestnut and Village Weavers)

n.b. In Tanzania, people with other occupations than farmers also owned farms. Many people other than those who said that they were farmers also suffer bird attack on their farms.

Q.4. ***What measures are you taking to solve the problem?***

The following methods were mentioned

- Field guarding by farmers
- Shouting and clapping
- Bird scaring methods using scarecrows, slings and movable networks of rattles
- Aerial spraying by the Government

Q.5. ***Are quelea a source of food in your area?***

- 81.75 per cent said Yes
- 18.25 per cent said No.

Q.6. ***What methods are used for catching quelea?***

Are the methods satisfactory?

- 37 per cent mentioned traditional basket traps and chick harvesting using hooked sticks
- 57 per cent mentioned lime
- 6 per cent mentioned drop traps and catapults.
- 81.75 per cent said that the methods are not satisfactory
- 18.25 per cent said – they did not know

Q.7. ***Who is trapping the birds?***

- 35 per cent said – trappers – only men
- 65 per cent said – small boys

Chick harvesting was said to be done by both men and women.

Q.8. ***Do you get enough?***

No. Only a few are caught or trapped

Q.9. ***What methods do use for preparing quelea for food?***

- 27 per cent said – cooking as a relish
- 33 per cent said – frying with vegetable cooking oil
- 40 per cent said – Roasting on firewood or charcoal. It is mostly done by young boys.

Q.10. ***Do you preserve some of the quelea for future use?***

No. Too few are obtained

Q.11. ***Here are a few different preparations of cooking quelea which you have to taste. You are required to rank them from the most to your least preference. You have to take about 2 to 3 minutes before you take the second taste until you finish. At the end you have to rank them***.

(i) **Fresh Fried quelea meat**

(ii) **Fresh Stewed quelea meat**

(iii) **Grilled quelea meat**

(iv) **Dried Stewed quelea meat**

(v) **Dry Heated quelea**

The results from ranking of quelea products from their best to the least favoured were as follows:

GROUP	RANKING FROM THE BEST TO THE LEAST					TOTAL
	1	2	3	4	5	
Fresh Fried Quelea (Group 1)	273	75	51	1	0	400
Fresh Stewed Quelea (Group 2)	91	254	49	6	0	400
Fresh Grilled Quelea (Group 3)	37	83	246	31	3	400
Dry Stewed Quelea (Group 4)	0	29	55	269	47	400
Dry Heated Quelea (Group 5)	0	0	7	94	299	400

Q.12. ***If quelea can be obtained in large quantities, can they be ranked high as an important food source for humans?***

Yes, they are good and nutritious.

Q.13. ***Do you have any comments on possibilities for improved processing and marketing of the birds?***

The following were the comments.

- Large quantities of quelea should be trapped and sold to people who like to eat them

- Processed and preserved quelea are good for food and for income generation

- Well processed and preserved quelea should be prepared and sold to people in many places in the country.

- Mass trapping methods should be demonstrated to many farmers/trappers in all places in the country where quelea are a problem.

- Improved processing and preserving methods should be demonstrated to farmers in the country where quelea are found.

- Well hooked devices should be found and given to people for chick harvesting to reduce their populations.

- Many new market places should be found for selling processed and well preserved quelea.

- Quelea contaminated with poison should not be eaten nor allowed to be sold to people for food.

Appendix 2a. SOME BREEDING RECORDS FOR *QUELEA QUELEA* IN SOUTHERN AND CENTRAL TANZANIA FROM 1991-2010. Those marked with an asterisk were involved in the studies reported in this thesis.

LOCATION	COORDINATES	DATE LOCATED	COLONY STATUS
Tinai	S 06 54 372	01Apr. 1991	Chicks 6 days old
	E 035 28 514		
Chitemo	S 05 33 418	03 Apr. 1991	Eggs
	E 035 51 574		
Makutupora	S 05 58 274	04 Apr. 1991	Chicks fledging
	E 035 45 678		
Zepisa	S 06 28 318	07 Apr. 1991	Chicks out of nests
	E 036 47 471		
Mbalawala	S 06 05 219	15 Apr. 1991	Chicks out of nests
	E 035 21 732		
Lukali	S 05 73 478	17 Apr. 1991	Chicks 6 days old
	E 035 25 192		
Isini	S 0508140	21 Apr. 1991	Eggs
	E 035 47490		
Serya	S 04 40 468	24 Apr. 1991	Chicks 3 days old
	E 035 41 653		
Mtera	S 06 19 517	24 Apr. 1991	Chicks out of nests
	E 035 30 872		

Tinae	S 06 82 684	25 Apr. 1991	Chicks out of nests
	E 035 57 919		
Lukali	S 05 27 137	31 March 1992	Eggs
	E 035 39 572		
Lamaiti	S 05 47 392	01 Apr. 1992	Building nests with 1 egg
	E 035 29 068		
Nguji	S 05 55 945	19 Apr. 1992	Chicks 5 days
	E 035 36 212		
Porobanguma	S 05 16 924	31 March 1992	Eggs
	E 035 30 093		
Kwadelo	S 0554 331	09 Apr. 1992	Chicks 6 days old
	E 036 08 595		
Idindiri	S 04 47 381	11 Apr. 1992	Fledging
	E 036 07 375		
Changarawe	S 06 54 234	24 Mar. 1992	Eggs
	E 037 22 527		
Kidogobasi	S 06 37 328	26 March 1992	Eggs
	E 37 03 562		
Ulaya mbuyuni	S 06 41 371	9 Apr. 1992	Chicks 4 days old
	E 037 52 446		

Miyombo	S 06 27 315	9 Apr. 1992	Chicks 5 days old
	E 037 45 572		
Paranga	S 05 10 637	01 May 1992	Eggs
	E 035 52 015		
Kwadelo	S 05 45 472	9 May 1992	Eggs
	E 036 18 618		
Msowero	E 06 57 456	17 May 1992	Eggs
	S 037 00 454		
Lamaiti	S 05 64 428	18 Apr. 1992	Eggs
	E 035 32 174		
Makutupora	S 05 82 327	20 Apr. 1992	Eggs
	E 035 45 618		
Dakawa	S 06 25 236	17 June 1992	Fledging
	E 037 33 216		
Mkiwa	S 05 32 936	27 May 1992	Chicks 5 days old
	E 034 57 022		
Mwakako	S 04 31 473	25 May 1992	Chicks 3 days old
	E 034 38 146		
Ngamu	S 04 42 274	26 May 1992	Chicks 5 days
	E 034 53 475		
Isini	S 05 28 272	02 Apr. 1993	Eggs
	E 035 37 518		

Chiboli	S 06 53 472	6 Apr. 1993	Eggs
	E 035 50 981		
Serya	S 04 55 771	22 May 1996	Eggs
	E 035 43 327		
Paranga	S 05 25 546	25 Apr. 1994	Eggs
	E 035 34 274		
Isini	S 05 13 174	03 May 1994	Chicks 2 days old
	E 035 52 258		
Mutua	S 04 53 216		
	E 036 27 577	6 April 1994	Chicks out of nests
Lukenge	S 06 18 377		
	E 037 55 819	25 May 1994	Chicks out of nests
Makasisi	S 06 26 422		
	E 037 43 683	31 Apr. 1994	Eggs
Mtibwa	S 06 12 627		
	E 037 35 278	14 June 1995	Fledging
Kisaki	S 04 48 678		
	E 035 27 814	05 May 1996	Chicks 5 days old
Murua	S 04 62 327		
	E 036 32 562	25 May 1996	Fledging
Kelema	S 05 06 542		

	E 035 49 582	26 May 1996	Eggs
Idindiri	S 04 83 475		
	E 036 27 658	5 June 1997	Chicks out of nests
Makanda	S 05 65 874		
	E 035 26 485	5 June 1997	Chicks 6 days old
Dakawa	S 06 27 258		
	E 037 56 434	30 June 1997	Chicks 4 days old
Mtibwa	S 06 13 044		
	E 037 39 848	26 June 1997	Chicks 6 days old
Ibugule	S 06 26 246		
	E 035 33 038	30 March 1998	Building nests with 1 egg
Loje	S 06 54 782		
	E 036 06 384	31 March 1998	Eggs
Dizungu	S 06 14 977		
	E 037 34 293	16 May 1999	Chicks 4 days old
Kwamkole	S 06 06 544		
	E 037 41 254	17 May 1999	Chicks 6 days old
Dumila	S 06 23 333		
	E 03720 106	17 May 1999	Eggs
Lusonge	S 06 42 517		
	E 037 43 520	20 May 1999	Eggs

Kanga	S 06 00 590		
	E 037 45 522	25 May 1999	Chicks 3 days old
Isini	S 05 13 374		
	E 035 38 726	15 May 1999	Eggs
Masimba	S 06 29 247		
	E 037 45 531	29 May 1999	Fledging
Mgungira	S 04 37 371		
	E 034 58 494	29 Apr. 2000	Fledging
Suli	S 06 49 071		
	E 035 24 310	20 Apr. 2000	Eggs
Loje	S 06 63 281		
	E 035 27 377	20 Apr. 2000	Eggs
Membe	S 05 52 230 E 036 14 426	15 May 2000	Chicks 5 days old
Bayakati	S 06 63 807	14 March 2001	Eggs
	E 035 45 968		
Loje	S 06 82 156	14 March 2001	Eggs
	E 036 59 458		
Suli	S 06 48 154	11 March 2001	Eggs
	E 036 54 456		
Paranga	S 05 22 818	11 March 2001	Eggs

	E 035 30 093		
Chingisili	S 06 58 861	11 March 2001	Chicks 3 days old
	E 035 45 951		
Igunguri	S 06 48 150	11 March 2001	Eggs
	E 036 54 455		
Chiboli	S 06 53 472	18 March 2001	Eggs
	E 035 50 981		
Msolwa	S 06 53 328	2 May 2001	Chicks 5 days old
	E 037 23 528		
Lukali	S 05 45 445	28 March 2002	Eggs
	E 035 32 336		
Nchinila	S 06 52 274	30 March 2002	Eggs
	E 035 35 145		
Igomadete	S 06 79 475	22 April 2002	Chicks 3 days old
	E 035 87 563		
Kongwa	S 06 15 822	13 March 2003	Eggs
	E 036 35 714		
Mwitikila	S 06 58 236	15 March 2003	Eggs
	E 035 73 627		
Chali	S 06 05 653	04 April 2003	Chicks 3 days old
	E 035 43 724		

Chifutuka	S 05 45 678	25 April 2003	Chicks out of nests
	E 035 47 864		
Chikopelo	S 05 75 643	5 May 2003	Chicks out of nests
	E 035 87 543		
Porobanguma	S 05 35 688	21 March 2004	Eggs
	E 035 41 567		
Mlimwa	S 05 58 476	26 March 2004	Eggs
	E 036 22 189		
Kongwa	S 06 05 701	07 Apr. 2004	Chicks 3 days old
	E 036 31 274		
Manyoni	S 05 54 278	10 Apr. 2004	Chicks 5 days old
	E 034 47 927		
Lukali	S 05 38 229	12 Apr. 2004	Fledging
	E 035 45 375		
Lahoda	S 05 04 934	21 March 2004	Eggs
	E 035 25 526		
Bubu River	S 04 38 274	22 March 2004	Eggs
	E 035 40 527		
Ipambe	S 05 47 382	22 Feb. 2005	Nest building with 1 egg
	E 034 34 274		
Mwitikila	S 06 30 833	24 Feb. 2005	Eggs

	E 035 40 668		
Bayakati	S 06 59 458	28 Feb. 2005	Eggs
	E 035 44 029		
Naguro	S 06 35 436	2 March 2005	Chicks 4 days old
	E 035 34 310		
Mulazo	S 06 31 243	6 March 2005	Chicks 6 days old
	E 035 38 329		
Ibada	S 05 51 324	10 March 2005	Eggs
	E 034 32 803		
Suruma	S 04 38 150	12 Mar. 2005	Eggs
	E 036 13 286		
Itaswi	S 04 32 173	12 Mar. 2005	Eggs
	E 036 07 077		
Lukenge	S 06 15 027	27 May 2005	Fledging
	E 037 39 854		
Mtibwa	S 06 06 776	29 May 2005	Chicks 6 days old
	E 037 59 884		
Dakawa	S 05 41 050	05 Aug. 2005	Fledging
	E 037 37 054		
Ipande	S 05 47 388	5 Aug. 2005	Chicks out of nests
	E 034 34 270		

Muhanga	S 05 51 639	6 Aug. 2005	Fledging
	E 034 36 394		
Farkwa	S 05 18 275	12 Apr. 2006	Eggs
	E 035 39 578		
Rofati	S 05 22 954	13 Apr. 2006	Eggs
	E 035 48 524		
Kidoha	S 05 23 968	13 Apr. 2006	Eggs
	E 035 85 936		
Haneti	S 05 67 286	1 May 2006	Fledging
	E 035 51 904		
Kidoka	S 05 26 785	2 May 2006	Chicks out of nests
	E 035 52 908		
Tumbakose	S 05 18 334	4 May 2006	Fledging
	E 035 45 526		
Pangalwa	S 05 21 883	7 May 2006	Chicks out of nests
	E 035 88 912		
Bayakati	S 06 59 458	9 May 2006	Fledging
	E 035 44 029		
Nchinila	S 06 29 334	10 Mar. 2007	Eggs
	E 035 28 038		
Suli	S 05 22 954	12 Mar. 2007	Eggs
	E 036 27 211		

Ikangwa	S 04 40 468	14 Mar. 2007	Eggs
	E 036 10 338		
		15 Mar. 2007	Chicks 6 days old
Bumbuta	S 04 36 085		
Nzasa	S 06 59 264	21 Mar. 2007	Fledging
	E 035 54 016		
Chiboli	S 06 54 457	23 Mar. 2007	Chicks out of nests
	E 035 49 137		
Chidilo *	S 06 25 173	20 Mar. 2008	Chicks 2 – 5 days old
	E 035 24 570		
Zejele *	S 06 24 285	20 Mar. 2008	Chicks 4 -days old
	E 035 24 305		
Chunyu	S 06 17 593	25 Mar. 2008	Fledging
	E 036 17 804		
Kitalalo	S 05 34 482	14 Apr. 2008	Fledging
	E 034 57 218		
Sasajila	S 05 55 959	25 Apr. 2008	Chicks out of nests
	E 034 58 108		
Kidago	S 06 88 550	13 May 2008	Chicks 5 days old
	E 037 04 753		
Dizungu	S 06 15 222	4 June 2008	Chicks 7 days old

	E 037 34 204		
Marundi	S 06 05 881	22 June 2008	Chicks fledging
	E 037 43 192		
Mbwasa	S 05 30 528	9 Mar. 2009	Nest building with 1 egg
	E 034 51 689		
Gawaye *	S 05 51 26	18 Mar. 2009	Eggs
	E 034 50 038		
Chihanga	S 05 55 384	23 March 2009	Nest building with one egg
	E 035 45 479		
Solya *	S 05 34 493	30 Mar. 2009	Chicks – 5 days old
	E 034 48 574		
Mamba *	S 05 57 274	4 Apr. 2009	Nest building with 1 – 2 eggs
	E 035 45 678		
Iyoli *	S 05 66 221	5 May 2009	Chicks 6 days old
	E 035 42 239		
Bufana	S 05 06 996	28 Apr. 2010	Fledging
	E 033 58 747		
Pikeo	S 07 16 908	30 Apr. 2010	Chicks 5 days old
	E 035 31 991		

Changushwa	S 07 28 709	1 May 2010	Chicks out of nests
	E 035 20 352		
Makula	S 07 40 573	2 May 2010	Eggs
	E 035 45 111		
Mahango	S 04 33 774	4 May 2010	Chicks 6 days old
	E 035 56 692		
Chemichemi	S 05 01 327	7 May 2010	Fledging
	E 035 42 440		
Kongwa	S 06 01 268	29 May 2010	Fledging
	E 036 36 406		
Mvomero	S 06 12 170	6 June 2010	Chicks out of nests
	E 037 40 901		

Appendix 2b. Roosts located in the research area from 2006 to 2010

DATE	REGION	DISTRICT	LOCATION	COORDINATES
2006				
02.4.2006	Dodoma	Chamwino	Kawawa	S 06 33 472 E 035 41 489
12.4.2006	Dodoma	Kondoa	Farkwa	S 05 18 275 E 035 39 578
13.4.2006	Dodoma	Kondoa	Rofati I	S 05 22 954 E 035 48 524
13.4.2006	Dodoma	Kondoa	Kidoha	S 05 23 963 E 035 85 937
14.4.2006	Dodoma	Kondoa	Paranga	S 05 08 702 E 035 51 423
17.4.2006	Dodoma	Chamwino	Suli	S 06 22 954 E 035 27 219
18.4.2006	Dodoma	Chamwino	Loje	S 06 54 782 E 035 00 387
01.5.2006	Dodoma	Bahi	Haneti	S 05 67 284 E 035 51 905
02.5.2006	Dodoma	Kondoa	Kidoka I	S 05 26 762 E 035 52 909

03.5.2006	Dodoma	Kondoa	Kidoka II	S 05 26 783 E 035 47 373
04.5.2006	Dodoma	Kondoa	Tumbakose	S 05 18 335 E 035 45 525
05.5.2006	Dodoma	Bahi	Haneti	S 05 67 286 E 035 51 906
06.5.2006	Dodoma	Kondoa	Bubutole	S 05 19 117 E 035 39 018
07.5.2006	Dodoma	Kondoa	Pangalua	S 05 21 883 E 035 88 912
08.5.2006	Dodoma	Kondoa	Rofati II	S 05 35 314 E 035 56 724
09.5.2006	Dodoma	Chamwino	Bayakati	S 06 04 642 E 035 40 315
19.5.2006	Morogoro	Kilosa	Mikumi	S 06 58 209 E 037 10 357
20.5.2006	Morogoro	Kilosa	Kilangali	S 06 68 368 E 037 46 894
21.5.2006	Morogoro	Mvomero	Mtibwa Sug	S 06 21 245 E 037 45 752
22.5.2006	Morogoro	Mvomero	Kanga	S 06 00 590 E 037 45 523

DATE	REGION	DISTRICT	LOCATION	COORDINATES
2007				
10.3.2007	Dodoma	Bahi	Nchinila	S 06 29 334 E 035 28 038
12.3.2007	Dodoma	Chamwino	Suli	S 05 22 954 E 036 27 211
14.3.2007	Dodoma	Kondoa	Ikengwa I	S 04 40 468 E 036 10 338
14.3.2007	Dodoma	Kondoa	Ikengwa II	S 04 40 874 E 036 10 572
15.3.2007	Dodoma	Kondoa	Bumbuta	S 04 36 085 E 035 59 011
16.3.2007	Dodoma	Kondoa	Idindiri	S 04 48 041 E 036 12 314
18.3.2007	Dodoma	Bahi	Chifukulo	S 06 34 004 E 035 27 211
21.3.2007	Dodoma	Dodoma (u)	Nzasa	S 06 59 264 E 035 54 016
23.3.2007	Dodoma	Chamwino	Chiboli	S 06 54 457 E 035 49 137
26.3.2007	Dodoma	Kondoa	Bumbuta	S 04 44 715 E 035 77 374

27.3.2007	Dodoma	Kondoa	Kisaki/Itaswi	S 04 36 083 E 035 59 011
28.3.2007	Dodoma	Kondoa	Isini	S 04 74 268 E 035 68 352
16.6.2007	Dodoma	Dodoma (u)	Mahata **	S 06 06 546 E 035 42 558
16.7.2007	Dodoma	Dodoma (u)	Swaswa	S 05 45 245 E 035 42 653
28.7.2007	Dodoma	Chamwino	Kawawa East	S 06 35 573 E 035 41 532
19.8.2007	Dodoma	Chamwino	Msanga	S 06 45 245 E 035 42 653
21.8.2007	Dodoma	Chamwino	Chamwino	S 06 43 437 E 035 35 563

DATE	REGION	DISTRICT	LOCATION	COORDINATES
2008				
20.3.2008	Dodoma	Bahi	Chidilo	S 06 25 173 E 035 24 570
20.3.2008	Dodoma	Bahi	Zejeli	S 06 24 285 E 035 24 305
21.3.2008	Dodoma	Dodoma (u)	Zuzu	S 06 16 728 E 035 37 764
25.3.2008	Dodoma	Mpwapwa	Chunyu	S 06 17 593 E 036 17 804
25.3.2008	Dodoma	Mpwapwa	Nghambi	S 06 27 475 E 036 19 362
29.3.2008	Dodoma	Bahi	Zanka	S 06 34 542 E 035 28 247
30.3.2008	Dodoma	Dodoma (u)	Mchemwa	S 06 28 432 E 035 37 348
13.4.2008	Singida	Manyoni	Makanda	S 05 58 567 E 035 44 427
14.4.2008	Singida	Manyoni	Kitalalo	S 05 46 475 E 034 56 579
25.4.2008	Singida	Manyoni	Sasajila	S 05 59 532 E 034 47 247

27.4.2008	Dodoma	Bahi	Bahi Makulu	S 06 34 673 E 035 25 678
29.4.2008	Dodoma	Dodoma (u)	Chigongwe	S 06 53 729 E 035 32 538
12.5.2008	Morogoro	Kilosa	Kilangali i	S 06 56 800 E 037 06 570
12.5.2008	Morogoro	Kilosa	Kilangali ii	S 06 58 785 E 037 06 437
13.5.2008	Morogoro	Kilosa	Kivungu	S 06 37 452 E 037 16 542
13.5.2008	Morogoro	Kilosa	Mulegeni	S 06 42 275 E 037 26 175
13.5.2008	Morogoro	Kilosa	Kidago	S 06 88 550 E 037 04 753
13.5.2008	Morogoro	Kilosa	Mulegeni	S 06 67 452 E 037 32 273
20.5.2008	Singida	Singida (r)	Mkiwa	S 05 33 275 E 034 67 832
23.5.2008	Dodoma	Bahi	Bahi Makulu	S 06 38 564 E 035 30 486
03.6.2008	Morogoro	Mvomero	Dizungu i	S 06 14 657 E 037 35 116

03.6.2009	Morogoro	Mvomero	Dizungu ii	S 06 22 456 E 037 41 238
04.6.2008	Morogoro	Mvomero	Dizungu	S 06 15 222 E 037 34 204
04.6.2008	Morogoro	Mvomero	Sechambo	S 06 00 583 E 037 44 829
04.6.2008	Morogoro	Mvomero	Kwamaganga	S 06 32 417 E 037 65 725
05.6.2008	Morogoro	Mvomero	Block 14C	S 06 12 080 E 037 44 829
05.6.2008	Morogoro	Mvomero	Block 15C	S 06 35 187 E 037 23 672
07.6.2008	Morogoro	Mvomero	Makutano	S 06 14 275 E 037 41 061
08.6.2008	Morogoro	Mvomero	Block 13k	S 06 17 324 E 037 54 412
18.6.2008	Dodoma	Bahi	Kitonga	S 06 40 434 E 035 33 273
20.6.2008	Morogoro	Mvomero	Block 12J	S 06 14 275 E 037 40 080
20.6.2008	Morogoro	Mvomero	Block 13J	S 06 19 345 E 037 76 225

20.6.2008	Morogoro	Mvomero	Block 13k	S 06 14 275 E 037 40 061
21.6.2008	Morogoro	Mvomero	Mwaluwala	S 06 03 148 E 037 43 604
21.6.2008	Morogoro	Mvomero	Kwa Ebo	S 06 04 987 E 037 43 604
21.6.2008	Morogoro	Mvomero	Mvivuhendi	S 06 02 770 E 037 42 848
22.6.2008	Morogoro	Mvomero	Malui	S 06 05 951 E 037 46 698
22.6.2008	Morogoro	Mvomero	Warundi	S 06 05 881 E 037 43 192
23.6.2008	Morogoro	Mvomero	Block 14C	S 06 12 080 E 037 44 829
23.6.2008	Morogoro	Mvomero	Block 13J	S 06 15 762 E 037 76 786
23.6.2008	Singida	Manyoni	Mkakatika	S 05 25 671 E 034 57 842

17.7.2008	Morogoro	Mvomero	Block 13J	S 06 17 426 E 037 88 819
18.7.2008	Morogoro	Mvomero	Dizungu	S 06 26 342 E 037 53 327
19.7.2008	Dodoma	Kondoa	Pongai **	S 05 24 765 E 035 40 539
20.7.2008	Dodoma	Konda	Tampori **	S 05 20 532 E 035 42 428

2009

DATE	REGION	DISTRICT	LOCATION	COORDINATES
4.3.2009	Dodoma	Dodoma(u)	Ndachi **	S 06 04 642 E 035 40 315
18.3 2009	Singida	Singida (r)	Kisaki	S 04 35 215 E 035 57 472
15.4.2009	Dodoma	Kongwa	Chimotolo	S 06 08 217 E 035 44 568
12.5.2009	Singida	Singida (r)	Mtipa	S 04 40 563 E 034 35 762
22.5.2009	Dodoma	Kondoa	Piho **	S 05 02 538 E 035 56 376
20.9.2009	Dodoma	Kondoa	Pongai **	S 05 24 765 E 035 40 539

DATE	REGION	DISTRICT	LOCATION	COORDINATES
2010				
25.2.2010	Dodoma	Dodoma (u)	Makutupora	S 05 56 279 E 035 45 702
26.2.2010	Dodoma	Mpwapwa	Chunyu	S 06 17 618 E 036 17 873
3.3.2010	Dodoma	Bahi	Bahi	S 06 02 876 E 035 19 370
4.3.2010	Dodoma	Chamwino	Chiboli	S 06 53 471 E 035 50 993
4.3.2010	Dodoma	Chamwino	Ibugule	S 06 53 355 E 035 18 545
5.3.2010	Dodoma	Bahi	Mwitikila	S 06 31 492 E 035 39 727
7.3.2010	Dodoma	Bahi	Chipanga	S 06 13 648 E 03518 549
12.3.2010	Dodoma	Bahi	Nchinila	S 06 29 414 E 035 28 128
27.3.2010	Singida	Manyoni	Ipande	S 05 07 763 E 034 34 513
30. 3. 2010	Singida	Manyoni	Itigi-Bumbua	S 05 40 889 E 034 25 880

5.4.2010	Morogoro	Mvomero	Mbigiri	S 06 28 662 E 037 27 769
11.5.2010	Dodoma	Kondoa	Paranga	S 05 10 673 E 035 52 254
27.5.2010	Dodoma	Kondoa	Idindiri	S 04 47 417 E 036 07 401
10.6.2010	Dodoma	Kondoa	Pongai	S 05 24 760 E 035 40 543

Source: Zonal Plant Health Services – Dodoma

*** Areas where research was conducted both for quelea mass-capture and soil sampling.**

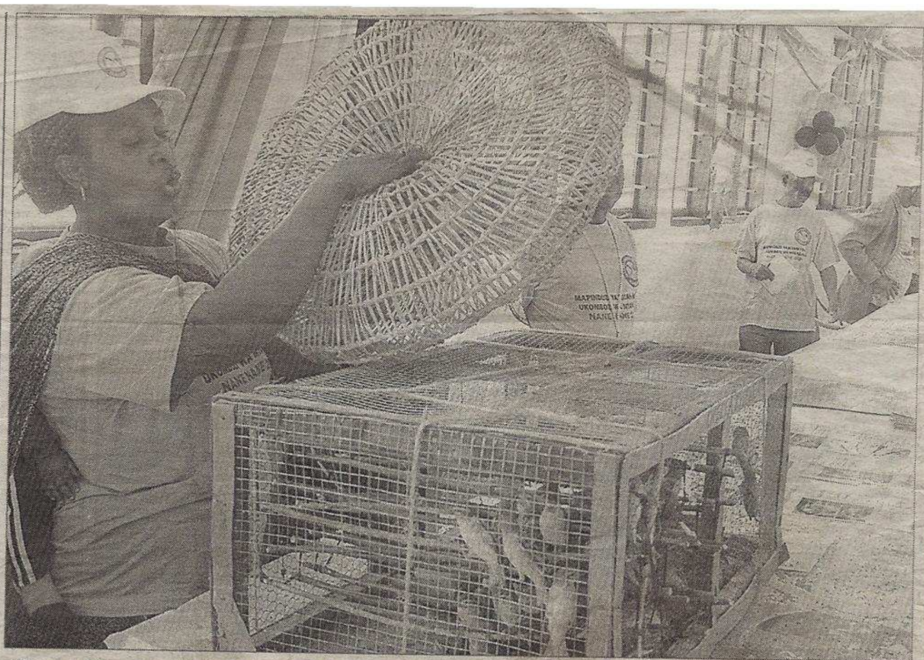
Appendix 3. Newspaper articles published during the study period (All the articles were in Swahili) and lists of broadcasts on quelea (some attached as videos).

Title	Newspaper	Date
1. Mtego wa kienyeji wa kunasia Kwelea kwelea (Traditional basket trap for quelea mass – capture)	Nipashe	4 Mar. 2008
2. Umewahi kuonja supu, skonzi ya Kwelea kwlea? (Have you tasted Quelea soup and bitings?	Mwananchi	12 Sept. 2008
3. Kwelea kwelea waangamizwa kwa sumu na hatari zake (The effects of chemical control of Quelea birds on the environment)	Mwananchi	21 Mar. 2009
4. Dawa ya Kwelea kwelea yaathiri viumbe (Quelea quelea avicide affects living organisms)	Mtanzania	10 Aug.2009
5. Uroho wa kitoweo wawatokea puani (People suffered after eating chemical sprayed quelea)	Mtanzania	21 Sept 2009

Channels of the broadcasts	Programme	Date
Tanzania Broadcasting Co-op.Ltd (TBC-Radio)	*Nane-nane* coverage	3,5,7 &8 Aug.2008
TBC Ltd (TV)	*Nane-nane* coverage	2,4,6 &8 Aug 2008
Tanzania Broadcasting Coop.Ltd (TBC-Radio)	*Nane-nane* coverage	1,5,7 &8 Aug.2009
TBC Ltd (TV)	*Nane-nane* coverage	2,3,6 &8 Aug 2009
Tanzania Broadcasting Coop.Ltd (TBC- Radio) special programme	Quelea quelea, farmers' enemy (40 minutes)	15,17 &18 Sept.2009

1. Mtego wa kienyeji wa kunasia Kwelea kwelea   Nipashe   4 March 2008

(Traditional basket trap for quelea mass – capture)



Afisa wa Wizara ya Kilimo, Idara ya Afya na Mimea sehemu ya Ndege, Bi. Halima Kimaro kutoka Wilaya ya Kondoa akionyesha mtego wa kunasia ndege aina ya kwelea kwelea katika Maonyesho ya Nane Nane yanayoendelea mkoani Dodoma mwishoni mwa wiki. ***(Picha na Omar Fungo).***

2. Umewahi kuonja supu, skonzi ya Kwelea kwlea? Mwananchi 12 Sept. 2008

(Have you tasted Quelea soup and bitings?)

Makinda ya ndege aina ya kwelea kwelea yakiwa yamevunwa na kujazwa katika beseni. Inadaiwa kuwa makinda hayo ni chaklula bora chenye protini nyingi.

Umewahi kuonja supu, skonzi ya kwelea kwelea?

Na **Habel Chidawali**

3. Kwelea kwelea waangamizwa kwa sumu na hatari zake   Mwananchi   21March 2009

(The effects of chemical control of Quelea birds on the environment)

Kwelea Kwelea waangamizwa

Habel Chidawali, Dodoma

WIZARA ya Kilimo, Chakula na Ushirika, juzi ilituma katika kijiji cha Ndachi, Dodoma helikopta maalum ya kunyunyiza sumu ya kuangamiza ndege waharibifu wa mazao, aina ya Kwelea kwelea.

Pamoja na kuangamiza ndege, hatua hiyo pia ililenga katika kutafiti madhara yanayotokana na hewa ambayo binadamu wanaivuta wakati ndege hiyo, inaponyunyiza sumu kwenye mashamba.

Hali kadhalika kujua madhara yanayoweza kumpata binadamu kwa kula mabaki ya ndege waliokufa kwa sumu hiyo.

Akizungumza katika kijiji hicho, mmoja wa maafisa wa Wizara ya Kilimo, Chakula na Ushirika, Boaz Mtobesya, alisema utafiti huo ulianza mwaka jana katika kijiji cha Zajela, wilayani Bahi.

Mtobesya ambaye ni mtaalamu kutoka katika kitengo cha mimea, alisema utafiti katika kijiji hicho, ulikuwa wa mafanikio.

Alisema pamoja na utafiti huo wizara pia imebuni utaratibu mwingine wa namna ya kuangamiza ndege hao, kama itabainika kuwa kuna madhara yanayotokana na unyunyiziaji.

Kwa mujibu wa afisa huyo, hii ni mara ya pili kwa Tanzania kuendesha utafiti wa aina hiyo ambao alisema ni wa gharama kubwa.

Mratibu wa mradi huo, Dk Monika Mulata, alisema wizara imepata fedha kutoka Umoja wa Ulaya kupitia Jumuiya ya Maendeleo Kusini mwa Afrika (SADC), ili kuendeshea utafiti huo. Baadhi ya wananchi katika kijiji hicho, walisema wamekuwa na mazoea ya kuokota mizoga ya ndege wakati helikopta inaponyunyuzia dawa mashambani, ili kuangamiza ndege waharibifu.

Walidai kuwa hawajawahi kudhurika kwa kula mizoga hiyo na kwamba wataendelea kuila.

4. Dawa ya Kwelea kwelea yaathiri viumbe Mtanzania 10Aug.2009

(Quelea quelea avicide affects living organisms)

Dawa ya kweleakwelea yaathiri viumbe

Pendo Mangala, Dodoma

DAWA ambayo imekuwa ikitumika kuulia kweleakwelea imebainika kuwa na madhara kwa viumbe wengine, imeelezwa.

Kwa sababu hiyo serikali imeshauriwa kuangalia njia mbadala ya kuwaua ndege hao ikiwamo kuwatega kwakutumia mitego maalum kama wanavyofanya wananchi wa wilaya ya Kondoa na maeneo mengine.

Ofisa Kilimo Mkuu wa Wwizara ya Kilimo, Chakula na Ushirika, Boaz Mtobesya alikuwa akizungumza na Mtanzania katika viwanja vya Maonyesho ya Nanenane mjini hapa juzi. Mtobesya alisema kuwa baada ya muda mrefu wa matumizi ya sumu hiyo imebainika kuwa imekuwa ikiua na viumbe wengine.

Alisema kuwa hali hiyo imesababisha wataalam wa kilimo kuangalia namna ya kutumia njia rafiki na mbadala ya utunzaji mazingira. Kwa kushirikiana na wananchi wa Kondoa hivi sasa wamekuwa wakiwanasa ndege hao katika mitego maalum badala ya kuwaangamiza kwa sumu, alisema.

5. Uroho wa kitoweo wawatokea puani Mtanzania 21Sept 2009

(People suffered after eating chemical sprayed quelea

Uroho wa kitoweo wawatokea puani

Wanakijiji Dodoma wala ndege waliopuliziwa sumu
Miili yao yaumuka kwa kuwasha, wengine wababuka

Na Debora Sanja, Dodoma

BAADHI ya wakazi wa Kijiji cha Gawaye, kilichopo katika Manispaa ya Dodoma, nje kidogo ya mji, wameathirika na kemikali baada ya kula ndege waliouawa kwa kupuliziwa sumu.

Wanakijiji hao wanadaiwa kula ndege hao aina ya kwelea kwelea ambao walinyunyiziwa sumu na wataalamu wa kilimo, kutokana na kuharibu mazao katika kijiji hicho.

Inaelezwa kuwa baada ya wataalamu hao kunyunyizia sumu hiyo, baadhi ya wakazi wa kijiji hicho walirudi kesho yake wakiwa na magunia na kuwazoa ndege hao kwa ajili ya kitoweo, licha ya kutahadharishwa na viongozi wa kijiji kuwa wanaweza kudhurika.

Akizungumza na Mtanzania, Diwani wa Kata ya Chihanga, Julia Mputu, alisema kabla ya wataalamu kupulizia sumu ndege hao, waliitisha mikutano ya hadhara na kuwaarifu watu wasiwale ndege watakaokufa.

"Pamoja na kuwaataarifu kuwa ndege hao ni hatari lakini walipuuza wakisema wamekuwa wakiwala ndege hao miaka yote baada ya kuuawa, na kwamba hawajahi kudhurika na kama ni madhara huwa ni ya muda mfupi tu," alisema Mputu.

Baadhi ya wanakiji waliojitokeza, walidai wanasikia kuwashwa mwili mzima na kwamba mara nyingine hutoka vipele kwa muda mrefu pamoja na kubabuka ngozi.

Wengine walieleza kuwa wanajisikia vibaya ikiwamo kuchoka wakati wote, kujisikia kichefuchefu, kuumwa kichwa, kupata kizunguzungu na kuvimbiwa wakati wote, lakini baadhi wakasema dalili hizo zilikuwa ni za muda mfupi na badaye zilitoweka.

Alipooulizwa, mtaalamu wa mambo ya ndege waharibifu kwa mazao, ambaye ni Ofisa Kilimo Mkuu Msaidizi, Kitengo cha Afya ya Mimea Kanda ya Kati, Damasa Shumbusho, alisema ni kweli kwamba sumu ya kuwaua ndege hao ni hatari na ni sumu kwa binadamu.

"Tumeshafanya tafiti mbalimbali kwa kuchukua udongo na kuupima kuona kama kemikali za sumu zipo, tumezikuta na mpaka sasa tafiti zinaonyesha zina uwezo wa kukaa zaidi ya miezi mitatu ndani ya udongo huo.

"Vilevile tumewapima ndege waliokufa tumewakuta na kemikali za sumu, hivyo siyo hali ya kushangaza binadamu kuathirika na sumu hiyo kwa kuwa ina uwezo wa kudhuru wanyama wengine, ndio maana tuliwatahadharisha watu wasiokote ndege hao," alisema Shumbusho.

Alisema bado wanawatafuta watu walioathirika na sumu hiyo ili wachukue sampuli ya damu zao kuona kama sumu hiyo ina uwezo wa kukaa kwenye mwili wa binadamu kwa muda gani na kuna madhara gani ya baadaye.

Kijiji hicho kilivamiwa na ndege hao waharibifu mwaka jana na Ofisi ya Kilimo Kanda ya Kati iliwapulizia dawa kwa kutumia ndege mapema mwaka huu.

Appendix 4a. Nutrient content of dried milled quelea tested May 2010.

NUTRIENT CONTENT	UNITS	RESULTS
Ash	%	16.9
Calcium	%	2.61
Copper	mg/kg	10
Crude Fibre	%	<1.0
FFA of extracted fat (as Oleic Acid)	%	15.1
Gross Energy	MJ/Kg	18.450
Iron	mg/kg	382
Magnesium	%	0.13
Manganese	mg/kg	5
Moisture	%	11.3
Nicotinamide	mg/kg	85.20
Nicotinic Acid	mg/kg	10.50
Potassium	%	0.88
Protein (N X 6.25)	%	57.7
Sodium	%	3.36
Total Vitamin B3	mg/kg	95.70
Vitamin A, Trans-Retinol	IU/g	<1.00
Vitamin B1(Thiamine HCL	mg/kg	2.00
Vitamin B2(Riboflavin)	mg/kg	4.8
Vitamin C (Ascorbic Acid)	mg/kg	0
Water Soluble Carbohydrate	g/Kg	5.0
Zinc	mg/kg	75

Source: Sciantec Analytical Services Ltd. Stockbridge Technology Centre, Cawood, North Yorkshire YO8 3SD, UK.

See Certificate of Analysis below.

Certificate of Analysis

Robert A Cheke
University of Greenwich

Client Reference	Sample 1
Details	150g
Date Received	19-Apr-2010
Date Reported	7-May-2010
Lab Reference No	304447
Order Number	
Certificate No	304447_Sample 1_1.pdf
Product	Miscellaneous Miscellaneous
Sampled Date	
Sample Source	

Method No			Test	Units	Result	Completed On
S1024	*		Ash	%	16.9	29-Apr-2010
S1015	*		Calcium	%	2.61	29-Apr-2010
S1015	*		Copper	mg/kg	10	29-Apr-2010
S1022	*		Crude Fibre	%	<1.0	22-Apr-2010
JAS1059	*		FFA of extracted fat (as Oleic Acid)	%	15.1	4-May-2010
	*	#	Gross Energy	MJ/Kg	18.450	23-Apr-2010
S1015	*		Iron	mg/kg	382	29-Apr-2010
S1015	*		Magnesium	%	0.13	29-Apr-2010
S1015	*		Manganese	mg/kg	5	29-Apr-2010
S1023	*		Moisture	%	11.3	20-Apr-2010
	*	#	Nicotinamide	mg/kg	85.20	4-May-2010
	*	#	Nicotinic Acid	mg/kg	10.50	4-May-2010
S1015	*		Potassium	%	0.88	29-Apr-2010
S1018	*		Protein (N x 6.25)	%	57.7	21-Apr-2010
S1015	*		Sodium	%	3.36	29-Apr-2010
	*	#	Total Vitamin B3	mg/kg	95.70	4-May-2010
JAS1072	*		Vitamin A, Trans-Retinol	IU/g	<1.00	28-Apr-2010
	*		Vitamin B1 (Thiamine HCl)	mg/kg	2.00	7-May-2010
	*		Vitamin B2 (Riboflavin)	mg/kg	4.8	22-Apr-2010
	*		Vitamin C (Ascorbic Acid)	mg/kg	0	6-May-2010
S1030	*		Water Soluble Carbohydrate	g/Kg	5.0	21-Apr-2010
S1015	*		Zinc	mg/kg	75	29-Apr-2010

Appendix 4b. Certificate of Analysis for safety of quelea meat conducted in April 2010.

The results are as follows:

JAS1128 * C.perfringens cfu/g 130

S2103 * Salmonella in 25g Not Detected

S2104 * Enterobacteriaceae cfu/g <10

These results relate only to the sample(s) tested and do not guarantee the bulk of the material to be of equal quality. This report shall not be reproduced except in full, without the written approval of Sciantec Analytical Services Ltd. Sciantec Analytical Services Ltd. was not responsible for sampling and cannot be held liable in respect of the use to which information is put.

A certificate having a number with a suffix of _2 or greater is supplementary to the original report. Tests marked with # are subcontracted to a UKAS accredited laboratory. Tests marked *# are subcontracted to a non UKAS accredited laboratory. Tests marked with * are outside UKAS scope of accreditation. Microbiological assays marked with (p) are presumptive.

Unless otherwise stated results are expressed on an 'as received' basis.

Source: Sciantec Analytical Services Ltd. Stockbridge Technology Centre, Cawood, North Yorkshire YO8 3SD, UK.

See Certificate of analysis below.

Certificate of Analysis

Robert A Cheke
University of Greenwich

Client Reference	Sample 2
Details	50g
Date Received	19-Apr-2010
Date Reported	27-Apr-2010
Lab Reference No	304448
Order Number	
Certificate No	304448_Sample 2_1.pdf
Product	Miscellaneous Miscellaneous
Sampled Date	
Sample Source	

Method No		Test	Units	Result	Completed On
JAS1128	*	C.perfringens	cfu/g	130	27-Apr-2010
S2103	*	Salmonella	in 25g	Not Detected	23-Apr-2010
S2104	*	Enterobacteriaceae	cfu/g	<10	21-Apr-2010

Unless otherwise stated results are expressed on an 'as received' basis.

Alan Ash
Technical Support Manager

Sciantec Analytical Services Ltd.
Stockbridge Technology Centre, Cawood, Yorkshire
YO8 3SD
t + 44 (0) 1757 242400
f + 44 (0) 1757 242401
www.sciantec.uk.com

Appendix 5. A comparison between the numbers of quelea caught in traditional basket traps with those caught in wire-mesh equivalents.

Appendix 5.1. A comparison between the numbers of quelea caught in traditional basket traps with those caught in wire-mesh with one entrance hole.

Date	**Type of Site**	**Type of Trap**	**No. of Traps**	**Time of Trapping**	**No. of Birds caught/hr**	**No of Birds caught/day**	**Average No. of birds caught/ trap/hr**
Day 1 3/9/ 09	Drinking	Grass Basket	5	10am	715		143
				11am	635		127
				12am	755		151
				16pm	620		124
				17pm	665		133
				18pm	775		155
Subtotal						**4165**	**833**
Day 2 4/9/09	Drinking	Grass Basket	5	10am	730		146
				11am	570		117
				12am	745		149
				16pm	645		129
				17pm	680		136
				18pm	715		143
Subtotal						**4085**	**820**
Day 3 5/9/09	Drinking	Grass Basket	5	10am	710		142
				11am	860		116
				12am	685		149
				16pm	695		119
				17pm	710		132
				18pm	720		144
Subtotal						**4380**	**802**
					Grand	**12630**	**2455**

					total			
Day 1 3/9/09	Site 1	Drinking	Wire-Mesh Basket	5	10am	1515		303
					11am	1095		219
					12am	1590		318
					16pm	1005		201
					17pm	1135		227
					18pm	1620		324
Subtotal							**7960**	**1592**
Day 2 4/9/09	Site 2	Drinking	Wire-Mesh Basket	5	10am	1470		294
					11am	1020		204
					12am	1580		316
					16pm	1020		204
					17pm	1165		233
					18pm	1610		322
Subtotal							**7865**	**1573**
Day 3 5/9/09	Site 3	Drinking	Wire-Mesh Basket	5	10am	1705		341
					11am	1125		225
					12am	1710		342
					16pm	1120		224
					17pm	1300		260
					18pm	1655		331
Subtotal							**8615**	**1723**
						Grand total	**24440**	**4888**

Appendix 5.2. The numbers of quelea caught by traditional basket traps in comparison with the numbers caught by wire-mesh traps with two entrance holes.

Date	Type of Site	Type of Trap	No. of Traps	Time of Trapping	No. of Birds caught/hr	No of Birds caught/day	Average No birds caught/ trap/hr
Day 4 6/9/09	Drinking	Grass Basket	5	10am	810		140
				11am	780		133
				12am	825		163
				16pm	830		158
				17pm	703		130
				18pm	865		167
Subtotal						**4813**	**891**
Day 5 7/9/09	Drinking	Grass Basket	5	10am	700		162
				11am	665		156
				12am	815		165
				16pm	790		166
				17pm	650		140.6
				18pm	835		173
Subtotal						**4455**	**962**
Day 6 8/9/09	Drinking	Grass Basket	5	10am	690		138
				11am	630		126
				12am	735		147
				16pm	755		151
				17pm	670		134
				18pm	815		163
Subtotal						**4295**	**859**
Grand total						**13563**	**2712**

Day 4 6/9/09	Drinking	Wire-Mesh Basket	5	10am	1560		312
				11am	1515		303
				12am	1620		324
				16pm	1685		337
				17pm	1490		298
				18pm	1755		351
Subtotal						**9625**	**1925**
Day 5 7/9/09	Drinking	Wire-Mesh Basket	5	10am	1690		338
				11am	1455		291
				12am	1950		390
				16pm	1920		384
				17pm	1380		276
				18pm	1965		393
Subtotal						**10360**	**2072**
Day 6 8/9/09	Drinking	Wire-Mesh Basket	5	10am	1785		357
				11am	1495		299
				12am	1805		361
				16pm	1840		368
				17pm	1535		307
				18pm	1870		374
Sub total						**10330**	**2066**
Grand total						**30315**	**6063**

Appendix 5.3. The numbers of quelea caught by traditional basket traps in comparison with the numbers caught by wire-mesh traps with three entrance holes.

Date	Type of Site	Type of Trap	No. of Traps	Time of Trapping	No. of Birds caught/hr	No.of Birds caught/day	Average No.birds caught/ trap/hr
Day 7 9/9/09	Drinking	Grass Basket (one entrance hole)	5	10am	810		162
				11am	725		145
				12am	755		151
				16pm	820		164
				17pm	675		135
				18pm	825		165
Subtotal						**4610**	**922**
Day 8 10/9/09	Drinking	Grass Basket (one entrance hole)	5	10am	825		165
				11am	695		139
				12am	800		160
				16pm	865		173
				17pm	680		136
				18pm	900		160
Subtotal						**4765**	**933**

Day 9 11/9/09	Drinking	Grass Basket (one entrance hole)	5	10am	860		172
				11am	685		137
				12am	710		142
				16pm	890		178
				17pm	735		147
				18pm	970		194
Subtotal						**4850**	**970**
Grand total						**14225**	**2825**
Day 7 9/9/09	Drinking	Wire-Mesh Basket	5	10am	2835		567
				11am	2765		553
				12am	2805		56I
				16pm	2860		572
				17pm	2455		491
				18pm	2790		558
						16510	**2741**

Day 8 10/9/09	Drinking	Wire-Mesh Basket	5	10am	2755		551
				11am	2685		537
				12am	2850		570
				16pm	2870		574
				17pm	2440		488
				18pm	2945		589
Subtotal						**16545**	**3309**

Day 9 11/9/09	Drinking	Wire-Mesh Basket	5	10am	2660		532
				11am	2430		486
				12am	2785		557
				16pm	2880		576
				17pm	2460		492
				18pm	2810		562
Sub total						**16025**	**3205**
Grand total						**49080**	**9255**

Appendix 5.4. The numbers of quelea caught by traditional basket traps in comparison with the numbers caught by wire-mesh traps with one, two or three entrance holes.

Date	Type of Site	Type of Trap	No. of Traps	Time of Trapping	No. of Birds caught/hr	No of Birds caught/day	Average No birds caught/ trap/hr
Day 1 13/9/09	Drinking	Grass Basket (One hole)	3	10am	477		159
				11am	438		146
				12am	471		157
				16pm	474		158
				17pm	417		139
				18pm	480		160
Sub total						**2757**	**919**
	Drinking	Wire-Mesh Basket (One hole)	3	10am	834		278
				11am	621		207
				12am	840		280
				16pm	858		286
				17pm	798		266
				18pm	852		284
Sub total						**4803**	**1601**
	Drinking	Wire-Mesh Basket (2 holes)	3	10am	1095		365
				11am	1059		353
				12am	1110		370
				16pm	1104		368
				17pm	902		302
				18pm	1122		374
Sub total						**6392**	**2132**

	Drinking	Wire-Mesh Basket (3 holes)	3	10am	1662		554
				11am	1611		537
				12am	1680		560
				16pm	1701		567
				17pm	1626		542
				18pm	1710		570
Sub total						**9990**	**3330**
Day 2 14/9/09	Drinking	Grass Basket (One hole)	3	10am	441		147
				11am	408		136
				12am	435		145
				16pm	465		155
				17pm	405		135
				18pm	444		148
Sub total						**2598**	**866**

	Drinking	Wire-Mesh Basket (One hole)	3	10am	810		270
				11am	786		262
				12am	834		278
				16pm	837		279
				17pm	792		264
				18pm	846		282
Sub total						**4905**	**1635**

	Drinking	Wire-Mesh Basket (2 holes)	3	10am	1086		362
				11am	1029		343
				12am	1104		368
				16pm	1110		370
				17pm	1008		336
				18pm	1116		372
Sub total						**6453**	**2151**
	Drinking	Wire-Mesh Basket (3 holes)	3	10am	1701		567
				11am	1620		540
				12am	1713		571
				16pm	1707		569
				17pm	1641		547
				18pm	1719		573
Sub total						**10101**	**3367**
Day 3 15/9/09	Drinking	Grass Basket (One hole)	3	10am	432		144
				11am	387		129
				12am	426		142
				16pm	456		152
				17pm	402		134
				18pm	435		145
						2538	**846**
	Drinking	Wire-Mesh Basket (One hole)	3	10am	816		272
				11am	771		257
				12am	843		281
				16pm	855		285
				17pm	726		242
				18pm	828		276
Sub total						**4839**	**1613**

	Drinking	Wire-Mesh Basket (2 holes)	3	10am	1101		367
				11am	1914		338
				12am	1095		365
				16pm	1122		374
				17pm	1035		345
				18pm	1110		370
Sub total						**7377**	**2159**
	Drinking	Wire-Mesh Basket (3 holes)	3	10am	1749		583
				11am	1698		566
				12am	1734		578
				16pm	1731		577
				17pm	1653		551
				18pm	1755		585
Sub total						**10320**	**3440**
					GRAND TOTAL	**73073**	**24059**
TOTAL FOR THE WHOLE OPERATION				**221703**			

Appendix 6. CDs and DVDs produced (available on request)

1. During the interviews
2. Quelea trapping using traditional basket traps
3. During the Farmer's Shows

Appendix 7 (a&b)

Scientific publications on studies conducted in conjunction with this thesis

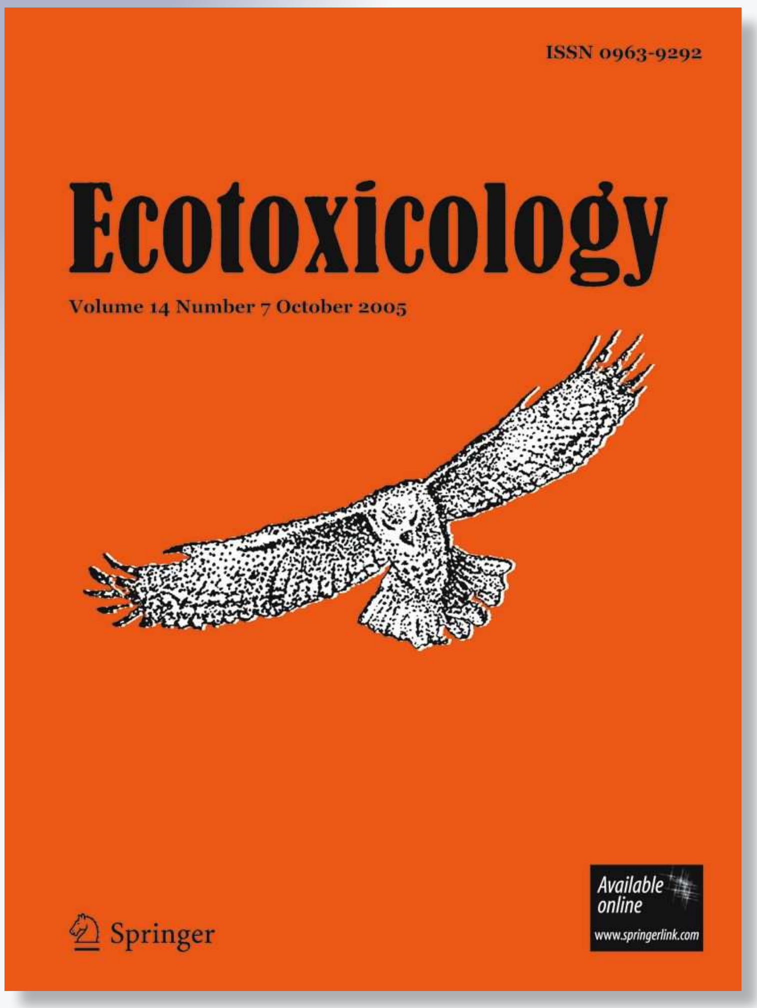
Effects of the organophosphate fenthion for control of the red-billed quelea Quelea quelea *on cholinesterase and haemoglobin concentrations in the blood of target and non-target birds*

Robert A. Cheke, Andrew N. McWilliam, Collen Mbereki, Etienne van der Walt, Boaz Mtobesya, Richard N. Magoma, Stephen Young & J. Patrick Eberly

Ecotoxicology

ISSN 0963-9292

Ecotoxicology
DOI 10.1007/s10646-012-0911-6



Springer

Ecotoxicology
DOI 10.1007/s10646-012-0911-6

Effects of the organophosphate fenthion for control of the red-billed quelea *Quelea quelea* on cholinesterase and haemoglobin concentrations in the blood of target and non-target birds

Robert A. Cheke · Andrew N. McWilliam · Collen Mbereki · Etienne van der Walt · Boaz Mtobesya · Richard N. Magoma · Stephen Young · J. Patrick Eberly

Accepted: 7 April 2012

Abstract The red-billed quelea bird *Quelea quelea* is one of sub-Saharan Africa's most damaging pests, attacking small-grain crops throughout semi-arid zones. It is routinely controlled by spraying its breeding colonies and roosts with organophosphate pesticides, actions often associated with detrimental effects on non-target organisms. Attributions of mortality and morbidity of non-targets to the sprays are difficult to confirm unequivocally but can be achieved by assessing depressions in cholinesterase activities since these are reduced by exposure to organophosphates. Here we report on surveys of birds caught before and after sprays that were examined for their blood cholinesterase activities to assess the extent to which these became depressed. Blood samples from birds were taken before and after sprays with fenthion against red-billed quelea in colonies or roosts, and at other unsprayed sites, in Botswana and Tanzania and analysed for levels of haemoglobin (Hb) and activities of whole blood acetylcholinesterase (AChE) and butyrylcholinesterase (BChE). Background activities of AChE, BChE and Hb concentrations varied with bird species, subspecies, mass, age and gender. Contrary to expectation, since avian erythrocytes are often reported to lack cholinesterases, acetylcholinesterase activities in pre-spray samples of adult birds were positively correlated with Hb concentrations. When these factors were taken into account there were highly significant declines ($P < 0.0001$) in AChE and BChE and increases in Hb after contact with fenthion in both target and non-target birds. BChE generally declined further (up to 87 % depression) from baseline levels than AChE (up to 83 % depression) but did so at a slower rate in a sample of quelea nestlings. Baseline activities of AChE and BChE and levels of Hb were higher in the East African subspecies of the red-billed quelea *Q. q. aethiopica* than in the southern African subspecies *Q. q. lathamii*, with the exception of BChE activities for adult males which were equivalent.

Keywords Bird pest control · Fenthion · Red-billed Quelea · Acetylcholinesterase · Butyrylcholinesterase · Haemoglobin · Non-target birds and reptiles · Africa

Electronic supplementary material The online version of this article (doi:10.1007/s10646-012-0911-6) contains supplementary material, which is available to authorized users.

R. A. Cheke (✉) · S. Young
Natural Resources Institute, University of Greenwich at Medway, Chatham Maritime, Kent ME4 4TB, UK
e-mail: R.A.Cheke@greenwich.ac.uk

A. N. McWilliam
The James Hutton Institute, Craigiebuckler, Aberdeen AB15 8QH, Scotland, UK

Present Address:
A. N. McWilliam
Stoneybrae, Glen Road, Lumphanan, Kincardineshire AB31 4PR, Scotland, UK

C. Mbereki
Division of Plant Protection, Ministry of Agriculture, Gaborone, Botswana

E. van der Walt
ARC, Plant Protection Research Institute, Pretoria, South Africa

B. Mtobesya · R. N. Magoma
Plant Health Services, Ministry of Agriculture Food Security and Cooperatives, Arusha, Tanzania

J. P. Eberly
EQM Research, 2814 Urwiler Ave., Cincinnati, OH 45211, USA

Published online: 27 April 2012

Introduction

The red-billed quelea bird *Quelea quelea* is one of sub-Saharan Africa's worst pests, causing damage up to the equivalent of US$79.4 million per annum at 2011 prices throughout semi-arid zones (Elliott 1989a, b). This migrant pest is a serious threat to the livelihoods of farmers growing small-grain cereals in much of western, southern and eastern Africa but particularly in Botswana, South Africa, Tanzania and Zimbabwe. A single bird can destroy 10 g of grain per day, of which only a quarter may be consumed (Elliott 1989a). The birds occur in flocks, sometimes countable in millions, and up to 12 million birds may roost together (La Grange 1989). Quelea bird control operations in southern Africa involve spraying of organophosphate pesticides (fenthion or cyanophos), from aircraft or from the ground, onto breeding colonies and night roosts; or destruction of roosting areas, and occasionally of colonies, using explosives. In an average year in South Africa alone, for example, there are 173 separate control operations, each one covering c.7 ha on average, with a total kill of c.50 million birds (Willemse 2000). Control of breeding colonies using fenthion has been carried out in Tanzania for the last four decades and, in Botswana, an average of 2,000 litres have been sprayed annually for more than two decades. In addition, explosives have been used in Botswana for the last 6 years.

Fenthion and an alternative avicide, cyanophos, are organophosphate compounds which are known to be hazardous. Environmental contamination is of serious concern in sprayed areas, as control operations can pose both direct and indirect health hazards to humans, livestock and other non-target organisms (Bruggers et al. 1989; Mullié et al. 1999; McWilliam and Cheke, 2004). Direct hazards result from spray applications and indirect hazards can result from consumption of contaminated food. For instance, in some areas of Tanzania, quelea birds are often used in homesteads as a source of protein and, after avicide spraying has been carried out, dead birds are frequently collected for consumption. Similar secondary poisoning amongst wildlife can occur if carnivorous mammals, birds or reptiles consume contaminated quelea.

Non-target organisms including birds are killed during the sprays, but it is difficult to disprove that such casualties have not been affected by other factors such as disease. Organophosphates (OPs) act by inhibiting acetylcholinesterase (Thompson 1991, 1999), which is essential for normal nerve function (Coye et al. 1986; Magnotti et al. 1988). Inhibition of the enzyme results in build-up of acetylcholine and prolonged transmission of nerve impulses leading to death from respiratory failure. In mammals cholinesterase exists in blood cells as erythrocyte acetylcholinesterase (AChE), identical to the enzyme found in the nervous system and thought to be a good indicator of neuronal activity, or in plasma as butyrylcholinesterase (BChE) and both types are markers of exposure to OPs. The turnover rate for red blood cells in mammals is slow (half-life of about 1 month) and AChE is typically used as a marker of *chronic* exposure. In contrast, BChE turnover is much quicker (half-life of about 2 weeks) and it is a better short-term indicator of *acute* poisoning due to its more rapid response to exposure (Whitaker 1986, Lawson and Barr 1987, Thompson 1999). However, the responses of each enzyme vary with the type of organophosphate applied as pointed out by Mullié et al. (1998) who drew attention to greater inhibition of BChE than AChE in response to monocrotophos (Van Sittert 1991), in contrast to methylated organophosphates such as azinphosmethyl which inhibit AChE but not BChE (Schneider et al. 1994). In birds there is AChE activity in the brain and plasma and BChE activity in plasma, but ever since early reports by Stedman and Stedman (1935) that there was no AChE in avian erythrocytes this has been widely accepted (e.g. see Walker and Thompson 1991). However, Stedman and Stedman (1935) only examined "fowl" and "duck" and they also reported a lack of AChE in cat erythrocytes, yet this is now known to be mistaken (e.g. see Harlin and Dellinger 1993). Furthermore, others have reported the presence of traces (Mendel et al. 1943) or even up to 0.3 ΔpH units h^{-1} (Onyeyili et al. 1992) of AChE in bird erythrocytes. Here we report that whole blood AChE of birds is positively correlated with Hb concentrations and further research on why this is the case is needed. It is likely that bird erythrocytes do contain AChE in higher activities than traces, especially as there is a highly significant correlation ($r = 0.93$, $P < 0.001$) between haemoglobin and erythrocyte counts of South African birds (Fourie and Hattingh 1983).

Since organophosphates depress cholinesterase concentrations, objective assessments of poisoning can be made by measuring the activities of AChE and BChE. A previous study confirmed that measurements of AChE in target and non-target birds before and after a fenthion spray in Kenya provided useful information on the spray's environmental impact (Bruggers et al. 1989). Although Bruggers et al. (1989) published data on cholinesterase levels in the brains of dead birds, they gave details of AChE activities in the blood of only a few free-flying birds and did not assess BChE activity or haemoglobin (Hb) levels, as presented here. Haemoglobin concentrations are often taken as indicators of a bird's condition (Bańbura et al. 2007, Lill 2011) and they vary with the season (Colombelli-Négrel and Kleindorfer 2008, Norte et al. 2009b), species (Cooper 1975, Fourie and Hattingh 1983), gender (Colombelli-Négrel and Kleindorfer 2008, Norte et al. 2009b), reproductive status as measured by nuptial or eclipse plumage

(Colombelli-Négrel and Kleindorfer 2008), levels of ectoparasitism (Whitworth and Bennett 1992, O'Brien et al. 2001) and levels of haematozoan parasitism (Norte et al. 2009a). Regarding the latter, the main taxon investigated here (*Q. q. lathamii*) is known to harbour high rates of parasitism (63.2 %) with *Haemoproteus* sp. and *Plasmodium* sp. (Durrant et al. 2007). Given the above factors, we wished to control for them by using Hb as a proxy measure of condition but, as already mentioned, we found that whole blood AChE was in any case positively correlated with Hb concentrations, so we adjusted for this finding in our analyses.

This is the first study to provide data on pre- and post-exposure activities of AChE, BChE and Hb concentrations in a wide variety of species of wild birds in Africa. From the data obtained, we test the null hypotheses (1) that organophosphate poisoning by fenthion cannot be detected in non-target birds by analysing their BChE as well as AChE activities; (2) that activities of AChE and BChE do not respond differently to the same exposures to fenthion; (3) that haemoglobin (Hb) levels are unaffected by contact with sprays and (4) that background levels of AChE, BChE and haemoglobin do not vary with bird species, subspecies, size, age and gender.

Materials and methods

Analyses of blood samples

To obtain baseline information on AChE and BChE activities in a variety of bird species for comparisons with those in birds found moribund after spraying operations, blood samples were collected from unaffected free-flying birds caught in mist-nets and then released, or from nestlings found in nests and returned to them. Post-control samples were taken from birds found moribund at sites sprayed with fenthion (o,o-dimethyl o-[3-methyl-4-(methylthio)phenyl] phosphorothiate) in both Botswana and Tanzania. The wing length (maximum chord, mm) and weight (g, measured using Pesola balances) of each bird was measured before blood was collected from the birds' brachial veins. Two 0.01 ml capillary tubes of blood were obtained per bird and the contents of each was immediately transferred to one of two vials of buffer solution (pH 7.6) containing a mixture of phosphate, surfactant and EDTA preservative and vigorously shaken. If analyses in the field were impractical, the vials were stored in a portable refrigerator at about 3 °C for up to 24 h before measurement. One vial was used to assay AChE and the other BChE. Hb readings were taken from each vial and the average of these used for analyses. Two custom-made kits were used for the assays, one reserved for AChE assays, the other for BChE. The kits were portable cholinesterase testing devices based on the Test-mate system commercially available for analysing human blood (EQM Research, Inc. Cincinnati, USA). The bird blood kit used a 12 V battery-operated photometric analyser for assays based on the Ellman method (Ellman et al. 1961) to measure the concentration of an indicator that increases in proportion to the activity of cholinesterase in test samples. The assay kit first heats up to a constant 37 °C and is then used to measure a blank of the buffer solution, a value for Hb (g dl^{-1}), then BChE (U ml^{-1}) or AChE (U ml^{-1}) and AChE adjusted for its associated haemoglobin levels (U g^{-1}), using methods described by Magnotti et al. (1988). Acetylthiocholine (AcTC) or butyrylthiocholine (BuTC) is hydrolysed by AChE or BChE respectively, producing carboxylic acid and thiocholine which reacts with the Ellman reagent (dithionitrobenzoic acid, DNTB) to form a yellow colour. This is measured spectrophotometrically at 470 nm and the rate of colour formation is proportional to the activities of either AChE or BChE, which are estimated in units (U) per ml. One unit (U) is defined as the amount of an enzyme that catalyzes the conversion of 1 micro mole of substrate per minute, equivalent to 16.67 nano katals (1 katal being defined as the amount of enzyme that converts 1 mol of substrate per second, as recommended by the General Conference on Weights and Measures in 1978 and adopted at its 21st meeting in 1999 as its resolution 12, see http://www.bipm.org/en/CGPM/db/21/12/). Before use, the kits were calibrated to agree with a laboratory spectrometer calibrated to the USA's National Institute of Standards and Technology (NIST) traceable standards. The molar absorption coefficient of 4,360 M^{-1} cm^{-1} used for the reduced DNTB (i.e. the TNB resulting from the reaction) was taken from Table 3 of Eyer et al. (2003) for 37 °C and 470 nm. Similar quality control was used for calibrating the haemoglobin measurements, which were performed using the molar extinction coefficient of 33,209 M^{-1} cm^{-1} for haemoglobin in water at 470 nm, with the calibration constant for Hb at 470 nm being independent of that for the TNB.

The avian classification and the sequence used in the supplementary material follow the *Handbook of the Birds of the World* (del Hoyo et al. 1992–2011).

Study areas

In Botswana, samples of pre-control birds were obtained between 20 February 2004 and 5 February 2010 at Atholl Holme Farm, a site approximately 20 km west of Gaborone at 24°45′S, 25°51′E and at Shakawe (4–5 March 2005; 18°22′S, 21°51′E). Both pre- and post-control samples were collected at various quelea breeding colony (c) or roost sites (r) including Sebalola (c; 1–4 March 2004; 21°1′4″S, 27°2′27″E), Kotolaname (r; 10 March 2005, 24°28′20″S, 25°16′33″E), Diboro (c; 16 January 2008, 24°16′45″S, 26°34′33″E), Musi (r; 22 May 2009; 25°31′34.0″S, 25°07′36.7″E), Naledi (r; 25 May 2009; 25°38′40″S, 24°52′3″E), Pilikwe (c: 23 January 2008; 22°50′2″S, 27°10′31″E), Maphoko (c; 19–20 January 2008; 23°28′45″S, 25°44′13″E), Masilajwe 1 (c; 27 January–1 February 2008; 21°50′2″S, 26°29′9″E), Masilajwe 2 (c; 2–3 February 2008; 21°49′50″S, 26°29 55″E), and a few birds were sampled 6 weeks after a cyanophos spray (from a fixed wing aircraft at 4 litres per ha of a 520 ULV formulation of cyanophos, Falcolan 520 UL, Symbiosis Technologies Pty Ltd; 520 g cyanophos per litre) in a colony at Pandamatenga (30–31 May 2009; 18°41′S, 25°30′E). In Tanzania, birds were sampled in 2008 and 2009 at quelea colonies at Chidilo (4–16 March 2008, 6°25′4″S, 35°25′32″E), Zejele (16 March 2008; 6°24′53″S, 35°24′35″E) and Gawaye (21 March 2009, 5° 51′S, 35° 50′E), at a roost at Ndachi (12–22 March 2009; 6°04′S, 35°40′E) and chickens were sampled at a farm at Chihanga (10 March 2009, 5°55′39S, 35°50′41″E). The locations of the study sites are depicted in Fig. 1.

In Botswana, the fenthion sprays were conducted using vehicle-mounted sprayers depositing fenthion (queletox, 640 UL) at 4 l ha^{-1}. In Tanzania, fenthion sprays were conducted from a fixed wing aircraft, similarly at 640 g of active ingredient per litre, but at 2 l ha^{-1}.

Results

Analyses of blood samples

Samples taken from 610 birds of 62 species were analysed. Of these 189 were from moribund birds caught after sprays. Values for mass (g), haemoglobin (Hb, g dl^{-1}), raw AChE (units ml^{-1}), AChE adjusted per g of Hb (U g^{-1}) and raw BChE (U ml^{-1}) were obtained for different sexes, ages and subspecies of each species. The requirement to adjust the AChE activities according to a bird's Hb concentration followed the discovery that raw AChE activities in pre-control samples of adult *Q. q. lathamii* were positively correlated with Hb concentrations (ANOVA, df = 1, $F = 13.27$, $P < 0.0004$, Fig. 2). Tests for effects of sex, interaction between sex and Hb or addition of mass data in an ANCOVA did not make any significant differences to the model. As cholinesterase production increases with a bird's age (e.g. see Fig. 1 of Thompson 1991) and baseline levels are species specific (Walker and Thompson 1991 and this paper), only data from adult birds with information from 8 or more replicates were used in an ANCOVA to test if this result was general, which was found to be the case ($r = 0.67$, $P < 0.0004$), with the species effect also highly significant ($P < 0.0001$).

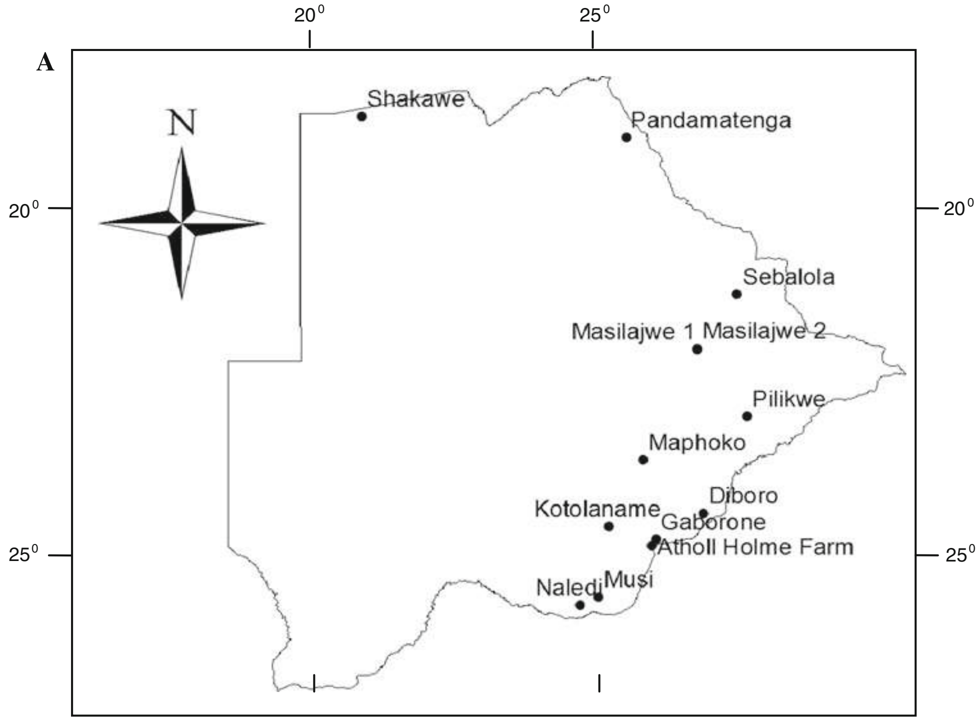
The supplementary material summarises the results for raw AChE activities, AChE adjusted for Hb concentrations, BChE activities and Hb concentrations for all taxa investigated according to species, age, gender and pre- or post-spray status.

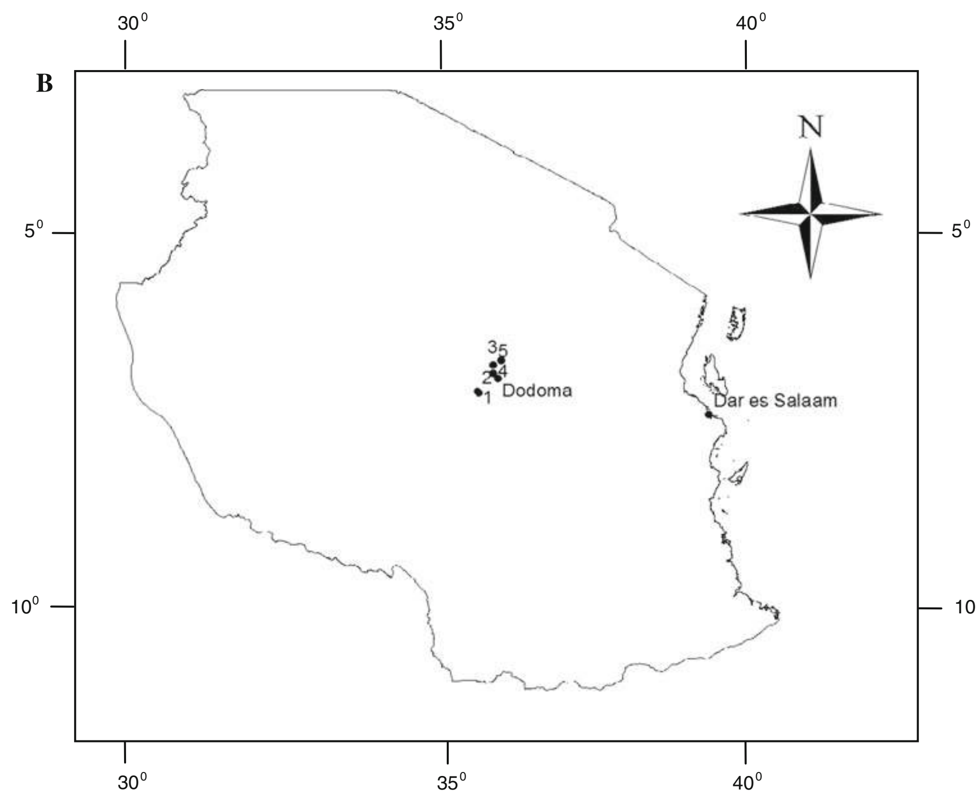
Among the nine species for which comparisons are possible, the extent of the percentage reductions in their combined data-sets for BChE levels were greater than those for adjusted AChE in six species (laughing dove 47 %/–6 %, respectively; kurrichane thrush 87 %/74 %; red-backed shrike, 87 %/83 %; red-billed quelea 66 %/60 %; southern red bishop, 79 %/76 %; southern masked weaver, 89 %/24 %), the same in one (chestnut-vented warbler, 13 %) and less in two (common whitethroat 64 %/75 %; vitelline masked weaver 50 %/73 %). Of the latter, the results for vitelline masked weaver were based on only one moribund bird, a nestling in which enzyme physiological systems may not have been fully developed anyway. Nestlings are known to have lower Hb values than fledged birds (Kostelecka-Myrcha et al. 1973). When the BChE values for this bird are compared with the AChE value unadjusted for Hb, then the extent of depression is indeed greater (50 % versus 54 %). Figure 3 shows comparisons of pre- and post-spray results for adjusted AChE and for BChE for nine taxa, without accounting for age, sex or mass. Post-spray activities for both cholinesterases are lower than pre-spray results in all cases except the AChE for *Streptopelia senegalensis*, which included two nestling birds.

The full data-set was analysed by ANOVA which revealed significant effects ($P < 0.0001$) of pre- or post-exposure status, age, sex and taxon on all of the biochemical measurements in most combinations except for pre- or post- spray for Hb, and for BChE the effect of sex was only significant at $P < 0.002$. Post-exposure levels were in general very much lower than baseline levels for AChE, adjusted AChE and BChE, but higher for Hb (supplementary material). Figure 4 shows the adjusted AChE results and BChE data, respectively, for different ages, sexes and subspecies of *Q. quelea.*

To test for the effects of bird size, the data were re-analysed after adjusting values by dividing them by ln (mass of bird). These results revealed the same trends but with even greater probabilities of significance and, now, Hb values were significant for the pre-spray: post-spray comparison ($P < 0.0001$), with post-spray values higher in contrast to the lower post-spray values for the cholinesterases. In summary, there were significant effects of species, spraying, age and sex, the interaction between species and spraying, the interaction between species and age on

Fig. 1 Maps showing the locations of sampling sites in **a** Botswana and **b** Tanzania, where 1 = Chidilo, 2 = Zejele, 3 = Gawaye, 4 = Ndachi and 5 = Chihanga. Latitudes are degrees South and longitudes are degrees East. Points 1 and 2 are marked by one spot





all of Hb, unadjusted AChE, adjusted AChE and BChE ($P < 0.0001$, except for sex on Hb, $P = 0.009$, species and spray on BChE, $P = 0.018$, and species and age on Hb, $P = 0.011$ and on BChE, $P = 0.0015$). In addition, there were significant effects of the interaction between spraying and age on Hb ($P = 0.017$), adjusted AChE and BChE (both $P < 0.0001$), of the interaction between species and sex on adjusted AChE ($P = 0.024$) and on BChE ($P = 0.0005$) and of the interaction between spraying and sex on adjusted AChE ($P = 0.004$).

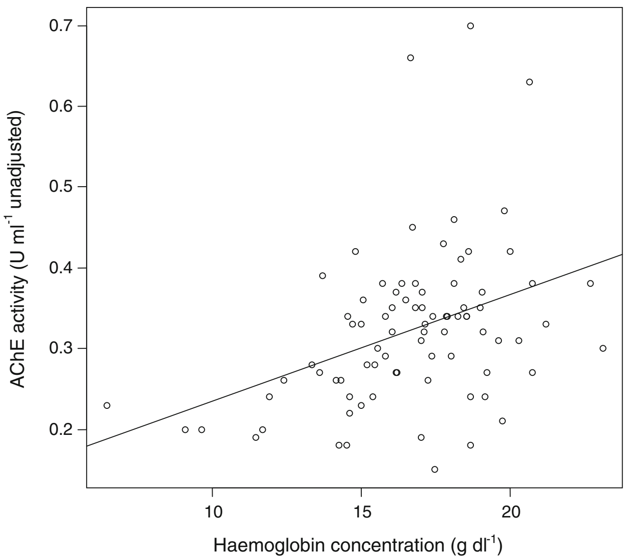


Fig. 2 Relation between AChE activity (U ml^{-1}, unadjusted) and haemoglobin concentration (g dl^{-1}) for adult *Quelea q. lathamii*, for which the regression equation is: AChE Activity $= 0.103 + 0.0132\text{Hb}$, $r^2 = 0.149$, $n = 82$

Given the finding that the results were dependent upon species, the data were further scrutinised according to subspecies by comparing data for the southern African subspecies of the red-billed quelea *Q. q. lathamii* with those for the eastern African subspecies *Q. q. aethiopica*. The analyses confirmed that when age and gender are accounted for there are subspecific differences in pre-exposure levels for unadjusted AChE, adjusted AChE and BChE (adult male *lathamii* < adult male *aethiopica*, $P < 0.0001$; adult female *lathamii* < adult female *aethiopica*, $P < 0.0001$ in each case, except for male BChE data, which were not significantly different, with significances increased when adjusted for ln (mass of bird)) (Table 1). There were no significant differences in pre- and post-spray levels of Hb for the subspecific data set with the exception of post-spray female *aethiopica* having significantly higher Hb than pre-spray adult females ($P = 0.04$) (Table 1). However, multiple comparison of means using Tukey's Honest Significant Difference tests confirmed the significance of pre- and post-spray differences in the cholinesterases of adult males and adult females for both *Q. q. aethiopica* and *Q. q. lathamii* and for juveniles and nestlings of *Q. q. lathamii*. For those pairs of pre- and post-spray data that were significantly different, the extents to which pre-spray values were depressed after the sprays were greater for BChE than for adjusted AChE, except for nestling *Q. q. lathamii* which were equivalent (Table 1).

Temporal trends in AChE levels

At Masilajwe a group of nestling *Quelea* were examined at different times after exposure and the results showed that

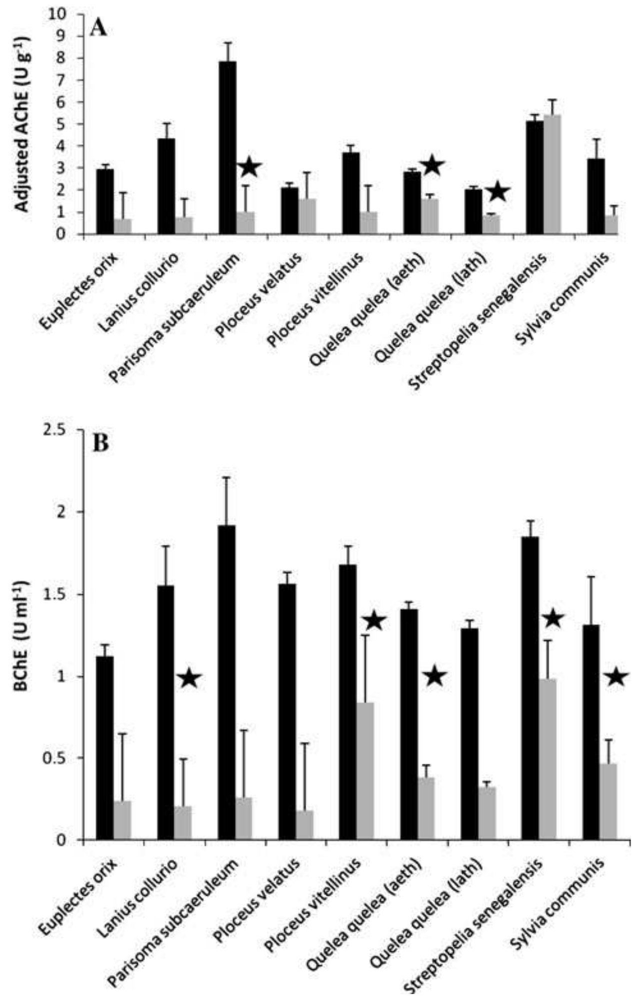


Fig. 3 Comparisons between pre-spray (*black bars*) and post-spray (*grey bars*) activities of **a** AChE adjusted for Hb concentrations and **b** BChE for all samples from nine taxa, without accounting for age, sex or mass. Stars indicate significantly lower post-spray results ($P < 0.0001$ for A; $P < 0.05$ for B). *Error bars* show positive standard error estimates based on ANOVA residuals

activities of AChE and BChE dropped with increasing time post-exposure. In both graphs the cholinesterase activities approach zero after about 40 h but, when analysed further, the rate of decline in the adjusted AChE values is faster than that for BChE. Figure 5 shows the data plotted with the x axis transformed by taking logarithms to the base 10. Regressions for the relationships derived from a mixed effects model with replicate as a random component, to allow for the repeated measures, are adjusted AChE activity (U g^{-1}) $= 3.4747\ (\pm\ 0.2057) - 1.7725\ (\pm 0.2065)$ log (time) and BChE activity (U ml^{-1}) $= 0.8506\ (\pm\ 0.2057) - 0.4210\ (\pm 0.2065)$ log (time), where time is measured in hours. The interaction between the compounds and time in the mixed effects ANCOVA was highly significant ($F = 31.4$; df $= 1$ and 26; $P < 0.0001$—residual df conservatively based on

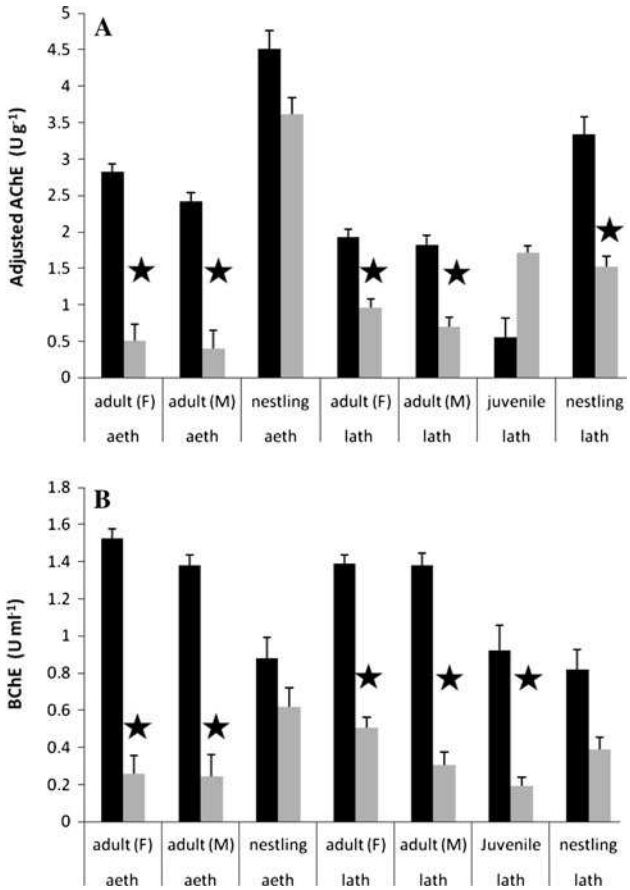


Fig. 4 Pre- (*black bars*) and post-spray (*grey bars*) activities of **a** AChE adjusted for Hb (U g^{-1}) and **b** BChE (U ml^{-1}) for different ages and sexes of *Q. q.aethiopica* (aeth) and *Q. q. lathamii* (lath). Stars indicate significantly lower post-spray results ($P < 0.05$, Tukey tests). *Error bars* show positive standard error estimates based on ANOVA residuals

number of replicates), confirming that these slopes were significantly different.

Avian and reptilian mortality and morbidity after sprays

The estimated percentage kills of target red-billed quelea in Botswana were low (e.g. <45 % at Maphoko) and few non-target mortalities were observed, even after extensive searches along transects throughout the sprayed areas. At Maphoko, 1 red-backed shrike *Lanius collurio* was found dead. At Pilikwe no dead non-targets were found. At Masilajwe 1, one red-faced mousebird *Urocolius indicus* was found dead and two nestling kurrichane thrushes *Turdus libonyanus* perished and at Masilajwe 2, 1 red-backed shrike *L. collurio* was found dead. At Masilajwe 1, a stripe-bellied snake *Psammophis subtaeniatus* was found moribund after the spray and some dead insects such as beetles were also found after the sprays. The snake eventually died and a post-mortem examination revealed that it had consumed 2 nestling quelea and had, presumably, died of primary and secondary poisoning. The only other known reptilian fatality as a consequence of spraying quelea was a lizard *Agama agama* reported by Mullié et al. (1999). In Tanzania, 2 chestnut weavers *Ploceus rubiginosus* were found dead after the spray at Chidilo, 1 shrike *Lanius* sp., 1 village weaver *Ploceus cucullatus* and 1 *Cisticola* sp. were found dead after the spray at Ndachi and a female common whitethroat *Sylvia communis* was dead after the spray at Gawaye.

Discussion

Both pre- and post-exposure activities of AChE, BChE and haemoglobin were dependent on the mass, age, sex, species and, in some cases, subspecies of the birds involved, as expected in the light of other studies on variation in avian cholinesterases (Walker and Thompson 1991; Fossi et al. 1996; Roy et al. 2005; Fildes et al. 2009) and haemoglobin (see Introduction). AChE and BChE activities were generally depressed after fenthion sprays, as expected following the study of Bruggers et al. (1989), and so can both be used in rapid field-based assessments of organophosphate exposure. Although the BChE values fell proportionally further than the adjusted AChE values (for *Q. quelea*, see Table 1; for other species see Fig. 3), their rate of decline was less than for AChE in nestlings (Fig. 5) contrary to the reported more rapid rate of depression of BChE in mammals (Whitaker 1986; Lawson and Barr 1987; Thompson 1999). In man, depression of cholinesterase to <50 % of normal indicates possible pesticide poisoning requiring removal from exposure and/or treatment with anticholinergics such as atropine and pralidoxime (Coye et al. 1986). Laboratory studies on birds suggest that cholinesterase activity of less than two standard deviations (about 20 %) below the control mean of brain acetylcholinesterase is indicative of exposure to anti-cholinesterases such as organophosphates (Ludke et al. 1975 cited in Grue et al. 1991). Therefore, the high percentage depressions (53–81 %) found among quelea and similarly depressed or low ChE values of the non-target species from the sprayed sites confirm the utility of this assay for assessing fenthion poisoning, although our data cannot be compared directly with other studies that examined depressions of brain cholinesterases. However, there is evidence that the latter are related to serum cholinesterase activities in birds (Fossi et al. 1992) and lizards (Sanchez-Hernandez and Walker 2000) so similar relations are likely to exist with the species that we studied but this requires confirmation. The observed interspecific variation and differences in ChE levels between adults and young emphasise the importance of obtaining baseline data

Table 1 Mean values ± SE (n) for haemoglobin (Hb, g dl^{-1} (ln(g))$^{-1}$), unadjusted acetylcholinesterase (AChE, U ml^{-1} (ln(g))$^{-1}$), acetylcholinesterase adjusted for Hb concentrations (U g^{-1} (ln(g))$^{-1}$) and butyrylcholinesterase (BChE, U ml^{-1} (ln(g))$^{-1}$), all adjusted by division by ln (mass of bird, g) for *Q. q. lathamii* and *Q. q. aethiopica* of different ages and sexes

Taxon, age and sex	Pre-spray Hb	Post-spray	Pre-spray Unadjusted AChE	Post-spray	Pre-spray Adjusted AChE	Post-spray	Pre-spray BChE	Post-spray
Q. q. lathamii	5.80 ± 0.18 (29)	6.62 ± 0.20 (24)	**0.11 ± 0.006 (29)**	**0.04 ± 0.006 (24)****	**0.65 ± 0.047 (29)**	**0.25 ± 0.051 (24)****	**0.49 ± 0.021 (29)**	**0.11 ± 0.023 (24)****
Adult males		114.1 %		**36.4 %**		**38.5 %**		**22.4 %**
Q. q. aethiopica	6.16 ± 0.35 (34)	7.07 ± 0.17 (8)	**0.15 ± 0.005 (34)**	**0.03 ± 0.011 (8)****	**0.84 ± 0.043 (34)**	**0.16 ± 0.089 (8)****	**0.48 ± 0.019 (34)**	**0.09 ± 0.040 (8)****
Adult males		114.8 %		**20.0 %**		**19.0 %**		**18.7 %**
Q. q. lathamii	5.62 ± 0.13 (53)	6.07 ± 0.17 (34)	**0.12 ± 0.004 (53)**	**0.06 ± 0.005 (34)****	**0.76 ± 0.034 (53)**	**0.34 ± 0.043 (34)****	**0.48 ± 0.015 (53)**	**0.18 ± 0.019 (34)****
Adult females		108.0 %		**50.0 %**		**44.7 %**		**37.5 %**
Q. q. aethiopica	**5.67 ± 0.17 (35)**	**6.95 ± 0.31 (10)***	**0.16 ± 0.005 (35)**	**0.06 ± 0.010 (10)****	**1.05 ± 0.042 (35)**	**0.18 ± 0.079 (10)****	**0.58 ± 0.019 (35)**	**0.09 ± 0.035 (10)****
Adult females		**122.6 %**		**37.5 %**		**17.1 %**		**15.5 %**
Q. q. lathamii	6.73 ± 0.37 (7)	5.94 ± 0.13 (56)	0.08 ± 0.012 (7)	0.03 ± 0.004 (56)	**0.59 ± 0.095 (7)**	**0.20 ± 0.033 (56)****	**0.26 ± 0.042 (7)**	**0.07 ± 0.015 (56)*****
Juveniles		88.3 %		37.5 %		**33.9 %**		**27 %**
Q. q. lathamii	4.18 ± 0.33 (9)	5.31 ± 0.21 (23)	0.13 ± 0.011 (9)	0.07 ± 0.007 (23)	**1.22 ± 0.084 (9)**	**0.57 ± 0.052 (23)*****	**0.30 ± 0.037 (9)**	**0.14 ± 0.015 (23)*****
Nestlings		127.0 %		53.8 %		**47 %**		**47 %**
Q. q. aethiopica	4.46 ± 0.33 (8)	11.44 ± 0.31 (10)	0.19 ± 0.011 (8)	0.42 ± 0.01 (10)	1.84 ± 0.089 (8)	3.62 ± 0.079 (10)	0.37 ± 0.040 (10)	0.616 ± 0.035 (10)
Nestlings		256.5 %		221.0 %		196.7 %		166.5 %

Percentages refer to post-spray values as percentages of the relevant pre-spray value. No samples of juvenile *aethiopica* were obtained

Significant differences are denoted in *bold* with P values derived from multiple comparisons of means using Tukey's Honest significant difference test as follows *$P < 0.05$, **$P < 0.001$, *** $P < 0.0001$

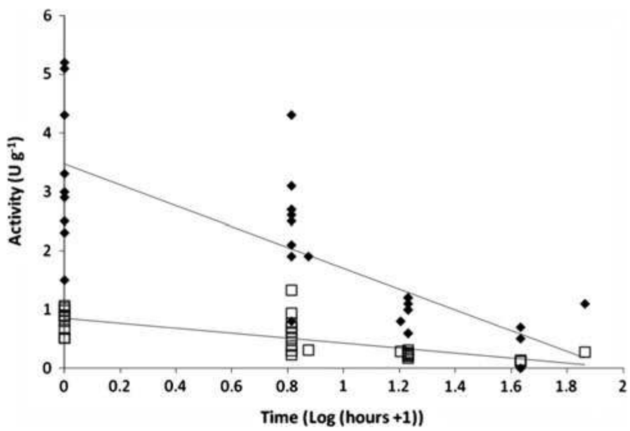


Fig. 5 Changes in activities of whole blood acetylcholinesterase adjusted for Hb concentrations (AChE, U g^{-1}) and butyrylcholinesterase (BChE, U ml^{-1}) of nestling *Q. q. lathamii* plotted against time in hours after the spray converted to logarithms to the base 10 + 1. *Diamonds* = AChE data; *open squares* = BChE data. The slope for the BChE relationship is significantly different from that for AChE ($P < 0.0001$). The regression equations are: AChE = 3.475 − 1.773.log(time + 1), $r^2 = 0.941$, $n = 32$, BChE = 0.851 − 0.421.log(time + 1), $r^2 = 0.473$, $n = 32$

(Roy et al. 2005, Fildes et al. 2006), for which our data (supplementary material) can be used as a starting point for southern and east African birds, provided that methods giving standardised results in U ml^{-1} can be used. The extent of the depressions of cholinesterases in the few spray-affected non-target birds found suggests that the extent of non-target morbidity and mortality was probably much higher than we were able to detect: many birds could have been dead or dying within dense thorn bush, taken by predators during the night before we could search for them or moved outside our sampled zones.

The finding of raised Hb levels after contact with fenthion was unexpected as chronically poisoned birds are known to have depressed Hb values (Geens et al. 2010), but presumably it was a physiological reaction by the birds to acute poisoning when attempting to summon resources to cope with the toxic shock of OP exposure likely to have led to dehydration and vomiting, both of which could contribute to increased Hb levels. The variation of baseline levels of Hb according to taxon, age and sex and its increase after sprays calls into question the use in ecological studies of unadjusted Hb values as indicators of condition or fitness (Bańbura et al. 2007) but is consistent with other data showing an effect of age on Hb (and on both AChE and BChE; Norte et al. 2009b).

Of the hypotheses tested all were refuted and so we have confirmed (1) that organophosphate poisoning by fenthion can be detected in non-target birds by analysing their BChE as well as AChE activities in blood; (2) that activities of AChE and BChE respond differently to the same exposures to fenthion; (3) that haemoglobin (Hb) levels are also affected by contact with sprays by increasing and (4) that background levels of AChE, BChE and haemoglobin vary with bird species, subspecies, mass, age and gender.

Acknowledgements The bulk of the research (2007–2010) was financed by the EU ICART CRARF programme (Project number 9 ACP SAD 1-13) managed by the Southern African Development Community (SADC). The initial research (2004–2005, projects R6823/R7967/R8314/R8426, Crop Protection Programme) was funded by the United Kingdom Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID. We thank many members of staff of the Ministries of Agriculture in Botswana and Tanzania and Pietie van Niekerk, Jan de Klerk, Joel Mooka and Ezekia Sgudlha for invaluable assistance in the field. Remi and Wendy Borello provided much assistance and hospitality in Botswana where R. Kgosi, P. Malikongwe, M. Modise, T. Moruti, M. Murata (SADC) and C. Tizikara (SADC) also provided much help. We are grateful to Christopher Ilori for preparing Fig. 1 and we also thank two anonymous referees and the editors for their constructive comments.

References

Bańbura J, Bańbura M, Kaliński A, Skwarska J, Slomczyński R, Wawrzyniak J, Zieliński P (2007) Habitat and year-to-year variation in haemoglobin concentration in nestling blue tits *Cyanistes caeruleus*. Comp Biochem Physiol A: Mol Integr Physiol 148:572–577

Bruggers RL, Jaeger MM, Keith JO, Hegdal PL, Bourassa JB, Latigo AA, Gillis JN (1989) Impact of fenthion on nontarget birds during quelea control in Kenya. Wildl Soc Bull 17:149–160

Colombelli-Négrel D, Kleindorfer S (2008) In superb fairy wrens (*Malurus cyaneus*), nuptial males have more blood parasites and higher haemoglobin concentration than eclipsed males. Aust J Zool 56:117–121

Cooper JE (1975) Haematological investigations of East African birds of prey. J Wildl Dis 11:389–394

Coye MJ, Lowe JA, Maddy KT (1986) Biological monitoring of agricultural workers exposed to pesticides. I. Cholinesterase activity determinations. J Occup Med 28:619–627

del Hoyo J et al (1992–2011) Handbook of birds of the world, vol 1–16. Lynx edicions, Barcelona

Durrant KL, Reed JL, Jones PJ, Dallimer M, Cheke RA, McWilliam AN, Fleischer RC (2007) Variation in haematozoan parasitism at local and landscape levels in the red-billed quelea. J Avian Biol 38:662–671

Elliott CCH (1989a) The pest status of the quelea. In: Bruggers R, Elliott CCH (eds) *Quelea quelea*: Africa's Bird Pest. Oxford University Press, Oxford, pp 17–34

Elliott CCH (1989b) The quelea as a major problem in a food-deficient continent. In: Mundy PJ, Jarvis MJF (eds) Africa's feathered locust. Baobab Books, Harare, pp 90–99

Ellman GL, Courtney KD, Andres V, Featherstone RM (1961) A new and rapid colorimetric determination of acetylcholinesterase activity. Biochem Pharmacol 7:88–95

Eyer P, Worek F, Kiderlen D, Sinko G, Stuglin A, Simeon-Rudolf V, Reiner E (2003) Molar absorption coefficients for the reduced Ellman reagent: reassessment. Anal Biochem 312:224–227

Fildes K, Astheimer LB, Story P, Buttemer WA, Hooper MJ (2006) Cholinesterase response in native birds exposed to fenitrothion during locust control operations in eastern Australia. Environ Toxicol Chem 25:2964–2970

Fildes K, Szabo JK, Hooper MJ, Buttemer WA, Astheimer LB (2009) Plasma cholinesterase characteristics in native Australian birds: significance for monitoring avian species for pesticide exposure. Emu 109:41–47

Fossi MC, Leonzio C, Massi A, Lari L, Casini S (1992) Serum esterase inhibition in birds: a non-destructive biomarker to assess organophosphorus and carbamate contamination. Arch Environ Contam Toxicol 23:99–104

Fossi MC, Lari L, Casini S (1996) Interspecies variation of "B" esterases in birds: the influence of size and feeding habits. Arch Environ Contam Toxicol 31:525–532

Fourie F le R, Hattingh J (1983) Comparative haematology of some South African birds. Comp Biochem Physiol 74A:443-448

Geens A, Dauwe T, Bervoets L, Blust R, Eens M (2010) Haematological status of wintering great tits (*Parus major*) along a metal pollution gradient. Sci Total Environ 408:1174–1179

Grue CE, Hart ADM, Mineau P (1991) Biological consequences of depressed brain cholinesterase activity in wildlife. In: Mineau P (ed) Cholinesterase-inhibiting insecticides. Elsevier, Amsterdam, pp 151–209

Harlin KS, Dellinger JA (1993) Retina, brain and blood cholinesterase levels in cats treated with oral dichlorvos. Vet Hum Toxicol 35:201–203

Kostelecka-Myrcha A, Pinowski J, Tomek T (1973) Changes in the hematological values during the nestling period of the great tit (*Parus major* L.). Bull Acad Pol Sci Biol 21:725–732

La Grange M (1989) The effect of rainfall on the numbers of queleas destroyed in Zimbabwe. In: Mundy PJ, Jarvis MJF (eds) Africa's feathered locust. Baobab Books, Harare, pp 126–129

Lawson AA, Barr RD (1987) Acetylcholinesterase in red blood cells. Am J Hematol 26:101–112

Lill A (2011) Sources of variation in blood glucose concentrations of free-living birds. Avian Biol Res 4:78–86

Magnotti RA, Dowling K, Eberly JP, McConnell RS (1988) Field measurement of plasma and erythrocyte cholinesterases. Clin Chim Acta 176:315–332

McWilliam AN, Cheke RA (2004) A review of the impacts of control operations against the Red-billed Quelea (*Quelea quelea*) on non-target organisms. Environ Conserv 31:130–137

Mendel B, Mundell DB, Rudney H (1943) Studies on cholinesterase. 3. Specific tests for true cholinesterase and pseudocholinesterase. Biochem J. 37:473

Mullié WC, Andreasen J, Abiola FA, Diatta F, van der Valk H (1998) Blood cholinesterase levels in crop protection workers after routine spraying operations with organophosphate insecticides in Senegal. In: Everts JW, Mbaye D, Barry O, Mullié WC (eds) Environmental side-effects of locust and grasshopper control, vol 2., Food and Agriculture Organization of the United NationsRome, Italy, pp 170–189

Mullié WC, Diallo AO, Gadji B, Ndiaye MD (1999) Environmental hazards of mobile ground spraying with cyanophos and fenthion for quelea control in Senegal. Ecotoxicol Environ Saf 43:1–10

Norte AC, Araujo PM, Sampaio H, Sousa JP, Ramos JA (2009a) Haematozoa infections in a Great Tit *Parus major* population in Central Portugal: relationships with breeding effort and health. Ibis 151:677–688

Norte AC, Ramos JA, Sousa JP, Sheldon BC (2009b) Variation of adult Great Tit *Parus major* body condition and blood parameters in relation to sex, age, year and season. J Ornithol 150:651–660

O'Brien EL, Morrison BL, Johnson LS (2001) Assessing the effects of haemotophagous ectoparasites on the health of nestling birds: haematocrit vs haemoglobin levels in house wrens parasitized by blow fly larvae. J Avian Biol 32:73–76

Onyeyili PA, Egwu GO, Jibike GI, Atori JO (1992) Plasma and red cell cholinesterase concentrations in guinea-fowl (*Numida meleagris*) and Nigerian domestic fowl (*Gallus domesticus*). Vet Res Commun 16:173–175

Roy C, Grolleau G, Chamoulaud S, Rivière J-L (2005) Plasma B-esterase activities in European raptors. J Wildl Dis 41:184–208

Sanchez-Hernandez JC, Walker CH (2000) In vitro and in vivo cholinesterase inhibition in lacertides by phosphonate- and phosphorothionate-type organophosphates. Pestic Biochem Physiol 67:1–12

Schneider F, Steenland K, Hernandez B, Wilson B, Krieger R, Spencer J, Margetich S (1994) Monitoring peach harvest workers exposed to azinphosmethyl residues in Sutter County, California, 1991. Environ Health Perspect 102:580–585

Stedman E, Stedman E (1935) The relative choline-esterase activities of serum and corpuscles from the blood of certain species. Biochem J 29:2107–2111

Thompson HM (1991) Serum "B" esterases as indicators of exposure to pesticides. In: Mineau P (ed) Cholinesterase-inhibiting insecticides. Their impact on wildlife and the environment. Elsevier, Amsterdam, pp 110–125

Thompson HM (1999) Esterases as markers of exposure to organophosphates and carbamates. Ecotoxicology 8:369–384

Van Sittert NJ (1991) Biologische monitoring, biologische effect monitoring en gezondheidsonderzoek in de arbeidstoxicologie. Tijdschr NVKC 1991:259–268

Walker CH, Thompson HM (1991) Phylogenetic distribution of cholinesterases and related esterases. In: Mineau P (ed) Cholinesterase-inhibiting insecticides. Their impact on wildlife and the environment. Elsevier, Amsterdam, pp 2–17

Whitaker M (1986) Cholinesterase. In: Monographs in Human Genetics Vol.11. Basel, Karger

Whitworth TL, Bennett GF (1992) Pathogenicity of larval *Protocalliphora* (Diptera: Calliphoridae) parasitizing nestling birds. Can J Zool 70:2184–2191

Willemse JP (2000) Redbilled quelea annual report 1 April 1999 to 31 March 2000. Republic of South Africa. National Department of Agriculture, Directorate, Agricultural Land Resources Management. Unpublished Report

Research Article

Received: 14 September 2011 Revised: 26 January 2012 Accepted article published: 15 March 2012 Published online in Wiley Online Library:

(wileyonlinelibrary.com) DOI 10.1002/ps.3311

Soil contamination and persistence of pollutants following organophosphate sprays and explosions to control red-billed quelea (*Quelea quelea*)

Robert A Cheke,[a*] Enoch Adranyi,[a] John R Cox,[a] Dudley I Farman,[a] Richard N Magoma,[b] Collen Mbereki,[c] Andrew N McWilliam,[a,d] Boaz N Mtobesya[b] and Etienne van der Walt[e]

Abstract

BACKGROUND: Red-billed quelea (*Quelea quelea*) are controlled at breeding colonies and roosts by organophosphate sprays or explosions. Contamination with organophosphates after sprays and with petroleum products and phthalates after explosions was assessed.

RESULTS: Concentrations in soil of the organophosphate fenthion the day after sprays were uneven (0–29.5 μg g^{-1}), which was attributable to excess depositions at vehicle turning points, incorrect positioning of nozzles and poor equipment maintenance. A laboratory study using field-collected samples provided an estimate of 47 days for the half-life of fenthion. After sprays, fenthion persisted in soil for up to 188 days. High concentrations were detected 5 months after negative results at the same sites, providing indirect evidence of leaching. Concentrations of total petroleum hydrocarbons (TPHs) and phthalates ranged from 0.05 to 130.81 (mean 18.69) μg g^{-1} and from 0 to 1.62 (mean 0.55) μg g^{-1} respectively in the craters formed by the explosions, but declined to means of 0.753 and 0.027 μg g^{-1} at 10 m away. One year after an explosion, mean TPHs of 0.865 and mean phthalates of 0.609 were detected.

CONCLUSION: Localisation of high concentrations of fenthion likely to have effects on soil biota could be mitigated by improved spray management. Given a half-life in the soil of 47 days for fenthion and the possibility of its leaching months after applications raises concerns about its acceptability. The pollutants left behind after explosions have been quantified for the first time, and, given their long-term persistence, their continued use poses a threat to environmental health.

Keywords: red-billed quelea; *Quelea quelea*; soil; organophosphate; fenthion; cyanophos; explosions; diesel; petrol; plastics; phthalates; persistence

1 INTRODUCTION

Control of the red-billed quelea (*Quelea quelea*) is conducted because it is a major pest of small-grain cereal crops in semi-arid areas of sub-Saharan Africa.[1,2] Three subspecies of the bird are recognised: the nominate form occurs in West Africa, *Q. q. aethiopica* in eastern Africa and *Q. q. lathamii* in southern Africa. All three subspecies are intra-African migrants moving with rain fronts to breed colonially during rainy seasons.[3] In the dry seasons they congregate at night to roost communally. Both the colonies and roosts are targets for lethal control measures using either organophosphate sprays or explosions. Such actions have deleterious environmental consequences by killing or debilitating non-target organisms by direct and indirect poisoning.[4] Non-lethal effects on non-target birds and mammals can be monitored by measuring cholinesterase levels,[5] but effects on invertebrates, vegetation and the wider environment, including soil, are poorly documented.

Early reports suggested that the most commonly used organophosphate, fenthion, broke down quickly, with a half-life on soil exposed to sunlight of only 11 h,[6] but other studies have suggested long-term persistence of 14–40 days in soil,[7] a half-life in soil of

* Correspondence to: Robert A Cheke, European Centre for Integrated Pest Management, Natural Resources Institute, University of Greenwich at Medway, Central Avenue, Chatham Maritime, Kent ME4 4TB, UK. E-mail: r.a.cheke@greenwich.ac.uk

a Natural Resources Institute, University of Greenwich at Medway, Chatham Maritime, Kent, UK

b Plant Health Services, Ministry of Agriculture, Food, Security and Cooperatives, Dar es Salaam, Tanzania

c Plant Protection Division, Ministry of Agriculture, Gaborone, Botswana

d The James Hutton Institute, Craigiebuckler, Aberdeen, Scotland, UK

e ARC Plant Protection Research Institute, Queenswood, Pretoria, Republic of South Africa

34 days,[8] persistence in soil for 4–6 weeks[9] and up to 42 days on soil invertebrates.[10] Also, because of strong adsorption to soil particles, it was thought that leaching through soil would be unlikely.[8,9] Similarly, but concerning explosions, a widely held but unsubstantiated belief was that control using explosives was less harmful to the environment, as no persistent organic pollutants (POPs) were involved: for instance, Meinzingen *et al.*[11] state that one of the advantages of explosions is that 'there is no chemical contamination of the environment'. In the present work, an examination is made of concentrations of pesticide residues and post-explosion contaminants before and at various intervals after colonies or roosts have been either sprayed with organophosphates, fenthion (Queletox®) or cyanophos, or blown up by detonating mixtures of diesel and petrol. The studies were conducted at sites where *Q. q. lathamii* were controlled by both pesticides and explosions in Botswana and where sprays only were used against *Q. q. aethiopica* in Tanzania.

2 MATERIALS AND METHODS

2.1 Study sites in Botswana and Tanzania: sprays

In Botswana, both pre- and post-control soil samples were collected at various *Q. q. lathamii* breeding colony or roost sites that were sprayed using vehicle-mounted Micronair AU8115 sprayers depositing fenthion {Queletox®, 640 UL; thiophosphoric acid or *O*,*O*-dimethyl-*O*-[3-methyl-4-(methylthio) phenyl phosphorothioite]} at 4 L ha^{-1}. These included breeding colonies at Sebalola (colony size 4 ha; 1–4 March 2004; 21° 1′ 4″ S, 27° 2′ 27″ E), Pilikwe (1.4 ha; 23 January 2008; 22° 50′ 2″ S, 27° 10′ 31″ E), Maphoko (2.35 ha; 19–20 January 2008; 23° 28′ 45″ S, 25° 44′ 13″ E), Masilajwe 1 (22 ha; 27 January–1 February 2008; 21° 50′ 2″ S, 26° 29′ 9″ E) and Masilajwe 2 (11.24 ha; 2–3 February 2008; 21° 49′ 50″ S, 26° 29′ 55″ E). Soil samples were also collected on 30–31 May 2009, 41 days after sprays from a fixed-wing aircraft on 18–19 April 2009 at four sites at Pandamatenga. Two of these, Pandamatenga Q5 (18° 29′ 12″ S, 25° 34′ 0″ E) and Pandamatenga Q13 (18° 32′ 19″ S, 25° 33′ 32″ E), were sprayed with a 640 UL oil-based formulation of fenthion [Avima (Pty) Ltd], and the other two sites, Q34 (18° 40′ 28″ S, 25° 33′ E) and Q47 (18° 41′ 18″ S, 25° 30′ 2″ E), were sprayed aerially at 4 L ha^{-1} with a 520 ULV formulation of cyanophos (Falcolan 520 UL; Symbiosis Technologies PTY Ltd; 520 g cyanophos L^{-1}). For the ground sprays, the vehicle travels along a previously designated route, the planning of which often requires the cutting down of *Acacia* sp. and other bushes along a 'cut line'. In Tanzania, studies were conducted after a fixed-wing aircraft had sprayed fenthion at 640 g AI L^{-1}, at 2 L ha^{-1}, at a *Q. q. aethiopica* colony at Gawaye (40 ha; 21 March 2009, 5° 51′ S, 35° 50′ E).

2.2 Study sites in Botswana: explosions

Quelea control operations with explosives were monitored in Botswana: (a) in 2005 at a roost at Kotoloname (3 ha; 10 March; 24° 28′ 20″ S, 25° 16′ 33″ E; 233 bombs); (b) in 2009 at two adjacent sites covering 3.04 ha at Good Hope (25° 28′ 27″ S, 25° 27′ 0″ E), where 216 bombs were deployed on 19 May, plus 95 bombs at a third separate site nearby, at two adjoining sites near Jwaneng, Naledi 1 (0.219 ha; 25° 38′ 40″ S, 24° 52′ 3″ E) and Naledi 2 (0.15 ha), where 298 bombs were exploded on 20 May, at Musi (0.903 ha; 25° 31′ 34″ S, 25° 07′ 37″ E; number of bombs unknown) exploded on 22 May, at Pandamatenga Farm 213 (0.216 ha; 18° 33′ 18″ S, 25° 33′ 49″ E, number of bombs unknown) on 27 May, at Batabeli (0.047 ha; 18° 34′ 43″ S, 25° 38′ 58″ E, 28 bombs) on 2 June and at Pandamatenga Farm Q13 (0.2 ha, 18° 33′ 19″ S, 25° 33′ 48″ E, number of bombs unknown) on 4 June; (c) in 2010, one site at Nchakateng (1 ha; 21° 56′ 51″ S, 28° 23′ 27″ E, 200 bombs) was monitored on 31 January. In addition, three samples were collected at Gobojango (21° 51′ 42″ S, 28° 46′ 13″ E) on 28 January 2010 from a site where there had been explosions at the end of February in both 2008 and 2009.

The technique involves the detonation of 5 L plastic containers, filled with 2.5 L of a mixture of fuels: one-third diesel to two-thirds unleaded petrol was used in 2009 and 2010, but a 50 : 50 mixture of 1 L of diesel and 1 L of petrol was used in 2005; the addition of diesel keeps the flame alight longer than petrol alone, but also gives rise to smoke. Each plastic container (white opaque containers were used in 2005–2008, but green ones in 2009–2010) is placed beneath a bush where quelea birds are either nesting or expected to roost. Each container has an explosive charge placed beneath it. In 2005 this consisted of 150 g of Trojan C150 cast boosters, 38 × 120 mm of pentolite and a mixture of TNT and RDX, encased in yellow plastic [manufactured by Ensign-Bickford, (Pty) Ltd, South Africa]. Each booster had a hole drilled in the middle, through which red detonating cord (plastic cord, 8 g m^{-1}; Auxim Tech. Ltd, China) was fed. At the ignition site, about 120 cm of yellow safety fuse of slow-burning (8–10 mm s^{-1}) gunpowder was placed at the beginning of the cord (total length 1050 m for 233 plastic containers at Kotoloname in 2005), giving approximately 2.5 min between ignition and detonation. The fuse was connected to an electric detonator cord containing a white powdered high-explosive core to set off the detonator. This created a shock wave to the detonating cord, along which it travelled at 6400 m s^{-1}, exploding each booster in turn. In 2009 and 2010 the explosive used was Powergel™ (see www.oricaminingservices.com/download/file_id_4292/for information on its toxicology), a commercially available ammonium nitrate product, with a detonation velocity of 1780 m s^{-1} [$<$6400 m s^{-1} for TNT (see above), and $<$8400 m s^{-1} for pentaerythritol tetranitrate (PETN), which was also used in years before 2006), mixed with aluminium powder to enhance its performance. These charges were connected by cordex fuse cord, made of powdered PETN, to a central electric detonator that started the reaction with 1 g of metallic-derived explosives or after being activated by a slow-burning safety fuse of gunpowder (black powder). When the explosion takes place, the fuel mixture is first splashed up onto the trees where it forms a mist and then ignites.

2.3 Soil collections and analyses

A global positioning system (GPS) device was used to record locations of samples so that follow-up samples could be taken from close to the original locations. At Sebalola, 20 precontrol soil samples were taken, with four obtained every 100 m along the 'cut line': one at a randomly chosen central location, with the three others taken at the circumference of a circle 5 m away from it at randomly chosen directions, from a choice of due north, 120° and 240°. Twenty post-control samples were taken on 4 March 2004, the day after the spray, using the same procedure. Using similar protocols along the 'cut line', samples were taken at other sites as follows. At Maphoko, five precontrol samples were taken, and nine post-control samples on 20 January 2008, the day after the spray, followed by five samples at intervals thereafter (28 February, 15 April, 4 July, 27 July). At Pilikwe there were no precontrol samples, and eight samples were taken on 23 January 2008, the day after the spray, and eight on four subsequent dates (26 February, 19 March, 14 April, 13 July). At Masilajwe 1, five precontrol samples were taken, followed by 14 samples on 31 January 2008, the day after the spray, and 14 on each of 19 March, 15 April and 3 and 27 July. At Masilajwe 2, five precontrol samples were taken, followed by nine samples on 19 March, the day after the spray, 15 April and 3 and 27 July. At the Pandamatenga sites, no precontrol samples were taken, and two post-control samples were taken on 29 May at each of the four subsites (41 days after the sprays). At Gawaye, five samples were taken at randomly chosen places within the sprayed colony on 21 March 2009, the day after the spray, followed by five more on each of 28 March, 4 April, 21 April, 21 May, 21 June, 21 July, 21 August and 21 September. For the explosion studies, 2–4 precontrol samples were taken, and 3–9 post-control samples were taken from the centres of craters and at 5 and 10 m away (10 m only at Kotoloname) in randomly chosen directions. Soil samples of approximately uniform volumes (approximately 200 g, maximum depth 10 cm) were taken using trowels (washed with distilled water and wiped dry after each sampling) and stored in cloth bags. They were then air dried in sheltered shady conditions out of reach of rain or sunlight to minimise photolysis[12] and sieved, when any extraneous fresh vegetable material present was removed prior to the samples being double-wrapped in aluminium foil and sealed within polythene bags. All layers were labelled and kept in a deep freeze (−18 °C) pending analysis.

After the samples had been defrosted, they were allowed to warm to room temperature (approximately 20 °C). For fenthion residue estimates, each sample was then thoroughly mixed, and a 20 g subsample was placed into a 40 mL tube and extracted with 20 mL of acetone. A quantity of 50 µg of fenitrothion was added as an internal standard. Analysis was by gas chromatography–mass spectrometry (GCMS) using an Agilent 6890 GC connected to an Agilent 5973 MSD. Data collection and handling were performed using Agilent Chemstation. The capillary column used was a 30 m DB5 column of 0.25 mm internal diameter with 250 µm film thickness. The GC oven was programmed from 100 to 300 °C at 15 °C min^{-1}. The carrier gas was helium, at a flow rate of 1 mL min^{-1}. Example chromatograms are shown in Figs 1–3. The calculated lower limit of determination (i.e. the residue that could be identified and measured with confidence) was 0.002 mg kg^{-1}.

For samples collected before and after explosions, concentrations of petroleum products and plastic derivatives were assayed in defrosted soil samples extracted as described for the organophosphate analyses (see above). A quantity of 5 µg of decyl acetate was added as an internal standard. Analysis was by gas chromatography with a flame ionisation detector (GC-FID). The GC oven was programmed from 100 to 250 °C at 10 °C min^{-1}. Data collection and handling were performed using Agilent EZChrom Elite. For the residues from petroleum products, the results for 2009 and 2010 are expressed as total petroleum hydrocarbons (TPHs) (in µg g^{-1}), which here refer to the sum of all residues of tetradecane, pentadecane, hexadecane, heptadecane, octadecane, nonadecane, eicosane, heneicosane, docosane, tricosane and tetracosane. TPH is formally defined as the measurable amount of petroleum-based hydrocarbon in environmental media.[13] Petroleum products include both aliphatic compounds (straight-chain, branched-chain and cyclic alkanes and alkenes) and aromatic compounds (benzene and alkyl benzenes, naphthalenes and PAHs), and some may contain non-hydrocarbon additives such as alcohols, ethers, metals and other potentially toxic chemicals. For the residues from plastics, the results are expressed as total phthalates (in µg g^{-1}), which is the sum of residues of diethyl phthalate, dibutyl phthalate and dioctyl phthalate.

2.4 Laboratory studies on persistence

Soil samples collected before and after the spray on 3 March 2004 at Sebalola were used for tests on persistence. After the initial analyses by gas chromatography (GC) using a nitrogen phosphorus detector had revealed a heterogeneous distribution of fenthion concentrations, with a peak after spraying of 1.52 µg g^{-1} at one sample site shortly after the spray, three subsamples from samples that had the highest concentrations (1.52 µg g^{-1} sample T3-2, 0.34 µg g^{-1} sample T2-4 and 0.15 µg g^{-1} sample T5-2) were frozen. Following thawing in early 2007, an experiment

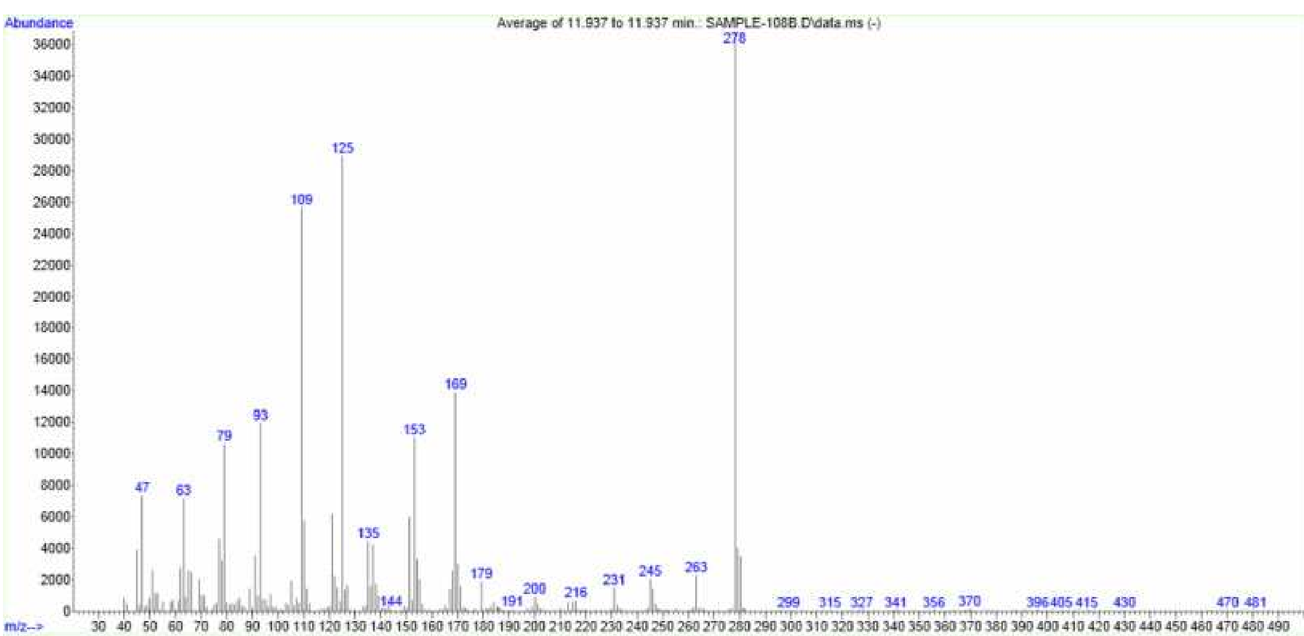


Figure 1. GCMS chromatogram from soil samples from Maphoko, showing GCMS spectra of fenthion.

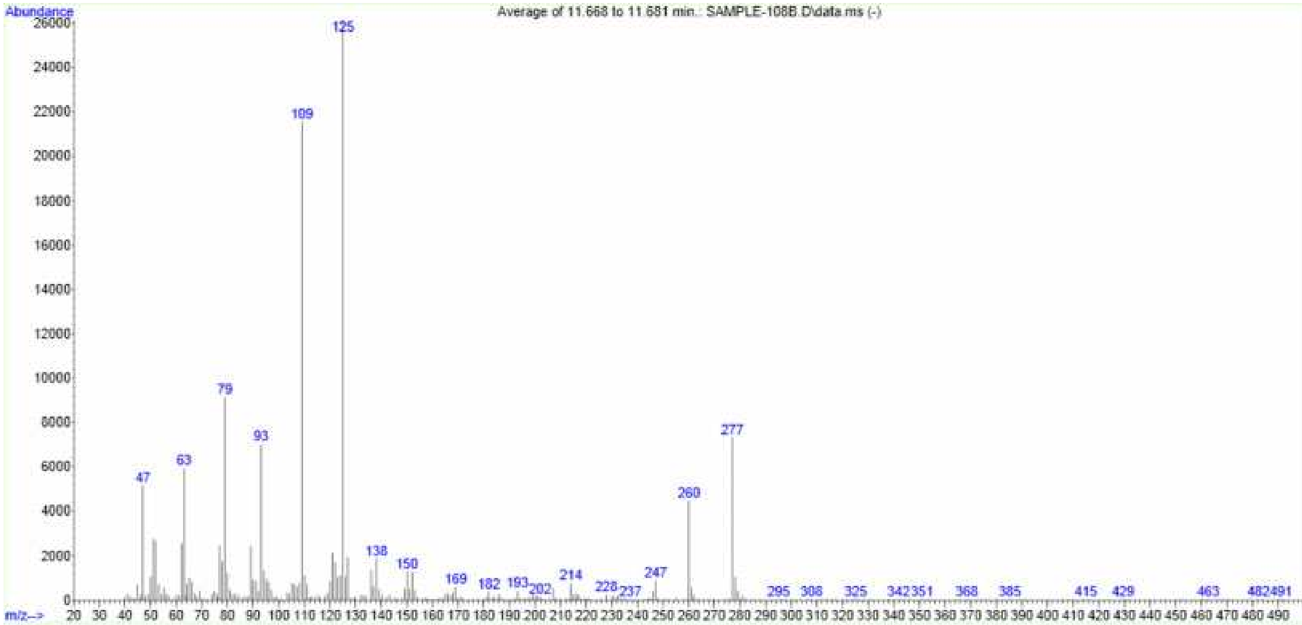


Figure 2. GCMS chromatogram from soil samples from Maphoko, showing GCMS spectra of fenitrothion.

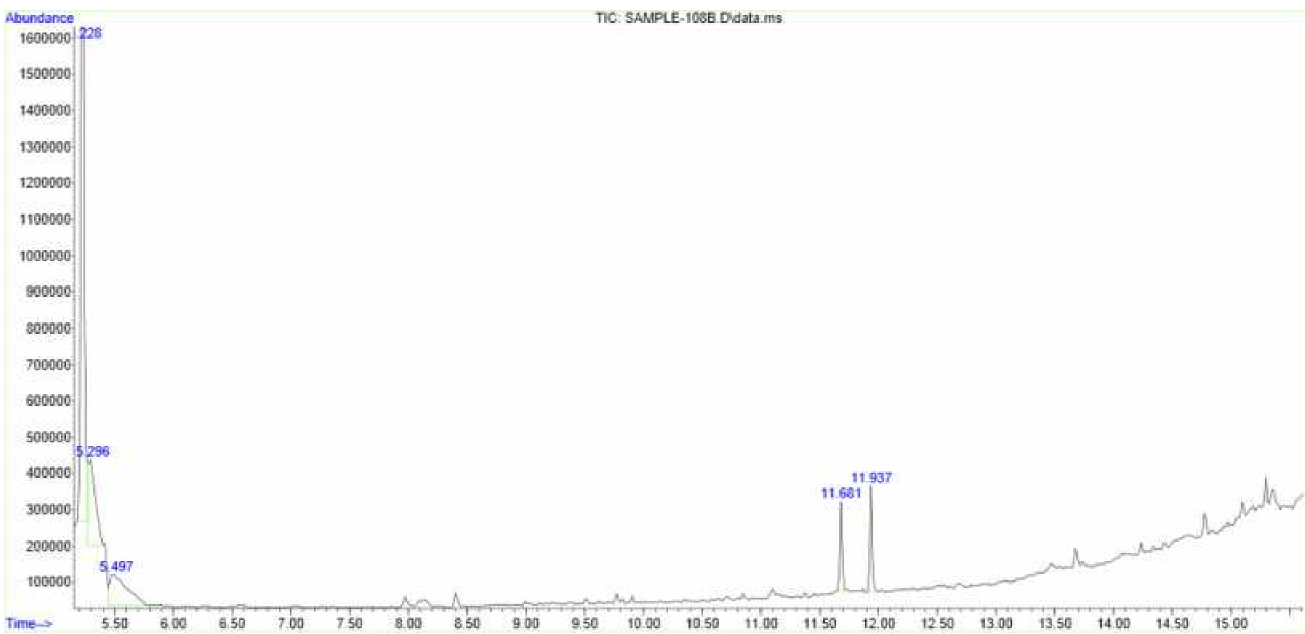


Figure 3. GCMS total ion chromatogram, showing fenitrothion at 11.681 min and fenthion at 11.937 min.

was conducted to determine decay rates and how long the pesticide could remain in the soil at potentially harmful levels under laboratory conditions. The samples were exposed to the air at room temperature (approximately 20 °C) in a laboratory at Chatham, and subsamples were analysed by GC at intervals over 64 days.

In March 2005, an experiment was conducted involving a deliberate application of fenthion (Queletox®, 640 UL) to soil to standardise the results of the residue analysis and to assess further its rate of breakdown. A sample of soil from Kotoloname was used, from which 5–6 g subsamples were packed into glass tubes. On 14 March, 250 µL of fenthion was added to each of 20 tubes, five of which were immediately closed with lids and deep frozen. The remainder were left in the shade at ambient temperature with their lids off. Next, five more were closed with lids and deep frozen at 24, 39, 101 and 168 h intervals. Each of the whole soil samples (between 5 and 5.5 g) was washed with acetone and Soxhlet extracted, with acetone, for 4 h. Analysis was then conducted as for the 2004 soil samples (see above). In addition, a sample of the solution of fenthion used for the experiment was also analysed. A quantity of 250 µL of the fenthion formulation used was transferred, by syringe, to a 25 mL volumetric flask and diluted to the mark with acetone (std T1); 5.0 mL of this solution was then diluted to 10 mL with acetone (std T2). Calculation of percentage recovery was based on comparison with these two standards.

3 RESULTS

3.1 Contamination after sprays

3.1.1 Botswana and Tanzania: fenthion in the soil and evidence for leaching

Fenthion was detected only at the $<0.002\ \mu g\ g^{-1}$ level in precontrol samples at Sebalola. This was also found for one of the post-control samples there, but a wide range ($0.002-1.52\ \mu g\ g^{-1}$) was detected among the other 19 post-control samples that had a mean value of $0.125\ \mu g\ g^{-1}$ (SD = 0.348). With the exception of the results from Pilikwe (range $0-2.445\ \mu g\ g^{-1}$), the concentrations of fenthion in post-control samples was very variable and heterogeneous (Table 1). Ranges of concentrations found were 0–12.98 for Maphoko, 0–14.32 for Masilawe 1 and 0–14.06 for Masilawe 2 (Table 1). Table 2 gives the results for Gawaye in Tanzania, where very high concentrations were detected the day after the spray (up to $29.48\ \mu g\ g^{-1}$; mean = 15.138; SD = 12.655; n = 5).

At the sites examined at Pandamatenga 41 days after aerial sprays with fenthion, $0-0.769\ \mu g\ g^{-1}$ of fenthion were still detectable (mean = 0.214; SD = 0.371; n = 4). That the fenthion persists in the soil for such periods and longer was also confirmed at other sites where sampling was continued beyond the morning after a spray. For instance, high concentrations of fenthion were still detectable many months after the spraying events (up to $11.69\ \mu g\ g^{-1}$ at Maphoko after 188 days; up to $1.44\ \mu g\ g^{-1}$ at Pilikwe after 172 days; up to $0.60\ \mu g\ g^{-1}$ at Masilajwe 1 after 182 days; up to $9.20\ \mu g\ g^{-1}$ at Masilajwe 2 after 175 days; up to $0.01\ \mu g\ g^{-1}$ at Gawaye after 93 days) (Tables 1 and 2). However, except for Gawaye, all of these late positive results were recorded following months during which no fenthion was detectable. Even at Gawaye, positive results were obtained at two subsites 1 and 2 months after negative results respectively. It is assumed that these reappearances of fenthion were because, after sequestration within the soil, the pesticide residues leached back up to near the surface following rainfall.

3.1.2 Botswana: cyanophos in the soil

The concentrations of cyanophos detected in samples collected on 29 May 2009, 41 days after the spray at the Pandamatenga sites Q34 and Q47, ranged from 0.009 to $0.169\ \mu g\ g^{-1}$ (mean 0.051; SD = 0.078; n = 4). Also, cyanophos (up to $0.024\ \mu g\ g^{-1}$; mean = 0.014; SD = 0.008) was detected in the samples where only fenthion was thought to have been sprayed. This was probably because the same aircraft was used for both sprays, and, if cyanophos was sprayed first and the pesticide tanks had not been flushed out properly, the sprays with fenthion could have included some cyanophos as well.

3.2 Laboratory experiment: estimation of the half-life of fenthion residues in soil

A plot of the combined raw data for fenthion against time was curvilinear, with a steeper slope at the beginning of the decay process (Fig. 4). The data were linearised by conversion to natural logarithms of the fenthion concentrations. For each of the three samples, the slopes of the lines calculated from regression analysis, representing decay rates for the fenthion residues in the sampled soils, were: for sample number T3-2, −0.01957; for T2-4, −0.01039; for T5-2, −0.01402. No significant difference between the slopes was found (F = 2.45; P = 0.05). Given this result, it was possible to calculate a common slope for the three relationships, giving a decay rate of fenthion of $-0.01466\ \mu g\ g^{-1}\ day^{-1}$.

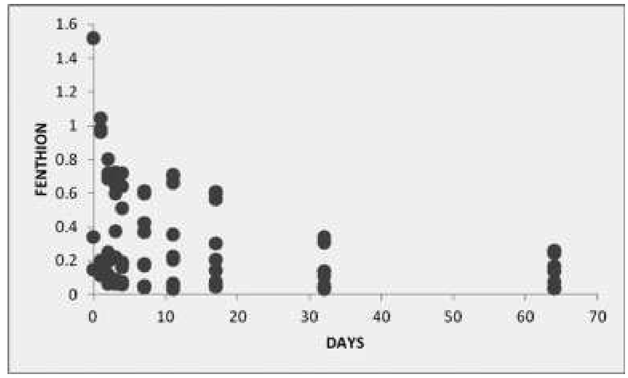


Figure 4. Fenthion concentrations ($\mu g\ g^{-1}$) at different times (days) during the laboratory experiment. Combined raw data from the three samples involved.

From the decay rates it was possible to estimate the half-life of fenthion in the soil from the half-life relation: $t_{1/2(\text{fenthion})} = 0.693 \cdot \lambda^{-1}$, where λ is the decay constant. The half-life was determined for each of the three samples as 35.4 days (sample T3-2), 66.7 days (T2-4) and 68.7 days (T5-2), and, using the common decay rate $k = -0.01466$ from the combined sample population, the half-life was estimated as 47.3 days.

3.3 Contamination experiment

The results of the deliberate contamination experiment revealed almost 90% recovery of the concentration of pesticide deposited after 24 h, decaying to only 45% after 168 h. After 24 h, percentage recoveries ranged from 70.5 to 96.4 (mean 88.3%), after 39 h from 38.3 to 110.8 (mean 84.1), after 101 h from 45.6 to 62.5 (mean 54.9) and after 168 h from 37.2 to 54.9 (mean 45). This result, suggesting fast decay, reflects the situation at the beginning of the degradation function (see Fig. 4).

3.4 Explosions in Botswana

3.4.1 Soil samples in 2005

Diesel and plastic residues were detectable in the soil samples. The characteristic chromatographic pattern of diesel oil, observed on FID analysis, was confirmed by gas chromatography–mass spectrometry as C12–C28 hydrocarbons, as expected in diesel fuel. The relative concentrations of each hydrocarbon differed from those available in reference texts, but these variations were probably explicable by variation in the source of the diesel and its purity and, possibly, by increased volatilisation of some hydrocarbon fractions. Figure 5 shows the GLC traces (chromatograms) from pre- and post-explosion samples. The precontrol samples from Kotoloname contained trace quantities of diesel (mean = $0.08\ \mu g\ g^{-1}$; SD = 0.04), but after the explosion the concentrations were much higher. The centres of the craters were contaminated with a mean $4.4\ \mu g\ g^{-1}$ of diesel (range 1.08–9.31; SD 2.83), significantly greater than the precontrol values (P < 0.001; two-tailed t-test assuming unequal variances). Soils from 10 m either side of the craters were less heavily contaminated: those from the left did not differ from those from the right of the craters (P = 0.28), and the combined sample (range 0.16–3.12) had significantly lower concentrations than those from the centres (P = 0.001; mean = 0.42; SD = 0.66), but still greater than the precontrol values (P = 0.04). Residues of dibutyl phthalate were also detected in some post-explosion samples (but not in any

Table 1. Fenthion concentrations (μg g^{-1}) found in soil samples collected on various dates after ground-based sprays at four sites in Botswana during 2008. The first date for each site refers to the day after spraying. No residues were detected in any of the precontrol samples (none conducted at Pilikwe)

		Date				
Site	Sample	20.01.08	28.02.08	15.04.08	04.07.08	27.07.08
Maphoko	1.1	0.115	0	0	0	0
	1.2	0.253	–	–	–	–
	2.1	0.809	0	0	1.293	11.694
	2.2	2.662	–	–	–	–
	3.1	–	0	0	0	10.415
	3.2	0	–	–	–	–
	4.1	0	0	0	0	3.528
	4.2	0	–	–	–	–
	5.1	2.126	0	0	0	0
	5.2	12.983	–	–	–	–
Mean (SD)		2.105 (4.198)	0	0	0.259 (0.578)	5.127 (5.617)
		Date				
Site	Sample	23.01.08	26.02.08	19.03.08	14.04.08	13.07.08
Pilikwe	1	0	0	0	0	0
	2	0.183	0	0	0	0
	3	0.357	2.445	0	0	0
	4	1.538	0	0	0	0
	5	0	0	0	0	0
	6	0.069	0	0	0	0
	7	0	0	0	0	0
	8	0	0	0	0	1.440
Mean (SD)		0.268 (0.528)	0.306 (0.864)	0	0	0.18 (0.509)
		Date				
Site	Sample	31.01.08	19.03.08	15.04.08	03.07.08	27.07.08
Masilajwe 1	1	0.280	0	0	0	0
	2	1.665	0	0	0	0
	3	0.760	0	0	0	0
	4	2.361	0	0	0	0
	5	0.913	0	0	0	0
	6	0.096	0	0	0	0
	7	1.161	0	0	0	0
	8	4.935	0	0	0	0
	9	1.849	0	0	0	0
	10	0.950	0	0	0	0
	11	3.634	0	0	0	0
	12	13.912	0	0	0	0
	13	14.319	0	0	0	0
	14	2.306	0	–	0	0.605
Mean (SD)		3.510 (4.678)	0	0	0	0.043 (0.162)
		Date				
Site	Sample	31.01.08	19.03.08	15.04.08	03.07.08	27.07.08
Masilajwe 2	1	14.058	0	0	0	0
	2	3.107	0	0	0	2.632
	3	1.489	0	0	0	0
	4	9.598	0	0	0	9.204
	5	0.529	0	0	0	0
	6	0.516	0	0	0	0
	7	0.019	0	0	0	0
	8	1.520	0	–	0	0
	9	7.158	–	0	–	0
Mean (SD)		4.222 (4.941)	0	0	0	1.315 (3.084)

Table 2. Concentrations of fenthion (μg g^{-1}) detected in soil samples collected at Gawaye, Tanzania, the day after spraying (21 March 2009) and at intervals thereafter. Monthly mean temperature and rainfall at nearby Dodoma during 2009 were as follows: January 24.9 °C, 102 mm; February 23.0 °C, 129 mm; March 24.2 °C, 80 mm; April 23.6 °C, 115 mm; May 22.6 °C, 0 mm; June 21.5 °C, 0 mm; July 20.0 °C, 0 mm; August 20.7 °C, 0 mm; September 22.5 °C, 4 mm; October 23.7 °C, 0 mm; November 24.2 °C, 35 mm; December 24.6 °C, 312 mm

	Date								
Sample	21.03.09	28.03.09	04.04.09	21.04.09	21.05.09	21.06.09	21.07.09	21.08.09	21.09.09
1	19.52	0.03	0.02	0	0.024	0	0	0	0
2	22.94	0.01	0.01	0	0	0	0	0	0
3	29.48	0.10	0.03	0.01	0.0014	0.01	0	0	0
4	0.65	0.45	0.05	0.01	0.0133	0	0	0	0
5	3.10	0.04	0	0	0.0009	0	0	0	0
Mean (SD)	15.138 (12.655)	0.126 (0.184)	0.022 (0.019)	0.004 (0.005)	0.008 (0.010)	0.002 (0.004)	0	0	0

pre-explosion samples), with identity being confirmed by GC-MS, but quantification of these residues was not attempted.

3.4.2 Soil samples in 2009 and 2010

Samples of the post-explosion craters appearing in the soil at the sites where each plastic container exploded at Naledi had a mean area of 0.14 m^2. Therefore, as nearly 300 bombs were detonated within 0.369 ha at Naledi, 42 m^2 or 113.8 m^2 ha^{-1} of the exploded area (1.14% of the affected zone) was damaged.

In every case except one (phthalates at Naledi) (Table 3), the pre-explosion results were positive for both total petroleum hydrocarbons (mean 0.152 μg g^{-1}) and total phthalates (mean 0.035 μg g^{-1}), reflecting the level of background pollution in the soil environment (some post-control samples were also zero for phthalates) (Table 3). However, after the explosions, TPHs ranged from 0.051 to 130.814 μg g^{-1} (mean 7.514; SD = 22.132; $n = 43$), and total phthalates ranged from 0 to 3.233 μg g^{-1} (mean 0.316; SD = 0.610; $n = 43$), i.e. 49 and 9 times the background levels respectively, on average, and, for the maxima, 861 and 92 times the background levels. For both TPHs and phthalates, the average concentrations declined markedly at 5 and 10 m distance from the craters (Tables 3 and 4).

No measurements were taken at the same sites in subsequent seasons, and, so far as is known, it was only at Gobojango that control operations had also occurred in the previous year and/or 2 years earlier. The samples taken at Gobojango at least 1 year after the last explosion there had mean TPHs of 0.865 μg g^{-1} (range 0.372–1.335; SD = 0.482; $n = 3$) and mean phthalates of 0.609 μg g^{-1} (range 0.72–0.854; SD = 0.315; $n = 3$), confirming the long-term persistence of these pollutants, unlike the shorter duration of fenthion.

4 DISCUSSION

4.1 Fenthion and cyanophos

Both at sites sprayed from the ground and those sprayed aerially, there was evidence that the pesticide residues persisted for up to at least 41 days (aerial sprays) and 188 days (ground sprays). The estimate of the half-life of fenthion from the laboratory study was, at 47 days, longer than a previous estimate of 34 days,[8] and the present results also suggest persistence in the soil for longer than earlier estimates of 4–6 weeks.[9] The longest persistence period (188 days) followed months with no fenthion detected and, at Maphoko, averaged higher concentrations than those found the day after the spray. These results, with the reappearance of fenthion reported at several sites, suggest that, contrary to previous suggestions,[8,9] fenthion is capable of leaching, perhaps returning to the surface with rainfall, and rain had been reported at the sites during the study period. For example, at Gawaye, above-average rain fell in April, possibly accounting for raised fenthion levels recorded in May 2009 (Table 2). Fenthion normally undergoes chemical, physical and biological changes, which result in various forms of degradation products.[14] Under temperate climatic conditions, fenthion dissipates from soil relatively rapidly under aerobic laboratory conditions, with a half-life of about 10 days. However, some experiments indicate slower dissipation outdoors (about 30 days) than under controlled laboratory conditions, and the dissipation appears to occur mainly via phototransformation, biotransformation and sorption.[15,16] Although the decay process was studied under temperate climatic conditions, the soil was of tropical origin and its composition is likely to have influenced the decay process. In soils with high amounts of organic carbon or clay content, increased photolytic degradation of organic chemicals may occur when the soil surface is irradiated by sunlight. It is therefore generally assumed that 50% or more of applied fenthion in soil or natural water with sediment is degraded to carbon dioxide within 6 months under temperate climatic conditions. The degradation is, however, speculated to take longer in tropical soils.[14] Although fenthion dissipates from water with a half-life of less than 7 days, its biotransformation rate in water–sediment systems is lower than that in a soil system.[15] In this study, however, the soils were air dried to remove most moisture, which minimised the likelihood of the degradation process being attributable to hydrolysis. There are, however, other uncontrolled factors that could have affected the present results, and so the conclusions need to be treated cautiously, especially in view of the marked heterogeneity in concentrations of the initial spray depositions. For instance, temperature, soil moisture, pH and soil type could affect degradation processes. Mean ambient temperatures were mostly between 20 and 26 °C, based on data from the sites sprayed in Botswana in 2008 where meteorological data were recorded every minute using a data logger. At Maphoko, the mean temperature for the period 16.34–19.54 h on 20 January was 24.6 °C, and the mean relative humidity was 77.1%. Mean temperatures and mean relative humidities at Masilajwe 1 (07.20 h on 28 January to 18.42 h on 1 February) and Masilajwe 2 (17.57 h on 2 February to 00.38 h on 4 February) were 22.9 °C and 69.2% and 21.8 °C and 64.9% respectively. Soil moisture and pH were not measured. At Masilajwe, Pilikwe and Sebalola the soil was black cotton soil, and at Gawaye and Maphoko it was sandy.

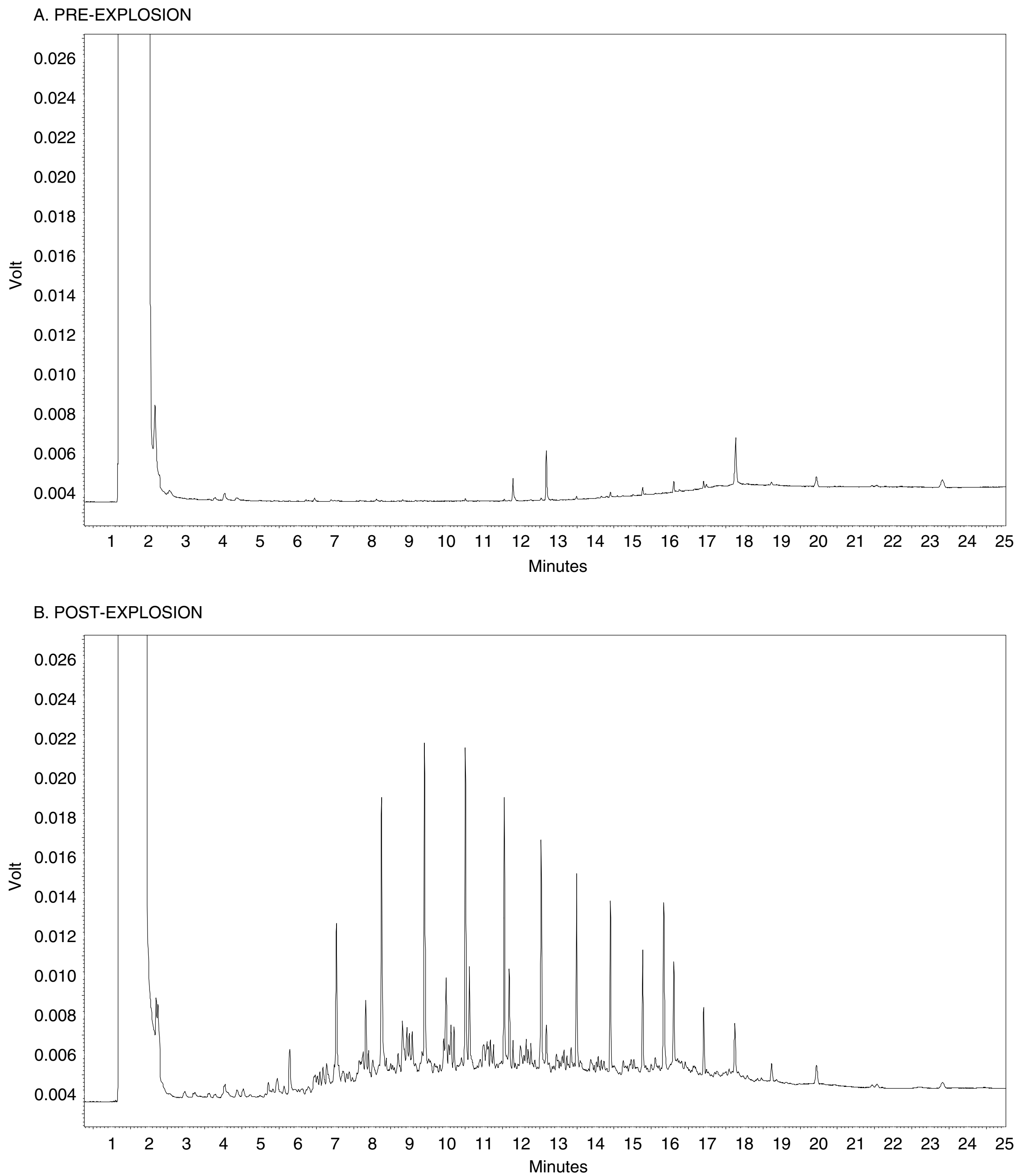


Figure 5. GC-FID chromatograms from soil samples from Kotoloname, (A) from a pre-explosion sample and (B) from a post-explosion sample, showing different hydrocarbon peaks, fractions from diesel and petroleum pollution.

Fenthion is a contact and stomach organophosphate and moderately toxic to the environment. It is effective against insects, moderately toxic to mammals (LD_{50} values ranging from 88 to 298 mg kg^{-1}) and highly to very highly toxic to birds (LD_{50} ranging from less than 4 to 26 mg kg^{-1}), but it is difficult to evaluate the precise effects of the residues reported on soil health, as its toxicity will be reduced if it is not bioavailable by being bound up in organic matter or clay particles. The maximum residue levels (MRLs) allowed on food by the European Union give a guide to acceptable levels for different commodities. For most commodities the MRL is 0.01–0.05 µg g^{-1}, with the exception of tea, coffee, herbal infusions and spices (for which it is 0.1), loquat (1), olives (1), cherries (2) and citrus fruits (3) (see http://ec.europa.eu/sanco_pesticides/public/index.cfm?event=substance.selection). There are no comparable data for cyanophos, but the UK pesticide authorities recommend a

Table 3. Results of analyses of soil samples collected before and after explosions in Botswana, 2009–2010. In some cases, post-explosion samples were taken from inside the craters and 5 and 10 m away in randomly chosen directions. No pre-explosion samples were taken at Musi or Batabeli

Site	Date of sample	Pre- or post-explosion	Distance from crater (m)	Mean total petroleum hydrocarbons (μg g^{-1}) (range; SD; *n*)	Mean total phthalates (μg g^{-1}) (range; SD; *n*)
Good Hope	18 May 2009	Pre	–	0.218 (0.048–0.556; 0.293; 3)	0.048 (0.004–0.134; 0.074; 3)
	19 May 2009	Post	0	22.23 (1.261–63.996; 36.169; 3)	0.614 (0.074–1.68; 0.923; 3)
	19 May 2009	Post	5	0.126 (0.078–0.184; 0.054; 3)	0.040 (0–0.119; 0.069; 3)
	19 May 2009	Post	10	0.156 (0.134–0.181; 0.126; 3)	0.003 (0–0.01; 0.011; 3)
Naledi	20 May 2009	Pre	–	0.104 (0.08–0.165; 0.073; 4)	0.009 (0–0.018; 0.009; 4)
	21 May 2009	Post	0	3.358 (1.447–4.559; 1.673; 3)	0.186 (0.071–0.246; 0.099; 3)
	21 May 2009	Post	5	0.180 (0.081–0.235; 0.086; 3)	0.008 (0.005–0.015; 0.006; 3)
	21 May 2009	Post	10	0.147 (0.051–0.208; 0.347; 3)	0
Musi	24 May 2009	Post	0	2.907 (1.92–3.889; 1.388; 2)	0.130 (0.117–0.144; 0.019; 2)
	24 May 2009	Post	5	0.399 (0.284–0.542; 0.131; 3)	0.011 (0–0.028; 0.015; 3)
	24 May 2009	Post	10	0.579 (0.327–0.908; 0.298; 3)	0.012 (0.007–0.019; 0.006; 3)
Pandamatenga Farm 213	27 May 2009	Pre	–	0.271 (0.125–0.417; 0.206; 2)	0.025 (0.008–0.043; 0.025; 2)
	28 May 2009	Post	0	55.04 (11.908–130.814; 65.831; 3)	0.638 (0.412–0.835; 0.213; 3)
	28 May 2009	Post	5	10.206 (3.656–13.705; 5.677; 3)	0.640 (0.153–1.389; 0.658; 3)
	28 May 2009	Post	10	1.702 (0.946–2.744; 0.932; 3)	0.089 (0.04–1.62; 0.065; 3)
Batabeli	3 June 2009	Post	0	0.512 ($n = 1$)	3.233 ($n = 1$)
	4 June 2009	Post	5	0.778 ($n = 1$)	0.087 ($n = 1$)
	4 June 2009	Post	10	2.042 ($n = 1$)	0.044 ($n = 1$)
Pandamatenga site Q13	4 June 2009	Pre	–	0.283 ($n = 1$)	0.138 ($n = 1$)
	5 June 2009	Post	0	14.501 (2.869–26.134; 16.451; 2)	0.662 (0.019–1.306; 0.91; 2)
Nchakateng	29 January 2010	Pre	–	0.027 (0.016–0.033; 0.009; 3)	0.030 (0.008–0.042; 0.019; 3)
	1 February 2010	Post	0	10.734 (2.445–22.922; 10.781; 3)	0.165 (0.056–0.275; 0.109; 3)

Table 4. Mean values of total petroleum hydrocarbons (TPHs) (μg g^{-1}) and total phthalates (μg g^{-1}) in precontrol samples, from the centres of craters after explosions and at 5 and 10 m distances away from them. Figures in brackets are standard deviations, followed by sample sizes (*n*)

Distance from crater (m)	TPHs	Phthalates
Pre-explosion control	0.141 (0.017; 12)	0.027 (0.037; 12)
0	18.695 (35.101; 15)	0.554 (0.856; 15)
5	2.578 (4.931; 13)	0.168 (0.382; 13)
10	0.753 (0.844; 13)	0.027 (0.045; 13)

default level of 0.01 μg g^{-1} for this organophosphate (see https://secure.pesticides.gov.uk/MRLs/). Even 6 weeks after the spray, levels more than 10 times greater than this default value were present. Thus, when values unacceptable for human consumption are present, surely it is likely that soil micro- and macrofaunas will be affected deleteriously. Furthermore, the results are in line with unpublished results of analyses of fenthion residues in quelea carcasses, which were very high, ranging from 9.0 to 180.0 μg g^{-1}, 1–2 weeks following fenthion applications (van der Walt E, unpublished). After 70 days and beyond, remains of the fenthion concentrations in the carcasses were still significant, ranging between 3.0 and 10.0 μg g^{-1}. These residue levels are substantially greater than the approved MRLs of fenthion in animal products (see above). It can therefore be deduced that quelea carcasses are toxic and potentially harmful for consumption by humans and other organisms, even after 70 days following Queletox® applications.

4.2 Botswana explosions

The extent of physical damage to soil, estimated as 113.8 m^2 ha^{-1} at Naledi, will vary from site to site as the density of trees varies. The depth of the craters will also be affected by the soil type at the different sites, it being deeper in loose sandy soils. Similarly, some of the variations in contamination observed may be attributable to soil characteristics. For instance, at Good Hope the soil was loamy and hard, but at Kotoloname, Musi and Naledi it was sandy, while at Batabeli and Pandamatenga Farm 213 it was damp, loamy, black cotton soil. Remains of unburnt plastic from incompletely incinerated containers littered the sites after an explosion, and these items may take as long as 10 years to decompose. Although it is now policy to collect as many fragments as possible, many from 2 years previously were still present at Gobojango in 2010. There were also residues of the plastic detectable in the soil at the crater sites, with concentrations up to 3.23 μg g^{-1}. The contamination with unburnt diesel and petrol was also substantial, with up to 9.31 mg kg^{-1} of diesel present in one crater in 2005 and a maximum level of 130.814 μg g^{-1} of TPHs in 2009, although residue levels declined markedly at 5 and 10 m to either side of the craters. The effects of diesel on the soil environment are poorly documented, but it is known that its effects on plants vary from species to species and even between subspecies. Diesel can delay seed emergence and reduce percentage germination. The volatile fraction of diesel fuel has been implicated in these functions, with the remaining fraction of diesel fuel in the soil further inhibiting germination by physically impeding water and oxygen transfer between the seed and the surrounding soil environment.[17] Seed germination and growth of soya beans and ryegrass were inhibited by a diesel fuel spill of 2.3 mL m^{-2}.[18] Further studies are required to establish the potential effects of the levels of contamination detected, but, if explosions are used regularly or at the same site in successive years, the environmental damage could be severe.

Byproducts of the explosions include carbon monoxide, carbon dioxide, water, carbon and nitrogen. The positive oxygen balance (20%) of Powergel™ produces a safer gas mix (carbon dioxide and water) than the black smoke plumes characteristic of TNT (oxygen balance −79%) and PETN (−10.1%) explosions. The lower detonation velocity of Powergel™, in comparison with those of TNT and PETN, account for there being more unexploded plastic and larger pieces of plastic remaining at the exploded sites in 2009 and 2010 than was the case in previous years. In South Africa the procedure differs. A detonation is made that just produces a noise to scare the birds into the air a few milliseconds before the main explosion, and this improves the kill. Also, in South Africa, 20 L plastic drums holding pentalite explosives and 15 L of aviation fuel or diesel are used with cordex fuse wire wrapped around the containers, and the explosions occur as late as 22.00 h. In reed beds, the drums are raised on poles.

Assessments of the significance of the results are difficult, as the poisoning potential of different constituents both of the TPHs, in which the health effects of aliphatic compounds differ from those of aromatic compounds, and of the total phthalates will differ. Although the TPHs will eventually be broken down, both sets of pollutants persist for long periods, as evidenced by the data from Gobojango. It is likely that the phthalates will persist for 10 years or more. An indication of the potential for health effects or environmental damage resulting from the concentrations of TPHs observed is their magnitudes in relation to minimum risk levels (MRLs) for acute exposure via inhalation to diesel oil (0.02 ppm), benzene (0.05), toluene (0.02) and xylenes (1),[19] citing data from elsewhere.[13] Even the pre-explosion background levels for TPHs were greater than the 0.02 MRL for diesel oil inhalation.

Petroleum hydrocarbons in soil may reach the groundwater[20–22] and contaminate it, but will also thereby be dispersed from the contaminated site. However, some contaminant compounds at the site may attach to soil particles and so remain in the soil for long periods, while others will be broken down by soil organisms.[13] Whatever the fate of the compounds left in the soil after the explosions, the levels detected seem to be high enough to cause concern that they are affecting the environment adversely.

4.3 General comments on results

Soil and water serve as the ultimate sink for unused residues of pesticides in the environment,[23,24] but soil is the principal reservoir of environmental pesticides. Thus, soil remains a major source from which most residues are released into the atmosphere, groundwater and living organisms. The relative mix of its various components (air, water, mineral and organic matter) influences how the chemicals are transported and transformed. Slow degradation of pesticides in soil makes them potential environmental contaminants. Their persistence in the environment enhances their tendency towards bioaccumulation and toxicity to non-target organisms, including humans.[24] Fenthion is a polar pesticide that can be moved from soil by run-off and leaching, thereby constituting a problem for the supply of drinking water.[16] However, estimates of the adsorption coefficient (K_s) for fenthion in laboratory experiments vary between 7.7 and 38 $dm^3\ kg^{-1}$, indicating strong sorption. Fenthion thus binds readily and strongly to various soils and is therefore considered to be immobile in soil; until the results reported here, it was considered to be unlikely to leach below the top first few centimetres of the soil profile. The mechanism of sorption of fenthion to soil and sediment is, however, only partially understood, and several factors may be involved, although it appears to be positively correlated with the organic matter content.[16]

The repeated finding of uneven distribution of fenthion residues was probably attributable to poor practices during spraying from the vehicle-mounted devices in Botswana. In some cases, nozzles were incorrectly positioned, speeds were not uniform and failure to turn off the device at corners may have led to excessive contamination, compounded by poor maintenance of the equipment, all of which could be easily mitigated to at least minimise the ensuing environmental damage.

While it is not, at this stage, possible to advise whether spraying with fenthion is or is not safer than using explosive control measures, the present results have clearly shown that the use of explosives is not markedly advantageous with respect to pollution, and the statement that 'there is no chemical contamination of the environment'[11] is misleading.

ACKNOWLEDGEMENTS

The bulk of the research (2007-2010) was financed by the EU ICART CRARF Programme (project number 9 ACP SAD 1-13) managed by the Southern African Development Community (SADC). The initial research (2004-2005, projects R6823/R7967/R8314/R8426, Crop Protection Programme) was funded by the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID. The soil samples were imported under the UK Department for Environment, Food and Rural Affairs (DEFRA), licence number PHL 176C/6510 (02/2011). The authors thank many members of staff of the Ministries of Agriculture in Botswana and Tanzania and Pietie van Niekerk, Jan de Klerk, Joel Mooka, Ezekia Sgudlha, Agnes Mohutshiwa and Susan Maplanka for invaluable assistance in the field. Remi and Wendy Borello provided much assistance and hospitality in Botswana, where R Kgosi, P Malikongwe, M Mmopi, M Modise, T Moruti, M Murata (SADC) and C Tizikara (SADC) also provided much help, and where Sgt Major Lesedi Menyatso advised on the explosions. The authors thank Professor DR Hall for comments on the manuscript.

REFERENCES

1 Elliott CCH, The pest status of the quelea, in Quelea quelea: *Africa's Bird Pest*, ed. by Bruggers R and Elliott CCH. Oxford University Press, Oxford, UK, pp. 17–34 (1989).
2 Elliott CCH, The quelea as a major problem in a food-deficient continent, in *Africa's Feathered Locust*, ed. by Mundy PJ and Jarvis MJF. Baobab Books, Harare, Zimbabwe, pp. 90–99 (1989).
3 Ward P, The migration patterns of *Quelea quelea* in Africa. *Ibis* **113**:275–297 (1971).
4 McWilliam AN and Cheke RA, A review of the impacts of control operations against the red-billed quelea (*Quelea quelea*) on non-target organisms. *Environ Conserv* **31**:130–137 (2004).
5 Cheke RA, McWilliam AN, Mbereki C, van der Walt E, Mtobesya B, Magoma RN, Young S and Eberly JP, Effects of the organophosphate fenthion for control of the red-billed quelea *Quelea quelea* on cholinesterase and haemoglobin concentrations in the blood of target and non-target birds. *Ecotoxicology* DOI: 10.1007/s10646-012-0911-6 (2012).
6 *Fenthion (039)*. [Online]. Food and Agriculture Organisation (1995). Available: http://www.fao.org/ag/AGP/AGPP/Pesticid/JMPR/Download/95_eva/fenthion.pdf. Accessed [30 August 2011].
7 Pesticide residues in food. Report of the 1971 Joint Meeting of the FAO Working Party of Experts on Pesticide Residues and the WHO Expert Committee on Pesticide Residues. WHO Technical Report Series No. 502 (1971); FAO Agricultural Studies No. 88 (1972).

8 Wauchope RD, Buttler TM, Hornsby AG, Augustin-Beckers PWM and Burt JP, SCS/ARS/CES pesticide properties database for environmental decision making. *Rev Environ Contam Toxicol* **123**:1–157 (1992).
9 Harding WC, *Pesticide Profiles: Insecticides and Miticides*. University of Maryland Cooperative Extension Service, College Parks, MD (1979).
10 van der Walt E, Research at PPRI on environmental effects of quelea control operations, in *Workshop on Research Priorities for Migrant Pests of Agriculture in Southern Africa, 24–26 March 1999, Plant Protection Research Institute, Pretoria, South Africa*, ed. by Cheke RA, Rosenberg LJ and Kieser ME. Natural Resources Institute, Chatham, UK, pp. 91–95 (2000).
11 Meinzingen WW, Bashir EA, Parker JD, Heckel J-U and Elliott CCH, Lethal control of quelea, in Quelea quelea: *Africa's Bird Pest*, ed. by Bruggers RL and Elliott CCH. Oxford University Press, Oxford, UK, pp. 293–316 (1989).
12 Hirahara Y, Ueno H and Nakamuro K, Comparative photodegradation study of fenthion and disulfoton under irradiation of different light sources in liquid- and solid-phases. *J Hlth Sci* **47**:129–134 (2001).
13 Toxicological profile for total petroleum hydrocarbons (TPH). Research Triangle Institute unpublished report prepared for the US Department of Health and Human Services (1999).
14 Lacorte S, Jeanty G, Marty J and Barcelo D, Identification of fenthion and temephos and their transformation products in water by high-performance liquid chromatography with diode array detection and atmospheric pressure chemical ionization mass spectrometric detection. *J Chromatogr A* **777**:99–114 (1997).
15 Kyriakidis NV, Pappas C and Athanasopoulos P, Degradation of fenthion and fenthion sulfoxide on grapes on the vines and during refrigerated storage. *Food Chem* **91**:241–245 (2005).
16 Brun EM, Garces-Garcia M, Puchades R and Maquieira A, Enzyme-linked immunosorbent assay for the organophosphorus insecticide fenthion. Influence of hapten structure. *J Immun Meth* **295**:21–35 (2004).
17 Adam G and Duncan H, Influence of diesel fuel on seed germination. *Environ Pollut* **120**:363–370 (2002).
18 Wang X and Bartha R, Effects of bioremediation on residues, activity and toxicity in soil contaminated by fuel spills. *Soil Biol Biochem* **22**:501–505 (1990).
19 Rauckte T, Żak S, Zenon P and Oloyede A, Determination of oil and grease, total petroleum hydrocarbons and volatile aromatic compounds in soil and sediment samples. *J Environ Engng Landscape Manag* **18**:163–169 (2010).
20 Riccardi C, Di Filippo P, Pomata D, Incoronato F, Di Basilio M, Papini MP, *et al*., Characterization and distribution of petroleum hydrocarbons and heavy metals in groundwater from three Italian tank farms. *Sci Total Environ* **393**:50–63 (2008).
21 Pawlak Z, Rauckyte T and Oloyede A, Oil, grease and used petroleum oil management and environmental economic issues. *J Achiev Mater Mfg Engng* **26**:11–17 (2008).
22 Wang Z, Li K, Fingas M, Sigouin L and Ménard L, Characterization and source identification of hydrocarbons in water samples using multiple analytical techniques. *J Chromatogr A* **971**:173–184 (2002).
23 Singh BK, Kuhad RC, Singh A, Lal R and Tripathi KK, Biochemical and molecular basis of pesticide degradation by microorganisms. *Critical Rev Biotechnol* **19**:197–225 (1999).
24 Shea PJ, Machacek TA and Comfort SD, Accelerated remediation of pesticide-contaminated soil with zerovalent iron. *Environ Pollut* **132**:183–188 (2004).

