An assessment of lepidopteran stemborer species distribution in relation to diversity of wild host grasses in maize and sorghum growing zones in Kenya

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DECLARATION

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

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DEDICATION

This thesis is dedicated to the fond memories of my father, the late John Ong'amo whose silent presence has guided my effort throughout the study and research period.

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ABSTRACT

Lepidopteran stemborers pose a serious constraint to maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* L.) production in Africa. Despite the achievements made through biological, chemical and cultural control approaches, these methods are specific and result in proliferation of little affected species in the wild habitats. Information on spatial distribution of stemborer species is therefore needed for designing region specific management strategies. This study aimed at assessing the effects of climatic factors and wild host grasses on stemborer species distribution. A total of 357 fields of maize and sorghum randomly distributed across six agroclimatic zones were sampled during the long and short rain growing seasons. In each survey session, 400 stems of maize or sorghum were checked for stemborer infestation and infested stems destructively cut for dissection. 146,157 stems were checked for infestation, and 27,799 infested stems destructively cut and dissected for stemborer larvae identification. An average of 1.4 stemborer larvae were recovered per infested plant. 55.4% of the recovered larvae were identified as *Chilo partellus* (Swinhoe) (Pyralidae), 39.7% as *Busseola fusca* (Fuller) (Noctuidae), 4.5% as *Sesamia calamistis* Hampson (Noctuidae) and 0.8% as *Chilo orichalcociliellus* (Strand) (Pyralidae). Minor species present include *Eldana saccharina* Walker (Pyralidae), *S. nonagrioides* (Lefebvre) (Noctuidae), *S. cretica* Lederer (Noctuidae), *Sesamia sp. nov.* (Noctuidae), *Sciomesa piscator* Fletcher (Noctuidae), *Busseola sp* near *phaia* (Noctuidae), *Chilo* sp, *Emathеudes sp 1* (Pyralidae) and *Emathеudes sp 2* (Pyralidae). Logistic polynomial regression and spatial interpolation results indicated that the observed spatial distribution and seasonal variation in species composition are products of interactions among climatic parameters. Higher average infestation of 30.0 ± 3.3% was recorded in low elevation areas of moist low tropics where *C. partellus* dominated, while lower infestation of 11.7 ± 2.4% was recorded in cool & dry high tropical zone. Seasonal variation in field infestations was recorded in all zones except in moist high tropics ($t_{67} = 0.04$; $p > 0.05$) and moist mid-altitude ($t_{72} = 1.31$; $p > 0.05$) zones. These findings show that stemborer species are distributed within defined ecologically suitable areas under the influence of different environmental factors that vary between species.

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ABBREVIATIONS AND ACRONYMS

ACT	Almanac Characterization Tool.
ACZ	Agro-Climatic Zone.
CYMMIT	International maize and Wheat Improvement Centre.
GIS	Geographical Information System.
GMO	Genetically Modified Organisms.
GPS	Global Positioning System.
ICIPE	International Centre of Insect Physiology and Ecology
IPM	Integrated Pest Management.
IRD	Institut de Recherche pour le Développement
KARI	Kenya Agricultural Research Institute.
MDBP	Maize Database Project.
NSSB	Noctuid Stemborer Biodiversity Project

CHAPTER ONE

INTRODUCTION

1.1. **Background**

Agricultural systems in East Africa are characterised by regional diversity of crops, which are attributed to the interaction between climatic factors and soil conditions (Seshu Reddy, 1983; Degaga 2002; Guofa *et al.*, 2002). Within these diversities, sorghum, *Sorghum bicolor* L. (Moench) and maize, *Zea mays* L (Moench) are among the widely cultivated cereal crops. Successful distribution of sorghum after the initial domestication together with introduction of maize from Mexico (Polaszek and Khan, 1998) may be attributed to high productivity and availability of many varieties developed for diverse ecological zones. Despite the concerted efforts by different stakeholders in agricultural sector to improve crop production in response to increasing human population, optimum yields of these crops have never been achieved in a wide range of production environments (Okech *et al.*, 1994). Important among factors contributing to poor yields are arthropod pests as these crops offer little inherent resistance and suffer from field pest attacks from seedling stage to maturity (Schulthess *et al.*, 1997; Overholt *et al.*, 2001; Guofa *et al.*, 2002).

Bowden (1976) recorded more than 40 species of insect pests in fields of maize and sorghum with lepidopterans, mainly the armyworms, cutworms, earworms, borers and grain moths as economically important pests. Among the lepidopterans, stemborers belonging to Noctuidae and Pyralidae families are the most damaging (Overholt *et al.*, 2001). Borer species from these families usually occur as a community of *Busseola fusca* Fuller (Noctuidae), *Sesamia calamistis* Hampson (Noctuidae), *Chilo partellus* Swinhoe

(Pyralidae), and *Chilo orichalcociliellus* Strand (Pyralidae) in East Africa (Polaszek and Khan, 1998; Overholt *et al.*, 2001; Guofa *et al.*, 2002). In addition to the above four members of the stemborer comminuty, *Eldana saccharina* Walker (Pyralidae) and *Sesamia nonagrioides* Tams and Bowden (Noctuidae) which are important species in West Africa are occasionally found in fields of sorghum and maize in East Africa (Schulthess *et al.*, 1997)

Lepidopteran stemborers like other phytophagous insects may have undergone local genetic adaptation during evolution and their distribution closely follows the distribution of suitable hosts (Shanower *et al.*, 1993). The economic status of important stemborer species tend to vary with variation in environmental conditions that reportedly dictate crop cultivars grown (Megenasa, 1982; Songa *et al.*, 1998; Ndemah *et al.*, 2001). Considering that some of the conventional management options are species specific, there is need to identify factors (abiotic or biotic) governing spatial distribution of different stemborer species. This would be achieved through a study based on a defined survey plan across the main agro-climatic zones (ACZs).

1.2. **Statement of the problem**

Distribution of different species of stemborers is affected by both elevation and climatic factors (Megenasa, 1982). In addition, species establishment and subsequent carry-over between seasons is favoured by regional abundance of wild hosts (Degaga, 2002). Despite the achievements of biological, chemical and cultural control approaches in reducing stemborer population in cultivated fields, these methods present several disadvantages due to their specificity and are assumed to result in proliferation of less affected stemborer species in the wild habitat (Kumar, 1984; Polaszek and Khan, 1998). Information on spatial distribution of stemborer species that would necessitate design of region specific management strategies effective in both wild and cultivated compartments is lacking. Thus, this study evaluated the interaction between climatic factors and wild host grasses on stemborer distribution and infestation on maize and sorghum fields in Kenya.

1.3. Null hypotheses

1) Species of lepidopteran stemborers of maize and sorghum are equally distributed and abundant across Kenya.
2) Levels of stemborer infestations are equal regardless of seasonality across Kenya.
3) Distribution and abundance of different stemborer species are not governed by the presence of cultivated and wild host grasses

1.4. Justification for the study

Despite achievements made through cultural, biological and chemical control methods in reducing stemborer populations in farm environments, stemborers still pose serious constraint to maize and sorghum production in Kenya. There are examples illustrating the importance on uncultivated lands as a source of pests for adjacent crops (Kumar, 1984; Overholt *et al*., 2001). However, there is no currently accepted theory that explains the role of uncultivated land in stemborer invasions and outbreaks in cultivated crops (Polaszek and Khan, 1998).

Some basic information on the wild habitats as hosts of stemborers in Kenya is available (Polaszek and Khan, 1998; Overholt *et al*., 2001). From the applied perspective, a study of the relationship between spatial distribution of stemborers and wild hosts is necessary for the design of suitable management strategies specific to each region based on the most dominant stemborer species and wild host plants. The focus of this study was to investigate the effects of some biotic and abiotic factors on spatial distribution of different lepidopteran stemborer species in Kenya.

1.5. **Objectives of the study**

1.5.1. **General Objective**

This study aimed at assessing the effects of environmental factors on spatial distribution of lepidopteran stemborer species relative to diversity and abundance of wild host grasses in the main maize and sorghum growing zones in Kenya.

1.5.2. **Specific objectives**

a) To assess distribution and abundance of different stemborer species in the main maize and sorghum growing areas.

b) To assess variations in average stemborer field infestations between the long and short rain growing seasons across Kenya.

c) To identify principle factors among altitude, rainfall, potential evapotranspiration, moisture index, minimum and maximum temperatures that govern stemborer species distribution and abundance and establish the link between the stemborer species distribution and abundance of wild host grasses.

CHAPTER TWO

LITERATURE REVIEW

2.1. Importance of maize and sorghum

Maize, originally domesticated in Central America is currently among the most widely cultivated cereal crop in the world (Seshu Reddy, 1998). Its successful distribution may be attributed to its high productivity and availability of many varieties developed for diverse ecological conditions (Schulthess *et al.*, 1997). In tropical Africa, it is used for many purposes such as human food, feed for animals and raw materials for many industrial products. Similarly, sorghum is another widely grown cereal crop in tropical Africa. After initial domestication about 5000 years ago probably in the savannahs West of Ethiopia and East of Chad, cultivation of sorghum effectively spread to other parts of the world due to its good resistance to drought (Haile and Hofsvang, 2001). In Eastern Africa, sorghum is the staple food for millions of people and also grown to feed livestock in form of grain, forage and fodder (Seshu Reddy, 1983).

2.2. Constraints to production of maize and sorghum

Notable factors limiting production of maize and sorghum in tropical Africa include poor climatic conditions, low soil nutrients, weeds, diseases and insect pests (Bowden, 1976). Some of these limitations have been solved through improved farm management and development of suitable crop varieties. Important among these limitations are the crop damages caused by field insect pests. Notable among field insect pests are larval stages of stem boring lepidopteran moths belonging to Pyralidae and Noctuidae families (Seshu Reddy, 1998). In Africa, over 17 stemborer species belonging to these two families have been reported to attack cultivated cereals, accounting for about 20-50% yield losses in East Africa (Khan *et al*, 1997). In Kenya, *B. fusca* and *C. partellus* constitute the major proportion of the community and strongly limit yields of maize and sorghum crops from 20 – 80 % depending on region, borer population density and crop phenology during infestation (Seshu Reddy, 1983; Khan *et al*; 1997).

2.3. **Biology and damage symptoms of stemborers**

Stemborer species often associated with maize and sorghum in Kenya include *B. fusca*, *S. calamistis*, *C. partellus*, *C. oricalchociliellus* and *E. sacharina* (Overholt *et al.*, 2001). Other species such as *S. nonagrioides* and *S. cretica* are also present in some regions (Ingram, 1958; Overholt *et al.*, 2001). All stemborer species characteristically undergo holometabolous development with egg, larva, pupa and adult stages. Life cycle begins with emergence of adults and mating follows immediately after emergence by males finding females with the help of pheromones released by the female moths (Overholt *et al.*, 2001). Gravid moths oviposit on suitable young stems that are later attacked by first instar larvae after hatching. Larval attack on the meristematic tissue generally affects the translocation of nutrients in the plant resulting in reduced growth and in some cases death of the plant either through "dead heart" or breakage of the stem.

2.3.1. **Biology of *Busseola fusca***

Stemborer *B. fusca* is indigenous to tropical Africa, and attacks maize, sorghum and sugarcane in addition to other wild host grasses such as *Hyparrhenia rufa* (Nees) Stapf, *Panicum maximum* Jacq., *Pennisetum purpureum* Schumach, *Rottboellia exaltata*

L. f. (Overholt *et al.*, 2001). Gravid females lay several hundred eggs in batches of 30 – 50, inserted between the sheath and stem where incubation takes about one week. Upon hatching, larvae feed on young blades of the leaf whorls, and suspended on silk strands, they spread to neighbouring plants where they penetrate stems by boring through the whorl base (Ndemah *et al.*, 2001). After passing through six to eight stages in 30-45 days within the stem, they chew an outlet for exit of adult and then pupate in the tunnel for about 10-20 days. At the end of the rainy season, larvae of the last generation enter diapause in maize and sorghum stable or in wild grasses and up to four generations may be produced per year (Overholt *et al.*, 2001). Diversity and abundance of the alternative hosts are thought to favour stemborers establishment and their extensive distribution in relatively higher elevation (> 600m) (Guofa *et al.*, 2002).

2.3.2. **Biology of *Sesamia calamistis***

Sesamia calamistis occurs throughout most of tropical Africa (Overholt *et al.*, 2001). Like *B. fusca*, its ecological distribution is favoured by extensive distribution of alternative hosts in addition to cultivated maize, sorghum, sugarcane, finger millet and rice (Bernays and Graham, 1988). In 3-5 days, the female lays up to 350 eggs deposited in batches of 10-40 (Overholt *et al.*, 2001). Eggs are usually arranged in two to four contagious rows inserted between the lower leaf sheaths and stems. Several hours after hatching, the larvae leave oviposition sites and penetrate stems either directly or after feeding on the leaf sheath. During the larval stage that involves five to six moults depending on climatic conditions, the larvae may successively attack a number of young stems. Pupal period lasts 10-12 days at 25^0C. Under tropical conditions, five to six generations are completed throughout the year without diapause (Kfir, 1997).

2.3.3. **Biology of *Chilo partellus* and *C. orichalcociliellus***

Chilo partellus is native to Asia where it is considered to be a pest of maize and sorghum. It was first reported in Africa in 1930 in Malawi (Tams, 1932), and has since spread to most countries in eastern and southern Africa (Nye, 1960; Seshu Reddy, 1983; Guofa *et al.*, 2002). This spread has been facilitated by extensive cultivation of maize and sorghum as well as large expanses of wild hosts (Kfir, 1997). *C. partellus* and *C. orichalcociliellus* are the most important stemborer species in most low to medium elevation areas of eastern and southern Africa. Recent data suggest that *C. partellus* dominates over *C. orichalcociliellus* in low altitude areas and is increasingly becoming a pest in higher altitude areas (Guofa *et al.*, 2002). Overholt *et al.* (2001) reported similarity in their biology. Adult females are reported to mate soon after emergence and oviposit on two to three subsequent nights. Eggs are usually laid in 10-80 overlapping batches, on the upper and undersides of leaves mainly near the midrib (Overholt *et al.*, 2001). Eggs hatch in the early morning 4-8 days after ovipositions. First instar larvae on emergence ascend plants to enter the leaf whorls where they start to feed (Overholt *et al.*, 2001). Older larvae tunnel into the stem tissues where they feed and pupate after 2-3 weeks. Pupation takes about 5-12 days and under favourable conditions, the life cycle is completed in 25-50 days (Kfir, 1991).

2.4. **Management of stemborers**

Different control methods have been used in Africa to reduce losses associated with field insect pests (Nwanze and Mueller, 1989; Saxena *et al.*, 1990; Kfir, 1991). In Kenya, chemical, biological, cultural as well as planting of resistant crop varieties have been used in the management of stemborers

2.4.1. **Chemical control**

Chemical control of stemborers is difficult as pesticides are expensive, often toxic and at times relatively ineffective since target larvae often burrow inside the meristematic tissue (Kumar, 1984; Seshu Reddy, 1998). Despite these limitations, large-scale farmers in Trans-Nzoia district (Kenya) still apply insecticides such as carbofuran, carbaryl and endosulfan (Hassan *et al.*, 1998) for control of the first generation stemborer population. In addition to economic constraints, other problems associated with this management option that may follow routine application include the need for reapplication, effect on non-target organisms, problems of residues and eventual development of resistance among the target pests (Kumar, 1984).

2.4.2. **Cultural control**

Habitat management, early planting, removal or destruction of crop residues are among the cultural practices associated with stemborer management as they reportedly disrupt stemborer population build-up (Randriamananoro, 1996; Khan *et al.*, 1997).

2.4.2.1. **Habitat management**

Habitat management strategy for minimizing damage due to stemborers has been developed in maize-based farming systems for small- and medium-scale farmers of eastern Africa (Khan *et al.*, 1997; Polaszek and Khan, 1998). Stimulo-deterrent diversionary strategy (Push-pull) involved selection of plant species that could be employed as trap crops to attract stemborer colonization away from the cereal plants, or as intercrops to repel the pests. The two most successful trap crops Napier grass, *Pennisetum purpureum*, and Sudan grass, *Sorghum vulgare* var. *sudanensis* Hitchc attract greater oviposition by stemborers, than cultivated maize (Khan *et al.*, 1997). Intercrops giving maximum repellent effect are molasses grass, *Melinis minutiflora* Beauv. and a legume species, silverleaf, *Desmodium uncinatum* (Jacq.). Adoption of this management option has relatively been slow as proper groundwork to educate farmers on its potential has not been undertaken as this effort is still on experimental trials.

2.4.2.2. **Timely planting as a stemborer management option**

Stemborer management based on timely planting follows the principle of growing target crop when the pest is not present or when the pest is least abundant. Field survey results indicate that infested young plants are slow in their recovery unlike older plants that recover fast and compensate for the attack (Kumar, 1984). Through field studies, flying periods of most species (*B. fusca* and *S. calamistis*) have been determined and this has taken advantage of planting plan to avoid early sorghum and maize infestations (Khan *et al.*, 1997). Alternatively, maize or sorghum may be planted later in the cropping season after the flying period of most stemborer moths. This enables plants to escape infestation from the first generation and grow big enough to withstand infestations from populations of the second-generation. Utilization of this knowledge on stemborer management is very low particularly among subsistence farmers who depend on rainfed agriculture (Okech *et al.*, 1994). Only few farmers will accept to delay their planting during the beginning of growing seasons due to unpredictable weather pattern.

2.4.2.3. **Removal and destruction of crop residues**

Stemborers that are unable to complete their development stages in time enter diapause in stubbles / stalks of maize or sorghum left in the fields in anticipation of limited food resource or oviposition sites (Overholt *et al.*, 2001). This strategy enables various stemborer species to continue with normal development during favourable ecological conditions. Kumar (1984) recommended that burning or spreading residues / stalks in the field to expose larvae to the full effect of adverse weather conditions would limit stemborer carry-over between seasons. These recommendations are only practical in areas where crop residues / stubbles are neither used for animal feed nor fuel. In many parts of Kenya, stalks / residues are carried to different homes where they are used to feed animals and this encourages translocation of stemborers (Bonhof, 2000).

2.4.3. **Biological control**

Biological control is often used to include any biologically based methods of pest suppression. In its traditional sense, it means the manipulation of natural enemies of pests to reduce pest populations to levels where economic losses due to their attack are tolerable. Range of naturally occurring biological control agents, such as parasitoids, predators and diseases have been reported for different growth stages of stemborers. Few studies on their effectiveness as well as host/parasite relationships have been made. Biological control agents of interest to many researchers particularly in Kenya include the egg parasitoids, such as *Telenomus* and *Trichogramma* species, larval parasitoids including *Cotesia sesamiae* (Cameron) and pupal parasitoids eg *Pediobius furvus* Gahan among others.

Extensive distribution of exotic *C. partellus* and the resultant losses associated with its infestations in Coastal low altitude areas evoked the search for effective classical biological control agent from their area of origin (Overholt *et al*., 2001). Natural enemies of *Chilo* were collected in different ecological zones in India, and cocoons of *C. flavipes* Cameron, *Sturmiopsis inferens* Townsend and *Xanthopimpla stemmator* shipped to ICIPE, Kenya, for use in the management of *C. partellus* in East Africa. The braconid *C. flavipes* after release has established in most of the countries in East Africa where *C. partellus* dominates (Songa, 1999). There has been recorded reduction of losses by about 10% due to biological control of cereal stem borers by *C. flavipes*, which annually caused 10 to 40% loss in grain yield (Seshu Reddy, 1983; Guofa *et al*., 2002).

With above the recorded impact of *C. flavipes* on *C. partellus* population, efforts to manage other stemborer species are at their lowest. *C. flavipes* is only reported to be effective in *C. partellus* but do parasitise other species including certain biotypes of *B. fusca* which encapsulate *C. flavipes* rendering them ineffective, as they do not emerge. At the same time, other species that dominate high potential areas (*B. fusca* and *S. calamistis*) are given little attention though they cause higher maize losses compared to low potential areas (Eastern and Coastal) where *C. partellus* dominates (De Groote, 2002).

2.4.4. **Plant resistance**

Plant resistant strategy so far tried in the management of lepidopteran stemborers consists of introducing genetically engineered *Bt*-maize (*Bacillus thurigiensis - Bt*). The African pyralidae stemborers are close relatives to the European corn borers, against which the *Bt*-maize was constructed (Overholt *et al.*, 2001). The Swiss company Novartis in co-operation with the Kenya Agricultural Research Institute (KARI) and the Latin-American CYMMIT introduced *Bt*-maize in Kenya: in 2000, in a 5-year program. This is still in pilot phase despite oppositions from anti-GMO crusaders.

2.5. **Insect population carry-over between seasons**

Lepidopterous stemborers feed on one or more closely related plant families in addition to cultivated host crops (Polaszek and Khan, 1998; Haile and Hofsvang, 2001). During cropping seasons, stemborers occur in large numbers in maize and sorghum plants (Songa *et al.*, 1998). After harvest, gravid moths oviposit in alternative wild hosts where their populations survive during crop free periods (Ingram, 1958; Nye, 1960). Presence of alternative hosts and crop residues in or near a field can increase survival of stemborers, thereby increasing the population that colonise maize and sorghum crops in subsequent growing season. However, surveys in the forest zones of Cameroon, Côte d'Ivoire and Ghana showed that higher wild host abundance in surrounding fields was correlated with a lower pest incidence on maize (Schulthess *et al.*, 1997). Oviposition preference and life table studies revealed that some wild host species namely grasses, were highly attractive to ovipositing female moths, although survival of immature stages and adult moth fecundity were mostly close to 100% against 70 – 80% on maize (Shanower *et al.*, 1993). In addition, relatively high parasitism of *S. calamistis* eggs by *Telenomous* spp (Hymenoptera: Scelionidae) was found during the dry season on wild hosts in the inland valleys in Benin (Ndemah *et al.*, 2001). Although Schulthess *et al.*, (1997) showed that at the local scale level, wild host plants can attract pests and reduce damage on cultivated plants, there is a possibility of increase in damage in the next season since stemborers have higher survival on some alternative host plants (Polaszek and Khan, 1998). Therefore, there is need to assess the impact of wild host plants on stemborer damage over several generations.

2.6. **Stemborer distribution**

Agricultural systems are governed by both climatic and edaphic factors (Megenasa, 1982). Regional diversity of climatic characteristics has been well understood and crop cultivars developed to suit different conditions. From this background, crop pests and their status are likely to vary among different regions (Megenasa, 1982; Songa *et al.*, 1998).

Stemborers are among the field pests whose distribution is affected by environmental conditions throughout Africa (Sithole, 1987). In Eastern and Southern Africa, populations of the families of Noctuidae and Pyralidae often occur as community of species with overlapping spatial and temporal distribution (Seshu Reddy, 1983; Overholt *et al.,* 2001). Records are lacking on biotic and abiotic thresholds that govern establishment of different stemborer species. Apart from extensive surveys carried out in Kenya by Nye (1960) and Guofa *et al.* (2002), other studies attempting to assess the distribution of different stemborer species have been done within one or two growing seasons covering restricted areas in Nyanza, Coastal and Eastern Provinces (Songa *et al.*, 1998; Seshu Reddy, 1983). Based on the outcome of these surveys, Noctuids mainly *B. fusca* and *S. calamistis* are among species most often associated with maize and sorghum in Kenya (Seshu Reddy, 1983; Overholt *et al.*, 2001), while important Pyralid borers are mainly *E. saccharina* and two *Chilo* species (*C. partellus* and *C. orichalcociliellus*) (Seshu Reddy, 1983; Guofa *et al.*, 2002). Unfortunately, in these studies, there is general lack of information on the proportionate distribution of species by area and seasons.

Results from previous studies in most cases seemed to contradict each other in terms of species composition (Songa *et al.*, 1998; Guofa *et al.*, 2002). Seshu Reddy (1983) in a two-week survey conducted in Nyanza, Western, Rift valley, Eastern and Coast provinces during 1981, found *C. partellus, C. orichalcociliellus, S. calamistis, E. saccharina* and *B. fusca* as the important species infesting sorghum and maize. He presented *B. fusca* as the predominant pest (accounting for about 36% of the total stemborer complex) of maize in Eastern province. Extensive research work by Songa *et al.*, (1998) 15 years later showed a contradiction in species composition with *C. partellus* dominating the complex by 67.1%, *S. calamistis* 26.6% and *B. fusca* constituting 1.8%. Such contradictions may be due to differences in time of the season, maize growth stages, and a difference in the sites sampled since occurrence of stemborer species are influenced by altitude, environment and plant phenology (Megenasa, 1982; Songa *et al.*, 1998). Variations may as well occur due to a shift in species composition like it has happened to

Chilo species at the Kenyan Coast (Guofa *et al.*, 2002). There is therefore need to carry out a stemborer distribution survey that considers altitude, environment and plant phenology. In this study, factors responsible for the distribution of different stemborer species were identified and incorporated into a model that integrated all principle components.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of Kenya's agroclimatic zones

Kenya's maize database project (MDBP) sub-divided the country into eight agro-climatic zones (ACZs) on the basis of growing season variables crucial for maize production (Corbett *et al.*, 2001). This study was conducted in six out of the eight ACZs described as; cool and dry high tropics, moist high tropics, moist mid-altitude, dry mid-altitude, severe water stress and moist low tropics (Table 1)

Table 1: Agro-climatic zones across administrative boundaries in Kenya.

Agro-ecological zones	Altitude (m. asl)	Districts
Cool & dry highlands	1880 - 2450	Kiambu, Kericho, Nyeri, Nakuru, Narok, Uasin-Gishu and Laikipia.
Moist high tropics	1770 - 2330	Kisii, Bomet, Nandi, Trans-Nzoia, Kapenguria, Muranga, parts of Meru and Embu.
Moist mid-altitude	1170 - 2150	Kisumu, Rachuonyo, Siaya, Busia, Kirinyaga, Maragua, Suba, Migori, West part of both Bungoma and Kakamega.
Severe water stress and Dry mid-altitude	430 - 1360	Machakos, Makueni, Kitui, Mwingi Taita, Taveta districts, and some parts of Kerio valley.
Moist low tropics	32 - 417	Kilifi and Kwale

Source: Hassan *et al.* (1998).

These zones lie within different geographical locations and are greatly varied in terms of their production potential. Moist high tropical zone is the most important maize-producing zone, followed by cool & dry highland zone (De Groote, 2002). Moist high tropic and cool & dry highland zones together constitute high potential areas that produce approximately 80% of Kenya's maize within 63% of the total production area. Other zones make up about 30% of the total maize area but produce only 15% of Kenya's maize (De Groote, 2002). Moist lowland and dry mid-altitude zones are regarded as low potential areas, with sandy humus soils characterised with both low inherent fertility and low moisture retention. Dry mid-altitude and moist mid-altitude zones are considered as medium potential areas.

Rainfall in the six ACZs is highly variable in timing, duration and intensity. It is bimodal in areas receiving less than 1500mm annually; the long rains (LR) fall between March / April and May / August, and short rains (SR) between October and December. Due to rainfall variability, farmers in dry mid-altitude and severe water stress zones like majority of farmers in Kenya regard the March rains (LR) as the most important growing season. In cool and dry highland zone, moist high tropics and moist lowland areas, farmers plant only in one growing season from March to November unlike in moist mid altitude zone where over half of the farmers try a second cropping season.

3.2. Determination of sample size and survey locations

Sample size (n) was determined by the following formula (Zar, 1999).

$$n = \frac{Z^2 pq\, D}{d^2}$$

Where: n = sample size

p = Proportion of the target area (0.72)

$q = 1-p$ (0.28)

$Z = 1.96$

$d = 0.05$

D = Design effect (=1)

$$n = \frac{1.96^2 * 0.72 * 0.28 * 1}{0.05^2} = 310$$

In this study, 357 farms were clustered into groups of between four and five to give 68 localities. Working on the assumption that ACZs do not characteristically limit the distribution of stemborers, the 68 localities were randomly generated across Kenya using A Where ACT computer software prepared by Corbett *et al.* (2001) (Fig 1). Localities were then defined in terms of climatic conditions; Precipitation - P, Maximum temperature - Tmax, Minimum temperature - Tmin, Evapotranspiration - PE and Moisture index - P/PE based on average annual climatic data (Corbett *et al.*, 2001; Appendix 2).

3.3. Field collection, rearing and identification

Within each of the above localities, sorghum and / or maize farms with the corresponding vegetative stages were used as the basic sampling units. Field visits were made in selected farms during both LR and SR growing seasons of 2003. A total of 400 randomly selected stems were examined for stemborer infestation and infested stems destructively removed during each visit. The collected stems were later transported to ICIPE - Duduville laboratory for dissection. Recovered larvae were identified using external morphological features as described by Overholt *et al.* (2001), and their respective species recorded. Larvae were later reared on fresh two months old maize stems and during rearing; two larvae of the same species were introduced in 15cm long perforated maize stems held vertically in plastic vials where they fed until pupation (Plate 1).

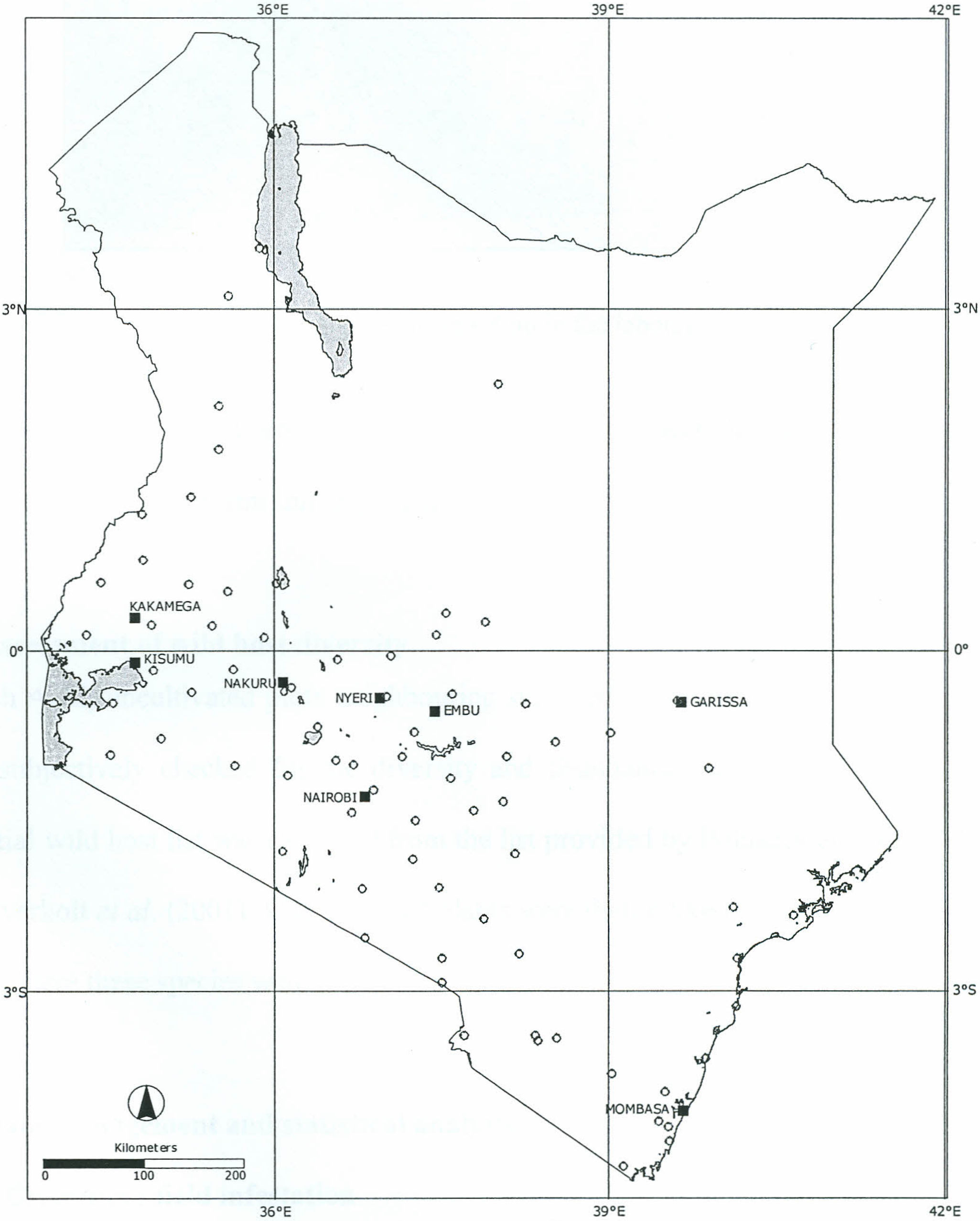


Figure 1: Map of Kenya showing randomly generated localities in maize and sorghum growing areas surveyed in 2003 during the long and short rain growing seasons.

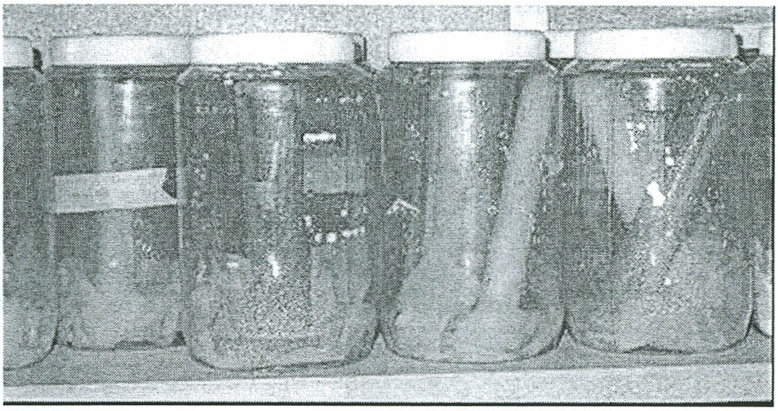


Plate 1: Larvae rearing set-up in the laboratory

Pupae were transferred in separate plastic vials where they were left until emergence and adult moths used to confirm initially recorded larval identities.

3.4. **Assessment of wild host diversity**

In each ACZ, uncultivated plots neighbouring surveyed farms within a distance of 50 m were subjectively checked for the diversity and abundance potential wild host plants. Potential wild host list was extracted from the list provided by Polaszek and Khan (1998) and Overholt *et al.* (2001). Potential host plants were then ranked based on the number of farms where these species were recorded (Table 6).

3.5. **Data management and statistical analysis**

3.5.1. **Estimating field infestation**

Average field infestation for individual farms were computed from the quotient of stems infested out of 400 stems (total number of plants sampled for infestation in each farm) as a percentage (Appendix 5.3). Results from individual farms were nested in their respective ACZs and used as replicates during the statistical analysis. Students' *t* test was used to compare average percentage infestations between LR and SR in each ACZ. After arcsine transformation, one-way analysis of variance (ANOVA) was used to compare proportions (%) of different stemborer species between the ACZs and significantly different means (< 0.05%) separated using Student-Newman-Keuls (SNK) multiple range test (SAS. 1992)

3.5.2. **Predicting spatial distribution**

Species distribution maps were generated using Geographical information system (GIS) software (Corbett *et al.*, 2001). Geo-position data on species occurrence from field data were used to characterize environmental conditions suitable for establishment of different stemborer species (*B. fusca*, *C. partellus*, *C. orichalcociliellus* and *S. calamistis*). Localities with similar stemborer species were grouped together and marched with their initially defined climatic variables and altitude. Environmental variables were subjected to correlation test and variables that showed significant inverse correlation with half of other variables were excluded among the interpolation parameters due to their surrogate effect (Jeske Rendell *pers. com.*). Mean and standard deviation (SD) of the environmental variables were computed for each stemborer species, and interpolation for suitable area done using ± 2 SD (95% confidence interval) from the mean as the upper and lower confidence limits.

3.5.3. **Modelling for species distribution**

Logistic polynomial regression model (quadratic expression) was developed for stemborers *B. fusca, S. calamistis, C. partellus* and *C. orichalcociliellus*. Percentage species composition was regressed against explanatory variables ignoring multi-collinearity that existed among significant variables even though they inflate the partial regression coefficients of significant variables.

$$Y = \text{intercept} + X1 + X1^2\ldots + Xi + Xi^2\ldots + Xn + Xn^2$$

Where: X1… Xi… Xn are different explanatory variables (Alt, P, PE, P/PE, Tmin, Tmax)

Contribution of each variable and its quadratic function in the model was checked and significant variables ($p < 0.05$) included in the final model.

CHAPTER FOUR

RESULTS

4.1. Stemborer infestation

Overall stemborer infestations varied significantly between the surveyed ACZs ($F_{5,333} = 2.95$; $p = 0.0128$; Table 2). Highest infestations (30.0 ± 3.3 %) were recorded in moist low tropical zone where more than 61% of the surveyed localities had over 20% field infestation. Significantly lower infestations (11.7 ± 2.4 %) were observed in cool & dry highland zones, where only 16% of the surveyed localities had more than 20% field infestation. Infestations in the other ACZs (moist high tropics, moist mid-altitude, dry mid-altitude and severe water stress) were not significantly different ($p < 0.05$) and varied between 20.3 and 21.5%.

Table 2: Mean (± SE) percentage stemborer infestation in different agro-climatic zones.

Agro-ecological zone	*n*	Mean (± SE) (%)	% Infested sites (> 20%)
Cool & dry highlands	37	11.7 ± 2.4^{b}	16
Moist high tropics	66	20.7 ± 2.8^{ba}	38
Moist mid-altitude	65	20.3 ± 2.4^{ba}	39
Dry mid-altitude	73	20.6 ± 2.0^{ba}	41
Severe water stress	54	21.5 ± 2.9^{ba}	43
Moist low tropics	44	30.0 ± 3.3^{a}	61

Mean (± SE) followed by the same superscripts are not significantly different (Student-Newman-Keuls multiple range test, $p > 0.05$); $F_{5,333} = 2.95$; $p = 0.0128$; n = number of fields surveyed

There was evidence of variation in field infestation between the seasons in some ACZs. Significantly higher infestations were observed during the SR compared to LR growing seasons in the dry mid-altitude ($t_{72} = 2.77$; $p < 0.01$), severe water stress ($t_{52} = 2.46$; $p < 0.01$) and moist low tropical ($t_{42} = 3.12$; $p < 0.005$) zones (Table 3). Conversely, in cool and dry high tropics, infestations during the LR seasons were significantly higher compared to the average infestations during the SR seasons (t_{35}=2.77; $p < 0.01$). Average infestations during the LR and SR seasons were not different ($p > 0.05$) in both moist high tropics and moist mid-altitude zones (Table 3).

Table 3: Seasonal variation in average stemborer infestations (%) in different agro-climatic zones.

Agro-ecological zone	Average % infestation (± SE)		*t*	*df*	*p*
	Long rain	Short rain			
Cool & dry highlands	10.00 ± 2.08^{b}	11.10 ± 3.20^{c}	2.77	35	< 0.01*
Moist high tropics	20.20 ± 3.30^{ba}	21.81 ± 5.40^{bac}	0.04	64	> 0.05
Moist mid-altitude	16.23 ± 2.55^{b}	20.52 ± 2.44^{bc}	1.31	63	> 0.05
Dry mid-altitude	15.95 ± 2.18^{b}	26.56 ± 3.32^{bac}	2.77	71	< 0.01*
Severe water stress	15.94 ± 3.25^{b}	30.33 ± 4.86^{ba}	2.46	52	< 0.01*
Moist low tropics	30.04 ± 3.27^{a}	26.56 ± 3.32^{a}	3.12	42	<0.005*

Mean (± SE) in the columns followed by the same superscripts are not significantly different (Student-Newman-Keuls multiple range test, $p > 0.05$); LR, $F_{5,218} = 4.76$; $p = 0.0004$; SR, $F_{5,179} = 4.33$; $p = 0.001$

4.2. Species composition

There was marked variation in stemborer species composition with *B. fusca, S. calamistis, C. partellus* and *C. orichalcociliellus* constituting the major proportion of the community. The other species present, *E. saccharina, S. nonagrioides* (Lefebvre), *S.*

cretica (Lederer), *Sesamia spp.* (Nov.), *Sciomesa piscator* (Fletcher), *Busseola spp* near *phaia*, *Chilo spp*, *Ematheudes spp.* 1 and *Ematheudes spp.* 2 constituted less than 1% of the total proportion.

Species proportions of the economically important stemborers varied significantly between the ACZs with little variation between the growing seasons (Table 4). *B. fusca* significantly varied in its proportion between the ACZs ($F_{5, 468} = 151.84$; $p = 0.0001$). Significantly higher proportions of *B. fusca* (> 90%) were recorded in high potential areas represented by both cool & dry highlands and moist high tropics, and lower proportions (< 5%) in low potential areas; severe water stress and moist low tropical zones. *Sesamia calamistis*, the second important Noctuid species occurred in all the ACZs surveyed but was significantly higher only in moist low tropics ($F_{5, 468} = 7.86$, $p = 0.0001$).

Chilo partellus was another dominant species, which showed significant variation in its percentage proportions across different ACZs. The highest average proportion of *C. partellus* (90.06 %) was recorded in severe water stress zone followed by moist low tropics (77.2 %) and dry mid-altitude zones (62.08 %) with significantly lower proportions ($F_{5, 468} = 95.32$; $p < 0.0001$) recorded in both moist high tropics (4.6 %) and cool & dry high tropical zone (0.05%) where *B. fusca* dominated. *C. orichalcociliellus* was recovered only in moist low tropics where it constituted 5.72 % of the community where *C. partellus* (77.2%) dominated followed by *S. calamistis* (16.9%) and indeed it was ranked 3rd . *S. calamistis* was the only stemborer species that occurred in all ACZs surveyed though it did not show dominance over other species in any ACZ. There was evidence of variations of *S. calamistis* proportion across different ACZs with highest percentage of 16.96 % recorded in moist low tropics and lowest percentage of 1.75% recorded in moist high tropics (Table 4).

Table 4: Average (± SE) percentage stemborer infestation in the six ACZ surveyed during the study.

Agro-climatic zones	Mean (± SE) percentage infestation			
	B. fusca	*S. calamistis*	*C. partellus*	*C. orichal*
Cool and dry high tropics	96.08 ± 1.27 ^{a}	3.77 ± 1.27 ^{b}	0.05 ± 0.07 ^{e}	0.00 ± 0.00 ^{b}
Moist high tropics	93.65 ± 2.25 ^{a}	1.75 ± 1.01 ^{b}	4.60 ± 2.07 ^{e}	0.00 ± 0.00 ^{b}
Moist mid-altitude	55.55 ± 3.75 ^{b}	7.08 ± 1.38 ^{b}	37.37 ± 3.80 ^{d}	0.00 ± 0.00 ^{b}
Dry mid-altitude	31.04 ± 4.23 ^{c}	6.88 ± 1.36 ^{b}	62.08 ± 4.25 ^{c}	0.00 ± 0.00 ^{b}
Severe water stress	3.40 ± 1.63 ^{d}	6.54 ± 1.61 ^{b}	90.06 ± 2.49 ^{a}	0.00 ± 0.00 ^{b}
Moist low tropics	0.12 ± 0.07 ^{d}	16.96 ± 2.94 ^{a}	77.20 ± 3.03 ^{b}	5.72 ± 1.26 ^{a}

Means within a column followed by the same superscripts are not significantly different (Student-Newman-Keuls multiple range test, $p > 0.05$); *B. fusca*, $F_{5, 468} = 151.84$, $p < 0.0001$; *S. calamistis*, $F_{5, 468} = 7.86$, $p = 0.0001$; *C. partellus*, $F_{5, 468} = 95.32$, $p < 0.0001$; *C. orichalcociliellus*, $F_{5, 468} = 23.51$, $p < 0.0001$

There was evidence of variation in species composition between the seasons for each zone (Table 5). Proportions of *B. fusca* were significantly higher during the *LR* growing season in moist mid altitude (60%) and dry mid altitude zones (53%; $F_{11, 473} = 72.86$, $p < 0.0001$). There was no significant difference in proportions of *B. fusca* between *LR* and *SR* growing seasons in other zones. Proportions of *C. partellus* in the community were higher during the *SR* in dry mid-altitude zones (72.29%) and during the *LR* in moist low tropics (78.72%). Proportions of both *C. partellus* and *C. orichalcociliellus* were also higher during the *LR* in moist low tropics.

Table 5: Seasonal variability in average (%) stemborer species composition in different agro-climatic zones in Kenya

ACZs	Season	Average percentage stemborer composition			
		B. fusca	*S. calamistis*	*C. partellus*	*C. orichalco.*
Cool and dry high tropics	LR	95.63 ± 1.78^{a}	04.23 ± 1.77^{bc}	00.14 ± 0.08^{e}	0.00 ± 0.00^{c}
	SR	96.83 ± 1.64^{a}	02.99 ± 1.64^{bc}	00.17 ± 0.12^{e}	0.00 ± 0.00^{c}
Moist high tropics	LR	96.24 ± 1.89^{a}	02.04 ± 1.51^{c}	01.72 ± 1.21^{e}	0.00 ± 0.00^{c}
	SR	88.19 ± 535^{a}	01.20 ± 0.73^{c}	10.01 ± 5.39^{e}	0.00 ± 0.00^{c}
Moist mid-altitude	LR	60.27 ± 6.61^{b}	06.00 ± 2.06^{bc}	33.72 ± 6.67^{d}	0.00 ± 0.00^{c}
	SR	53.13 ± 4.55^{cb}	07.63 ± 1.80^{bc}	39.24 ± 4.62^{d}	0.00 ± 0.00^{c}
Dry mid-altitude	LR	43.36 ± 6.68^{c}	04.27 ± 1.54^{bc}	52.36 ± 6.84^{c}	0.00 ± 0.00^{c}
	SR	18.1 ± 4.33^{d}	09.61 ± 2.20^{bc}	72.29 ± 4.47^{cb}	0.00 ± 0.00^{c}
Severe water stress	LR	3.31 ± 1.64^{d}	06.47 ± 2.10^{bc}	90.22 ± 2.91^{a}	0.00 ± 0.00^{c}
	SR	3.56 ± 3.40^{d}	06.65 ± 2.53^{bc}	89.79 ± 4.60^{a}	0.00 ± 0.00^{c}
Moist low tropics	LR	0.12 ± 0.08^{d}	14.58 ± 3.39^{a}	78.72 ± 3.56^{b}	6.58 ± 1.78^{a}
	SR	0.12 ± 0.12^{d}	21.15 ± 5.48^{a}	74.51 ± 5.60^{cb}	4.21 ± 1.47^{b}

Means within same column followed by the same superscripts are not significantly different (Student-Newman-Keuls multiple range test, $p > 0.05$); *B. fusca*, $F_{11, 473} = 72.86$, $p < 0.0001$; *S. calamistis*, $F_{11, 473} = 4.07$, $p < 0.0001$; *C. partellus*, $F_{11, 473} = 43.82$, $p < 0.0001$; *C. orichalcociliellus*, $F_{11, 473} = 11.20$, $p < 0.0001$

4.3. Distribution of the potential wild hosts of stemborers in different ACZs

There was relatively high diversity of wild hosts, which varied in their abundance from one ACZ to another. Both *P. purpureum* and *P. maximum* were abundant in all the ACZs (Table 6). In moist low tropics, *P. purpureum, P. maximum, Sorghum arundinaceum* (Desv.) Stapf. and *Rottbellia exaltalta* were present in more than 60% of the farms surveyed (Table 6). All other species were present in less than 30% of the farms surveyed in moist low tropics except for *Setaria sphacelata* (Schumacher), *Panicum deustum* Thunb, *Hyparrhenia rufa* and *Cyperus papyrus* L. (Table 6).

Table 6: Relative importance of potential wild hosts of lepidopteran stemborers in different agro-climatic zones

Host species	**Agro-climatic zones (ACZs)**					
	Moist low tropics	Severe water stress	Dry mid-altitude	Moist mid-altitude	Moist high tropics	Cool & Dry high tropics
P. purpureum	+ + +	+ + -	+ + +	+ + +	+ + +	+ + +
P. trachyphyllum	+ - -	- - -	- - -	+ - -	+ - -	- - -
Set. sphacelata	- - -	- - -	+ - -	+ - -	+ - -	+ - -
P. maximum	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
P. deustum	- - -	- - -	- - -	+ - -	- - -	- - -
S. arundinaceum	+ + +	+ + +	+ + -	+ - -	+ - -	- - -
Ech. pyramidalis	+ - -	- - -	- - -	+ - -	+ - -	+ - -
Ech. haploclada	+ - -	+ - -	- - -	- - -	- - -	- - -
Sporo. marginatus	+ - -	+ - -	+ - -	+ - -	+ - -	+ - -
Phrag.. kirki	+ - -	- - -	- - -	+ - -	- - -	- - -
R. exaltalta	+ + +	+ +	+ - -	+ - -	+ - -	- - -
Hyp. rufa	- - -	- - -	+ - -	+ + -	+ - -	+ - -
T. domingensis	+ - -	+ - -	+ - -	+ - -	+ - -	+ - -
Cyp. distans	+ - -	- - -	+ - -	+ - -	+ - -	- - -
Cyp. immensis	+ - -	- - -	+ - -	+ - -	- - -	- - -
Cyp. papyrus	- - -	- - -	+ - -	+ - -	+ - -	- - -

The above list of potential wild hosts of stemborers was extracted from the list provided by Khan *et al.* (1998) and Overholt *et al.* (2001) and ranked based on their abundance in different ACZs.; + + + present in more than 60% of the surveyed farms; + + - present in between 30 – 60% of the farms surveyed; + - - present in less than 30% of the surveyed farms; - - - not present in the surveyed farms.

In severe water stress zone, *P. maximum* and *S. arundinaceum* were present in more that 60% of the surveyed farms. Other species present in this zone included *Echinochloa haploclada* Stapf., *Sporobolus marginatus* Hochst, *R. exaltalta* and *Typha domingensis* Pers.. Similar diversity of potential hosts was recorded in dry mid and moist mid altitude zones apart from additional *Cyperus distans* L. f., *Cyperus immensis, C. papyrus. H. rufa* and *S. sphacelata* which were found in less than 30% of the surveyed farms. *Hyparrhenia* *rufa* was present in higher altitude ACZs (> 1000m asl) though its proportion was relatively higher (30 – 60%) in moist mid altitude zone (Table 6).

In moist high tropics and cool & dry high tropics, diversity of wild hosts were limited to a few farms. Notable among the potential wild hosts were *S. arundinaceum, E. haploclada, Phragmites kirki* and *C. immensis*. *Pennisetum trachyphyllum* Pilg., *S. arundinaceum* and *C. papyrus* were absent in cool & dry high topics but existed in less than 30% of the surveyed farms in moist high tropics. In most of the ACZs, the potential host species' existed together constituting a complex of diverse hosts (Plate 2).

Plate 2: Diverse wild hosts existing as a complex in the neighbouring uncultivated field (May 2003).

4.4. **Spatial distribution of stemborers**

Correlation test showed strong evidence of multi-collinearity among Altitude – Alt, Precipitation - P, Maximum temperature - Tmax, Minimum temperature - Tmin, Evapotranspiration - PE and Moisture index - P/PE variables (Table 7). Altitude showed a strong inverse correlation with three variables; PE ($r_{2\,(0.05)\,72} = -0.6$; $p = 0.00$), Tmax ($r_{2\,(0.05)\,72} = -0.81$; $p = 0.00$) and Tmin. ($r_{2\,(0.05)\,72} = -0.96$; $p = 0.00$). Similarly, P/PE showed inverse correlation with the three variables; PE ($r_{2\,(0.05)\,72} = -0.58$; $p = 0.00$), Tmax ($r_{2\,(0.05)\,72} = -0.57$; $p = 0.00$) and Tmin ($r_{2\,(0.05)\,72} = -0.5$; $p = 0.00$).

Table 7: Summary of correlation test results of altitude and average climatic variables; marked correlation coefficients are significant at $p < 0.05$; n = 72.

Variables	Alt	Tmin	Tmax	Pmm	E0	P / PE
Alt	1.00					
Tmin	-0.96*	1.00				
Tmax	-0.81*	0.88*	1.00			
Pmm	0.38*	-0.40*	-0.47*	1.00		
E0	-0.60*	0.72*	0.84*	-0.51*	1.00	
P / PE	0.45*	-0.50*	-0.57*	0.75*	-0.58*	1.00

Inclusion of these variables (Alt. and P/PE) in spatial interpolation inflates partial regression coefficient and reduced the extent of ecologically suitable area for establishment of recovered stemborers species; *B. fusca*, *C. partellus*, *C. orichalcociliellus* and *S. calamistis*. Both Alt. and P/PE were therefore excluded among the interpolation variables during individual species' characterisation (Table 8).

Table 8: Annual averages (Mean ± SD) of explanatory variables for localities where *B. fusca,, S. calamistis, C. partellus* and *C. orichalcociliellus* were recovered during the 2003 survey; *n* in parenthesis in species column is the total number of localities where respective species were recovered.

Species	Explanatory variables	Mean ± 2SD
B. fusca (*n* = 53)	Precipitation (mm)	1052.60 ± 580.6
	Evapotranspiration (mm)	1423.90 ± 293.8
	Minimum temperature (^{0}C)	11.40 ± 5.2
	Maximum temperature (^{0}C)	24.60 ± 6.8
S. calamistis (*n* = 46)	Precipitation (mm)	892.35 ± 595.69
	Evapotranspiration (mm)	1534.91 ± 152.89
	Minimum temperature (^{0}C)	16.01 ± 8.7
	Maximum temperature (^{0}C)	27.79 ± 7.1
C. partellus (*n* = 51)	Precipitation (mm)	805.30 ± 534.2
	Evapotranspiration (mm)	1586.00 ± 245.8
	Minimum temperature (^{0}C)	18.10 ± 6.8
	Maximum temperature (^{0}C)	29.30 ± 4.6
C. orichalcociliellus (*n* = 12)	Precipitation (mm)	907.30 ± 433.4
	Evapotranspiration (mm)	1578.30 ± 168
	Minimum temperature (^{0}C)	21.20 ± 4.4
	Maximum temperature (^{0}C)	30.30 ± 2.2

4.4.1. Ecologically suitable area for establishment of *Busseola fusca*

Potentially suitable areas for the establishment of *B. fusca* extend towards the western Kenya from Central province covering Rift valley, Nyanza and Western provinces (Fig. 2). On the east, only areas under dry mid-altitude zone in Eastern province falls within the interpolated suitable zone. Within this area, there is marked variation in percentage proportion of *B. fusca* that ranged from 5 and 100% within the complex with some localities recording less than 1%. Quadratic functions of explanatory variables included in the logistic polynomial regression model showed that only Tmax and altitude significantly ($p < 0.001$) influence its composition (Table 9).

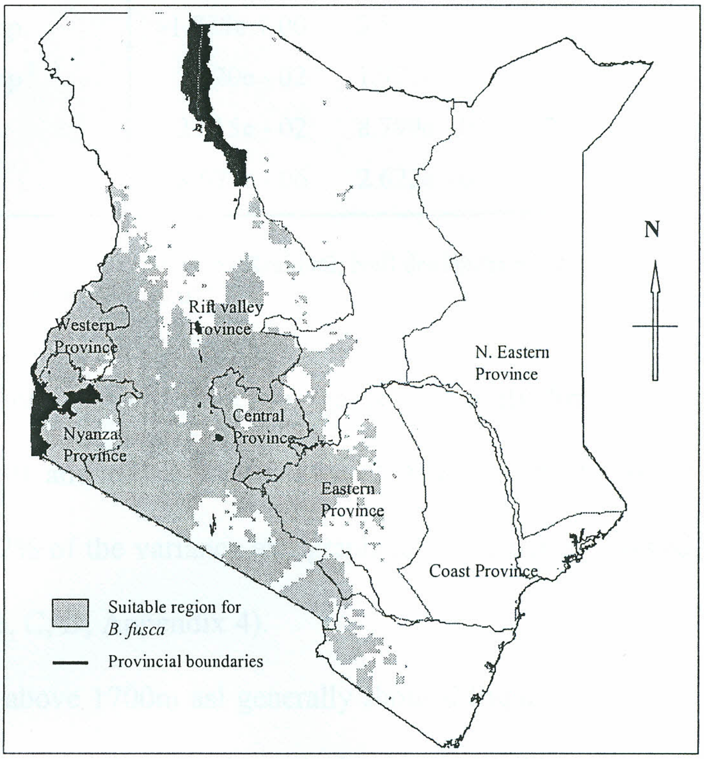


Figure 2: Map of Kenya showing interpolated area suitable for establishment of *B. fusca*.

These variables showed evidence of variation in levels and nature of influence. Both Tmax^2 (3.920e – 02) and Alt. (2.015e – 02) positively affected observed *B. fusca* composition while Tmax (-1.739e + 00) and Alt.^{2} (-3.677e – 06) inversely affected its proportions. *B. fusca* proportion in different localities was fitted from the partial regression coefficients of Tmax, Tmax^2, Alt, and Alt^2 above (Table 9)

$$\text{Logit}(\%\ B.\ fusca) = -3.385e + 00_{\text{(intercept)}} + (-1.739e + 00 * \text{Tmax}) + (3.920e - 02 * \text{Tmax}^2) + (2.015e - 02 * \text{Alt}) + (-3.677e - 06 * \text{Alt}^2).$$

$$\%\ B.\ fusca = \exp[\text{logit}(\%B.\ fusca)] \,/\, \{I + \exp[\text{logit}(\%B.\ fusca)]\}.$$

Table 9: Summary of final polynomial regression analysis on *B. fusca* proportion against significant environmental variables

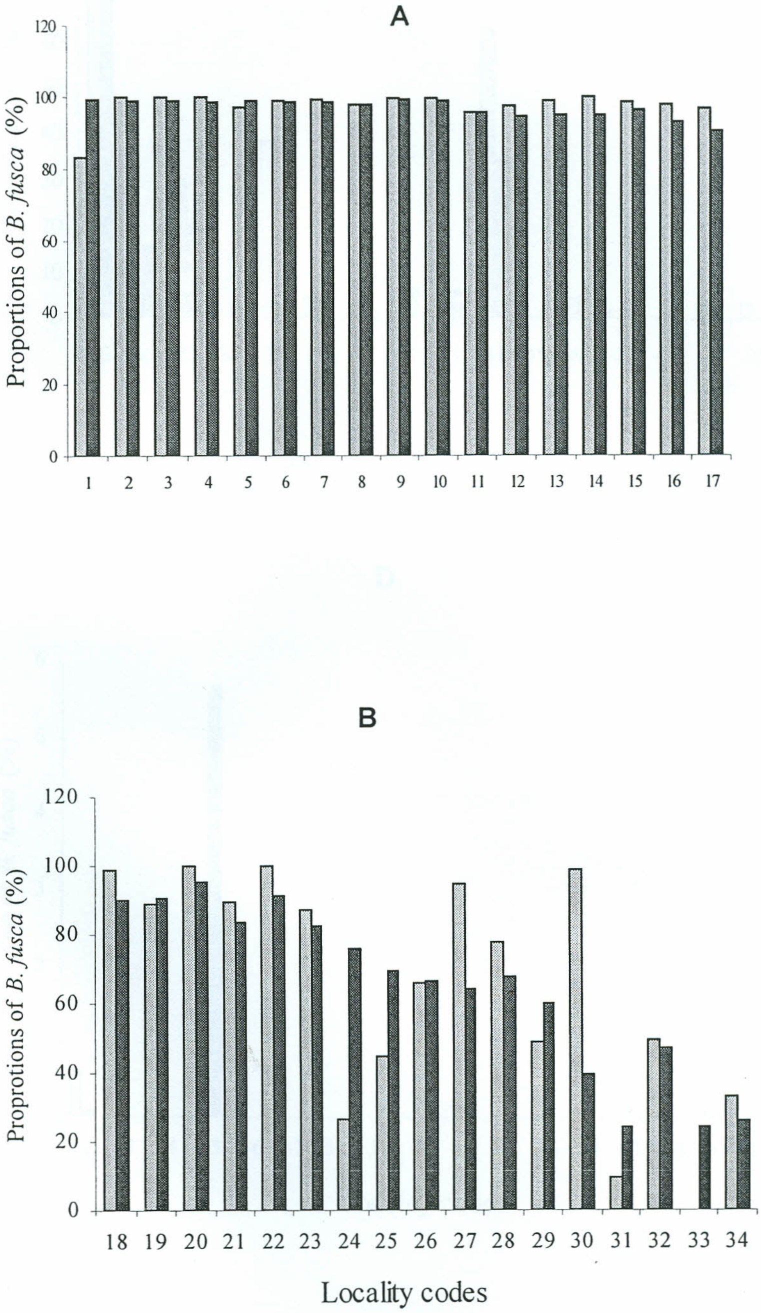
Explanatory variables	Estimate	Std. error	Z value	Prob. (> Z)
Intercept	-3.385e + 00	6.401e - 01	-5.289	1.23e - 07
Maximum temp.	-1.739e + 00	8.585e - 02	-20.261	< 2e – 16***
Maximum temp ^{2}	3.920e - 02	1.921e - 03	20.408	< 2e – 16***
Altitude	2.015e - 02	8.799e - 04	22.899	< 2e – 16***
Altitude ^{2}	-3.677e - 06	2.622e - 07	-14.024	< 2e – 16***

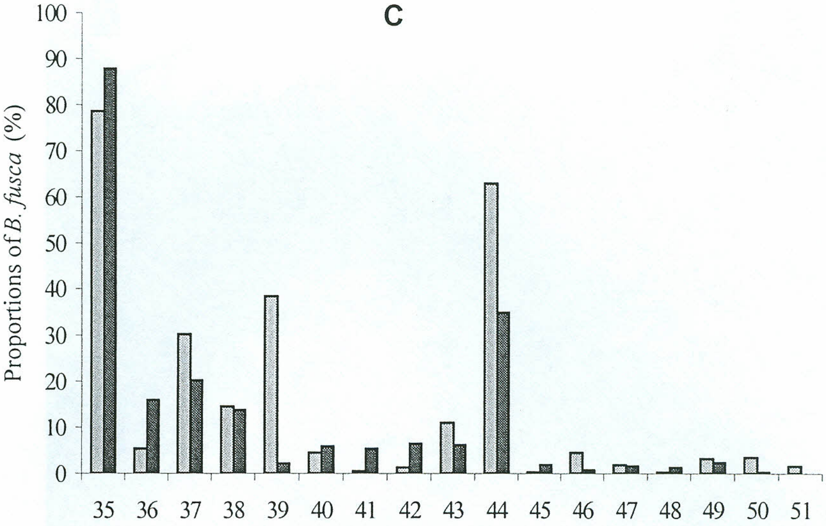
Degrees of freedom: 67 Total (i.e. Null); 63 Residual; Null deviance: 37521; Residual deviance: 3338.1; Significance codes: 0 ***; 0.001**; 0.01*

Normality test showed strong evidence against normality for both the observed (W = 0.7610; p = 0.000) and predicted (W = 0.7779; p = 0.000) proportions. This model accounted for 91.2% of the variance and graphical comparison showed very low residual error (Figs 3. A, B, C, D; Appendix 4).

Localities above 1700m asl generally showed higher proportions of the observed *B. fusca* (> 10%) compared to fitted proportions except in Nyahururu (n^{0}1), Meru 2 (n^{0}5), Kisumu 1 (n^{0}11) and Loitoktok 2 (n^{0}19) where the converse was observed (Fig. 3 B). Residual errors for other localities below 1600m asl were greatly varied without any consistent pattern. Observed proportions were higher compared to fitted proportions in Meru 1 (n^{0}27), Kisii 2 (n^{0}28), Kakamega (n^{0}30) and Kitui 2 (n^{0}33). *P. purpureum* was common in uncultivated fields neighbouring surveyed localities with high positive residual error (> 10%); Meru 1, Kakamega, Taita 2 and Rift 6. There were also large expanses of mixed populations of *P. maximum*, *S. arundinaceum* together with some species from *Hyparrhenia* genera in some localities (Plate 3).

Figure 3: Comparison of the observed and predicted proportions of *B. fusca* in different localities surveyed in the country based on the logistic polynomial regression model. Graphs are ordered in terms of elevations; **A**, > 1885; **B**, 1350 – 1884; **C**, 730 – 1349; **D**, < 730m asl;░ - Observed, ▓ predicted.




C
Proportions of B. fusca (%)
100
90
80
70
60
50
40
30
20
10
0
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51

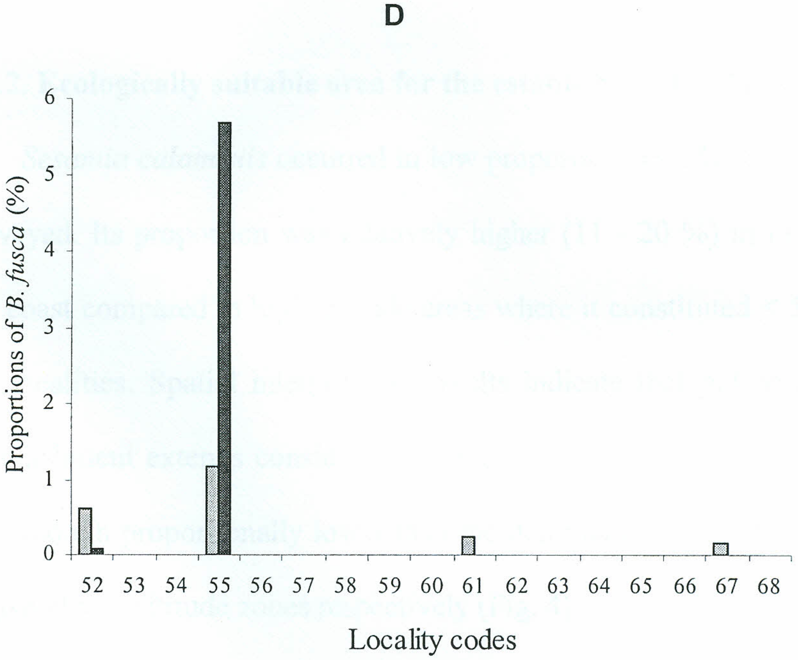

D
Proportions of B. fusca (%)
6
5
4
3
2
1
0
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
Locality codes

Plate 3: Wild grass habitats neighbouring the fields of cultivated Graminae; *Pennisetum purpureum* in Loitoktok 2 (March 2003)

4.4.2. **Ecologically suitable area for the establishment of *Sesamia calamistis***

Sesamia calamistis occurred in low proportions (< 5%) in over 80% of the localities surveyed. Its proportion was relatively higher (11 - 20 %) in low altitude areas towards the coast compared to high altitude areas where it constituted < 5% of the complex in all the localities. Spatial interpolation results indicate that potentially suitable area for its establishment extends considerably from low (20m asl) to high altitude regions (2000m asl), though proportionally lower than the dominant species; *B. fusca* and *C. partellus* in high and low altitude zones respectively (Fig. 4).

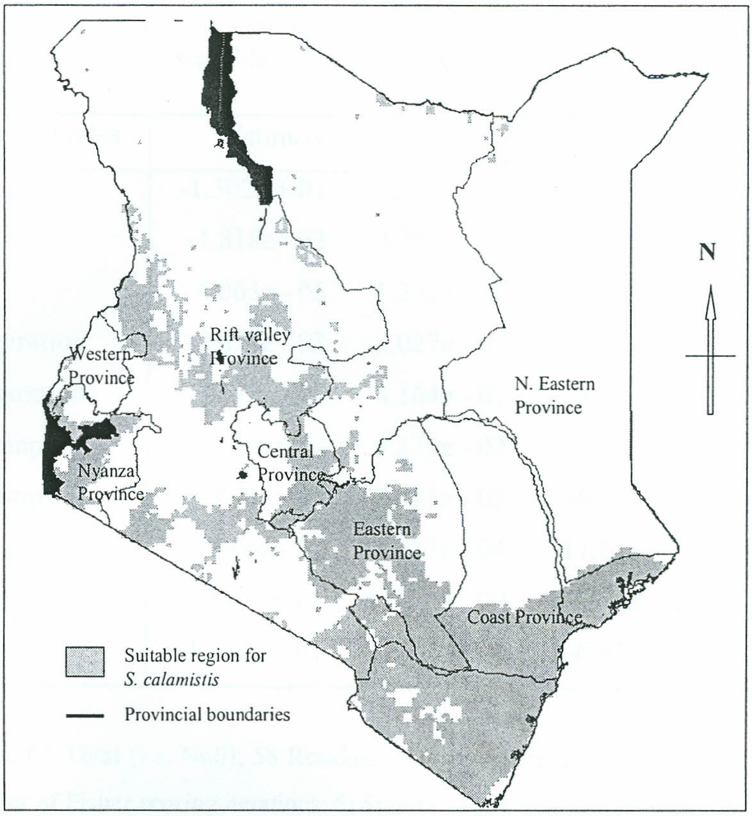


Figure 4: Map of Kenya showing interpolated area suitable for establishment of *S. calamistis*

Proportions of *S. calamistis* in the complex across the potentially suitable area (Fig 6) are highly varied. Logistic polynomial regression analysis showed that P, P^2, PE, PE^2, Tmin, $Tmin^2$, Alt, P/ PE and P/ PE^2 significantly interact ($p < 0.001$) to influence the establishment of *S. calamistis* (Table 10).

$$\text{Logit}\ (\%\ S.\ calamistis) = -1.502e + 01_{\text{(intercept)}} + (-1.818e - 02^{*}\ P) + (4.063e - 06^{*}\ P^2) + (-9.870e - 03^{*}\ PE) + (3.552e - 06^{*}\ PE^2) + (1.122e + 00\ {*}\ Tmin) + (-1.645e - 02^{*}\ Tmin^2) + (2.904e - 03^{*}\ Alt) + (3.674e + 01^{*}\ P/PE) + (-1.837e + 01^{*}\ P/PE^2).$$

$$\%\ S.\ calamistis = \exp\ [\text{logit}\ (\%S.\ calamistis)]\ /\ \{I + \exp\ [\text{logit}\ (\%S.\ calamistis)]\}$$

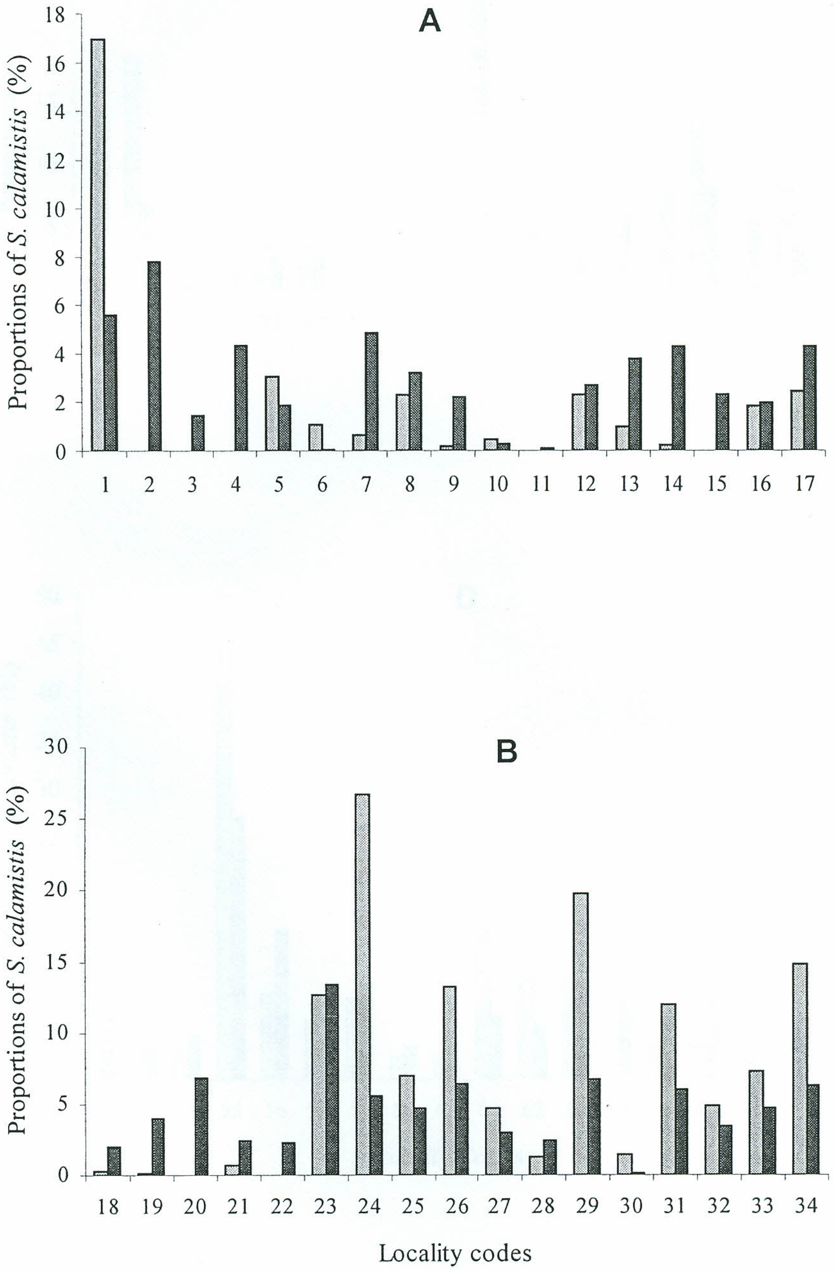
Table 10: Summary of final polynomial regression analysis on *S. calamistis* proportion against significant environmental variables

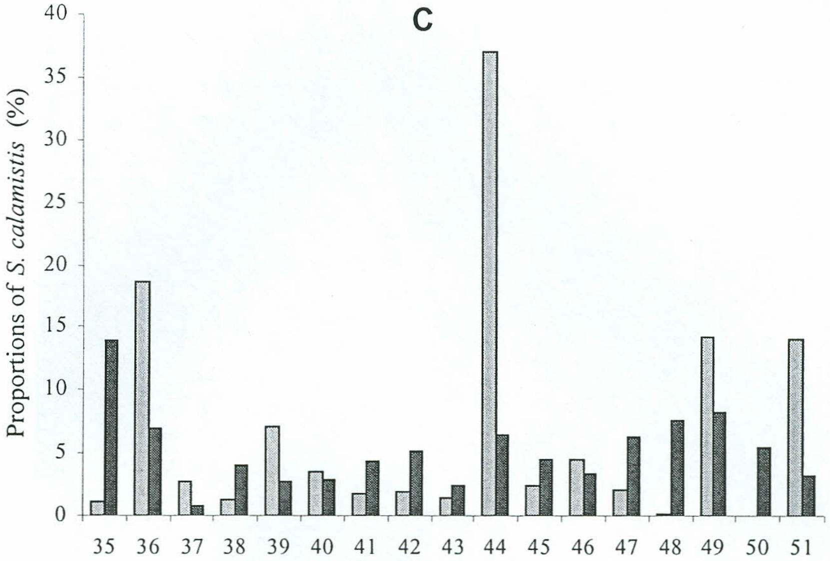
Explanatory variables	Estimate	Std. error	Z value	Prob. (> Z)
Intercept	-1.502e + 01	3.202e + 00	-4.691	2.72e – 06***
Rainfall	-1.818e - 02	3.760e - 03	-4.836	1.32e – 06***
Rainfall^2	4.063e - 06	1.252e - 06	3.245	0.00117**
Evapotranspiration	-9.870e - 03	3.027e - 03	-3.260	0.00111**
Evapotranspiration^2	3.552e - 06	8.164e - 07	4.350	1.36e – 05***
Minimum temp.	1.122e + 00	9.275e - 02	12.094	< 2e – 16***
Minimum temp.^{2}	-1.645e - 02	2.574e - 03	-6.393	1.63e – 10***
Altitude	2.904e - 03	1.683e - 04	17.251	< 2e – 16***
Moisture index	3.674e + 01	5.698e + 00	6.448	1.14e – 10***
Moisture index^2	-1.837e + 01	2.861e + 00	-6.421	1.35e – 10***

Degrees of freedom: 67 Total (i.e. Null); 58 Residual; Null deviance: 2364.7; Residual deviance: 1702.4; AIC: 1980.6; Number of Fisher scoring iterations: 5; Significance codes: 0 ***; 0.001**; 0.01*

Normality test showed strong evidence against normality for both the observed (W = 0.7157; $p = 0.000$) and fitted (W = 0.7718; $p = 0.000$) proportions. The model explained 25.8% of the variance when both the observed and fitted values were compared after arcsine transformation. Residual errors among the study localities were highly varied without any predictable trend. Most of the localities recorded residual error values less than 10% particularly in low altitude areas (Appendix 5.3). Positive residual error values were observed in Nyahururu (n^{0}1; 11%), Namanga 1 (n^0 24; 21%), Mombasa 1 (n^0 29; 13%), Loitoktok 1 (n^0 36: 12%), Rift 6 (n^0 44; 31%), Mombasa 7 (n^0 51; 11%), Turkana (n^0 55; 17%) and Shimba 1 (n^0 61; 11%) while high residual error value (>10%) was recorded in Kerio 1 (n^0 35; 12%). In the neighbourhood of the above localities, there were large expanses of potential host grasses.

Figure 5: Comparison of the observed and predicted proportions of *S. calamistis* in different localities surveyed in the country based on the logistic polynomial regression model. Graphs are ordered in terms of elevations; **A**, > 1885; **B**, 1350 – 1884; **C**, 730 – 1349; **D**, < 730m asl; ▨- Observed, ■ predicted




C
Proportions of S. calamistis (%)
0
5
10
15
20
25
30
35
40
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51

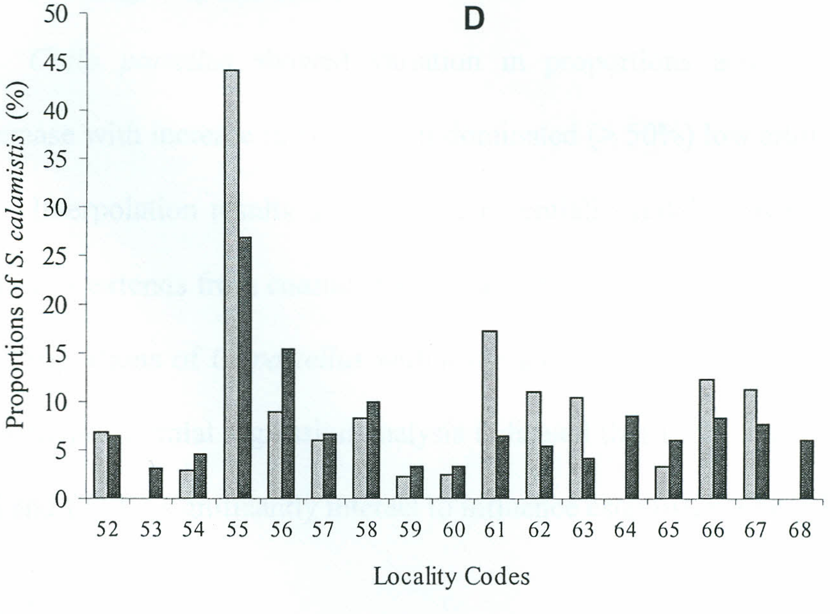

D
Proportions of S. calamistis (%)
0
5
10
15
20
25
30
35
40
45
50
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
Locality Codes

Plate 4: *Pennisetum trachyphyllum* neighbouring the fields of cultivated maize (July 2003)

4.4.3. **Ecologically suitable area for the establishment of *Chilo partellus***

Chilo partellus showed variation in proportions across Kenya with a general decrease with increase in altitude. It dominated (> 50%) low altitude localities (< 1500m asl). Interpolation results indicate that potentially suitable area for establishment of *C. partellus* extends from coastal strip towards the central region at altitude 1800m asl (Fig. 6). Proportions of *C. partellus* within the above potentially suitable area are varied and logistic polynomial regression analysis indicated that P, P^2, PE, PE^2, $Tmax^2$, Alt, Alt^2, P/ PE and P/ PE^2 significantly interact to influence establishment of *C. partellus* (Table 11).

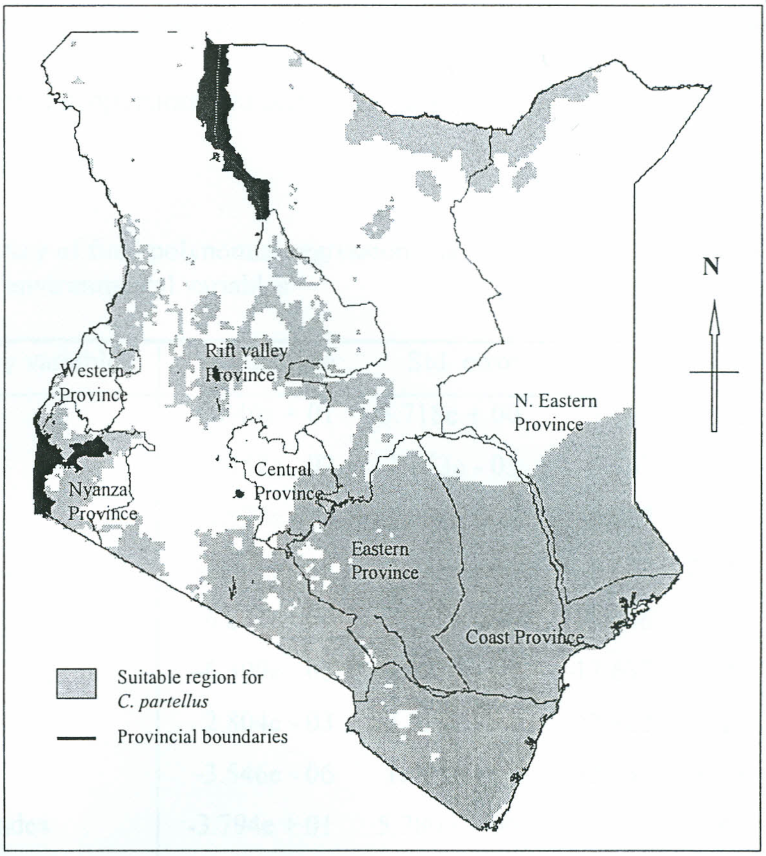


Figure 6: Map of Kenya showing interpolated area suitable for establishment of *C. partellus*

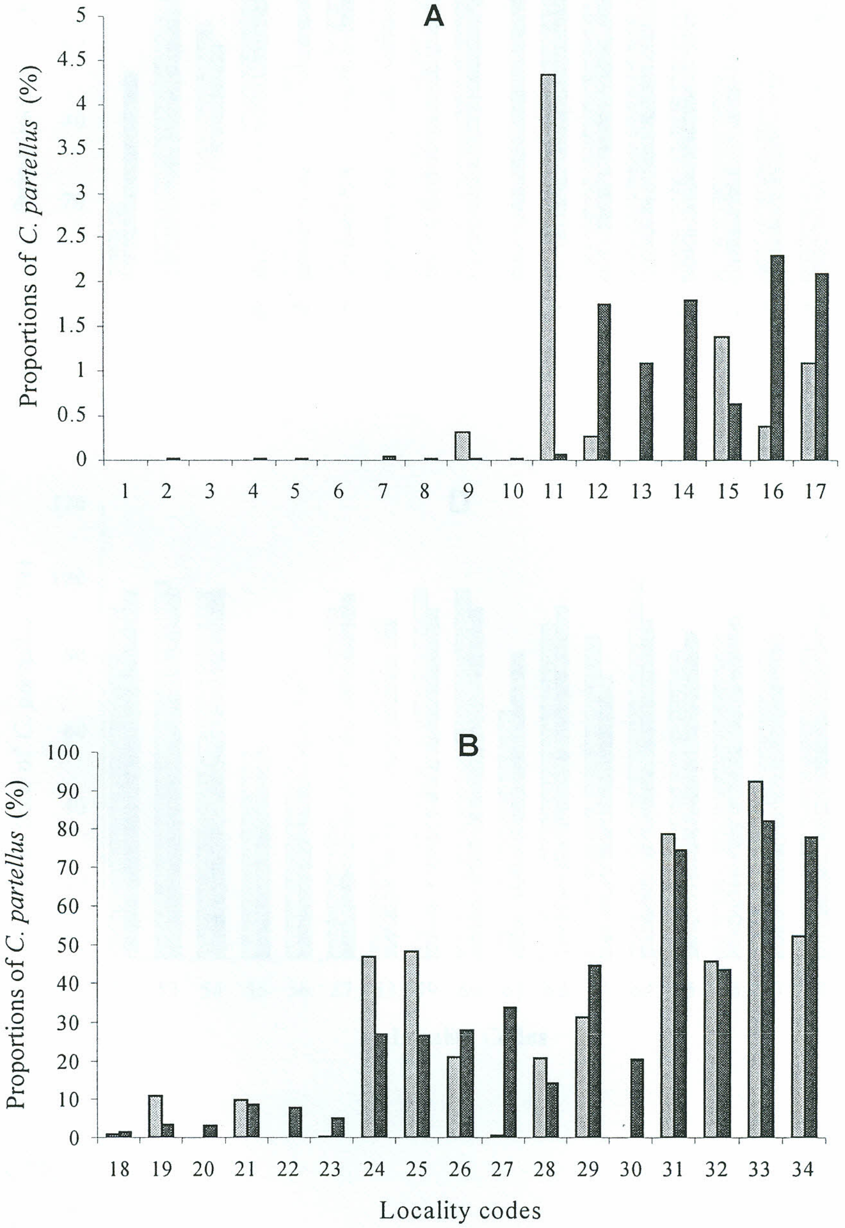
Normality test revealed strong evidence against normality for both the observed (W = 0.7984; *p* = 0.000) and fitted (W = 0.7998; *p* = 0.000) proportions of *C. partellus*. These variables explained 86.9% of the variance after arcsine transformation. Observed and fitted proportions varied among some localities accounting for the residual error values. Observed proportions exceeded the fitted values by about 10% in Namanga 1, (n^0 24; 19.8%); Mt. Kenya 1 (n^0 25; 21.6%); Mombasa 6, (n^0 63; 10.3%); Lamu, (n^0 64; 10.3%) and Garissa 1, (n^0 33; 10.4%). In Meru 1 (n^0 27; 33%), Mombasa 1 (n^0 29; 13%), Kakamega (n^0 30; 21%), Kitui 1 (n^0 34; 26%), Kerio 1 (n^0 35; 33%), Taita 2 (n^0 39; 24%), Rift 6 (n^0 44; 86%), Rift 3 (n^0 49; 10%), Mombasa 7 (n^0 51; 14%), and Shimba 1 (n^0 61; 15%) the predicted proportions exceeded the observed values by over 10%.

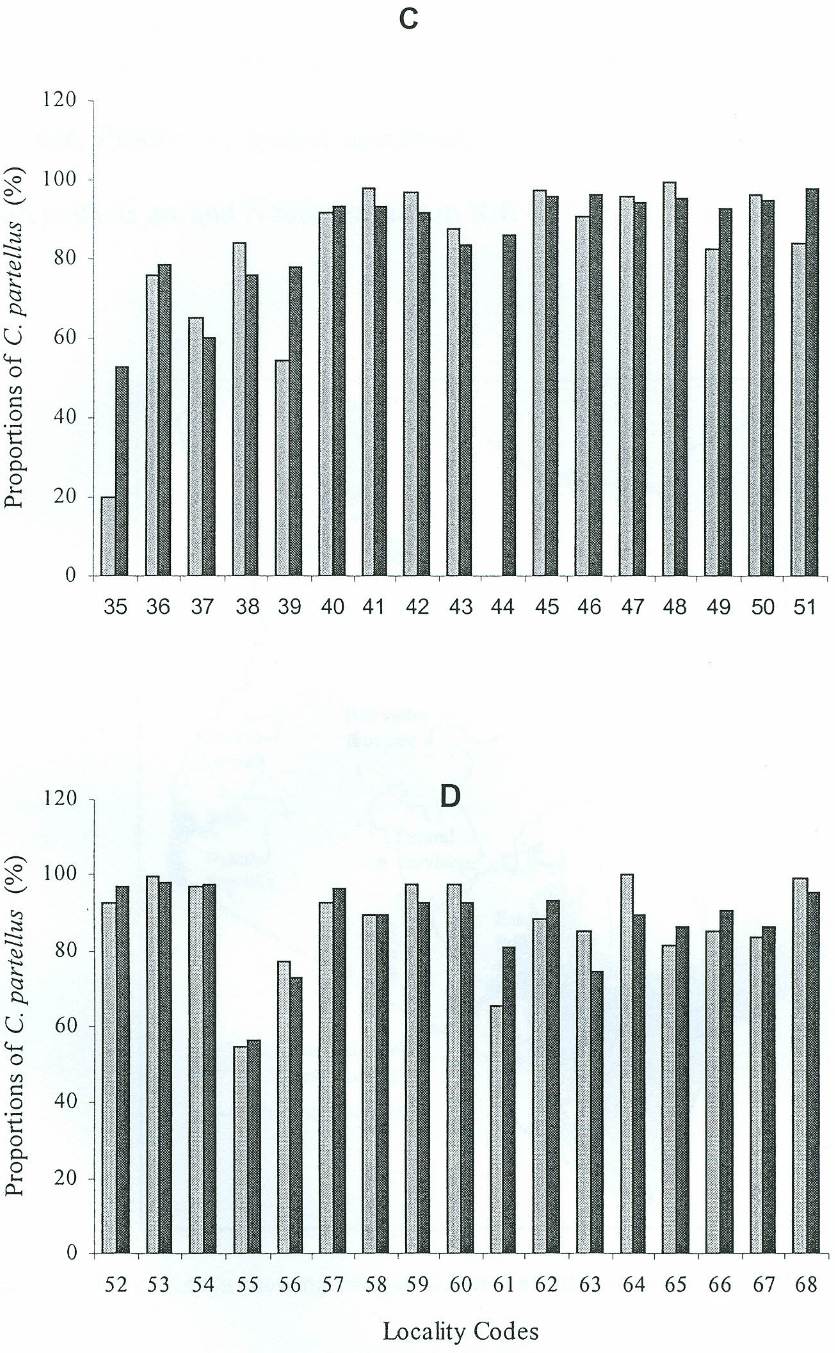
Table 11: Summary of final polynomial regression analysis on *C. partellus* proportion against significant environmental variables

Explanatory variables	Estimate	Std. error	Z value	Prob. (> Z)
Intercept	2.846e + 01	3.718e + 00	7.656	1.92e – 14***
Rainfall	2.452e - 02	3.863e - 03	6.347	2.20e – 10***
Rainfall^2	-4.822e - 06	1.204e - 06	-4.007	6.15e – 05***
Evapotranspiration	-2.335e - 02	4.335e - 03	-5.387	7.14e – 08***
Evapotranspiration^2	6.832e - 06	1.252e - 06	5.456	4.88e – 08***
Maximum temp^2	-6.309e - 03	4.627e - 04	-13.637	< 2e – 16***
Altitude	2.804e - 03	2.029e - 04	13.822	< 2e – 16***
Altitude^2	-3.546e - 06	1.103e - 07	-32.133	< 2e – 16***
Moisture index	-3.794e + 01	5.780e + 00	-6.563	5.26e – 11***
Moisture index^2	1.025e + 01	2.783e + 00	3.684	0.00229***

Degrees of freedom: 67 Total (i.e. Null); 55 Residual; Null deviance: 2364.7; Residual deviance: 1522.6; Number of Fisher scoring iterations: 5; Significance codes: 0 ***; 0.001**; 0.01*

Figure 7: Comparison of the observed and predicted proportions of *C. partellus* in different localities surveyed in the country based on the logistic polynomial regression model. Graphs are ordered in terms of elevations; **A**, > 1885; **B**, 1350 – 1884; **C**, 730 – 1349; **D**, < 730m asl; ░ Observed, ▓ predicted




C
Proportions of C. partellus (%)
120
100
80
60
40
20
0
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
D
Proportions of C. partellus (%)
120
100
80
60
40
20
0
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
Locality Codes

4.4.4. **Ecologically suitable area for the establishment of *Chilo orichalcociliellus***

Chilo orichalcociliellus was recovered in low altitude localities mainly in the Coast Province. Product of spatial interpolation was restricted along the coast strip with some small pockets around Namanga area in Rift Valley (Figs. 8).

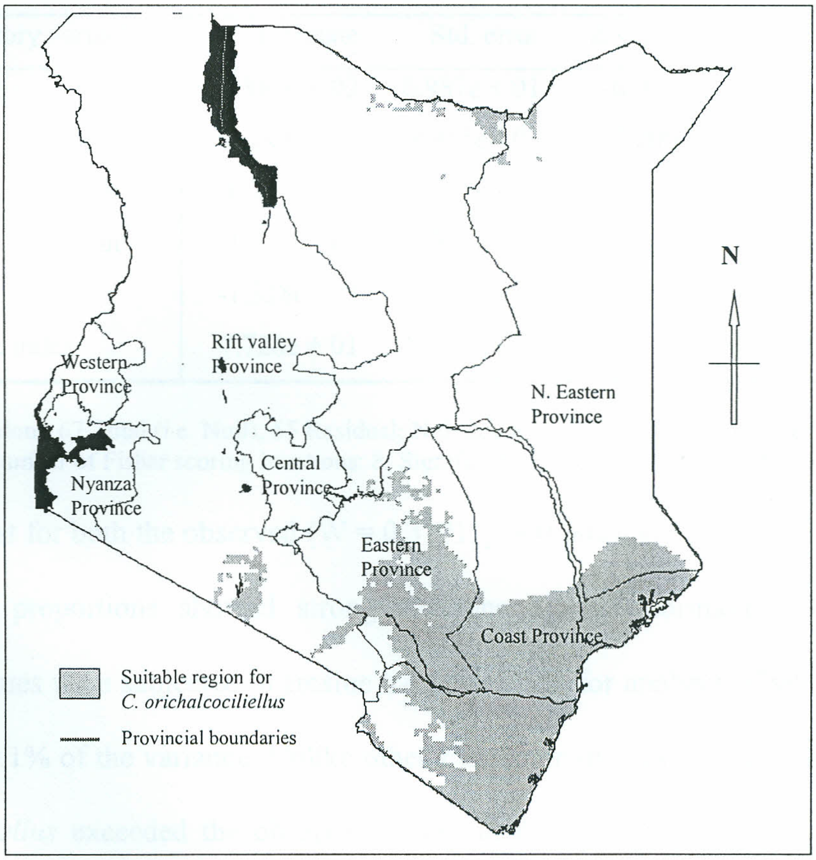


Figure 8: Map of Kenya showing interpolated area suitable for establishment of *C. orichalcociliellus*

Polynomial regression analysis showed that P, PE, PE^2 Alt and P/PE significantly ($p < 0.001$) influence establishment of *C. orichalcociliellus* of which PE and P/PE showed a positive influence (Table 12).

Logit (% *C. orichalcociliellus*) = -4.884e + 02 $_{\text{(intercept)}}$ + (-5.248e - 02* P) + (-6.101e - 01* PE) + (-1.913e - 04* PE^2) + (-1.538e – 03 * Alt) + (7.728e + 01* P/PE)

% *C. orichalcociliellus* = exp [logit (%*C. orichalcociliellus*)] / {I + exp [logit (%*C. orichalcociliellus*)]}

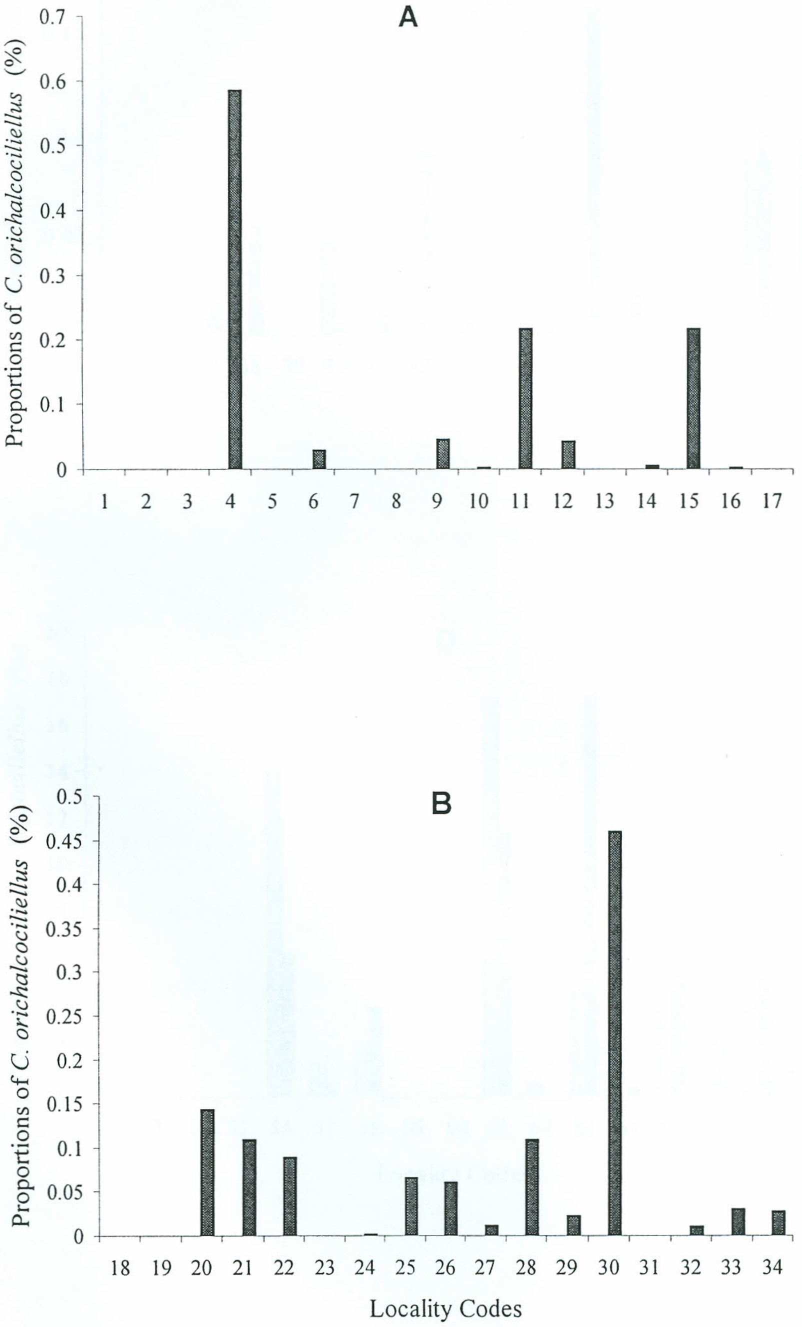
Table 12: Summary of final polynomial regression analysis on *C. orichalcociliellus* proportion against significant environmental variables

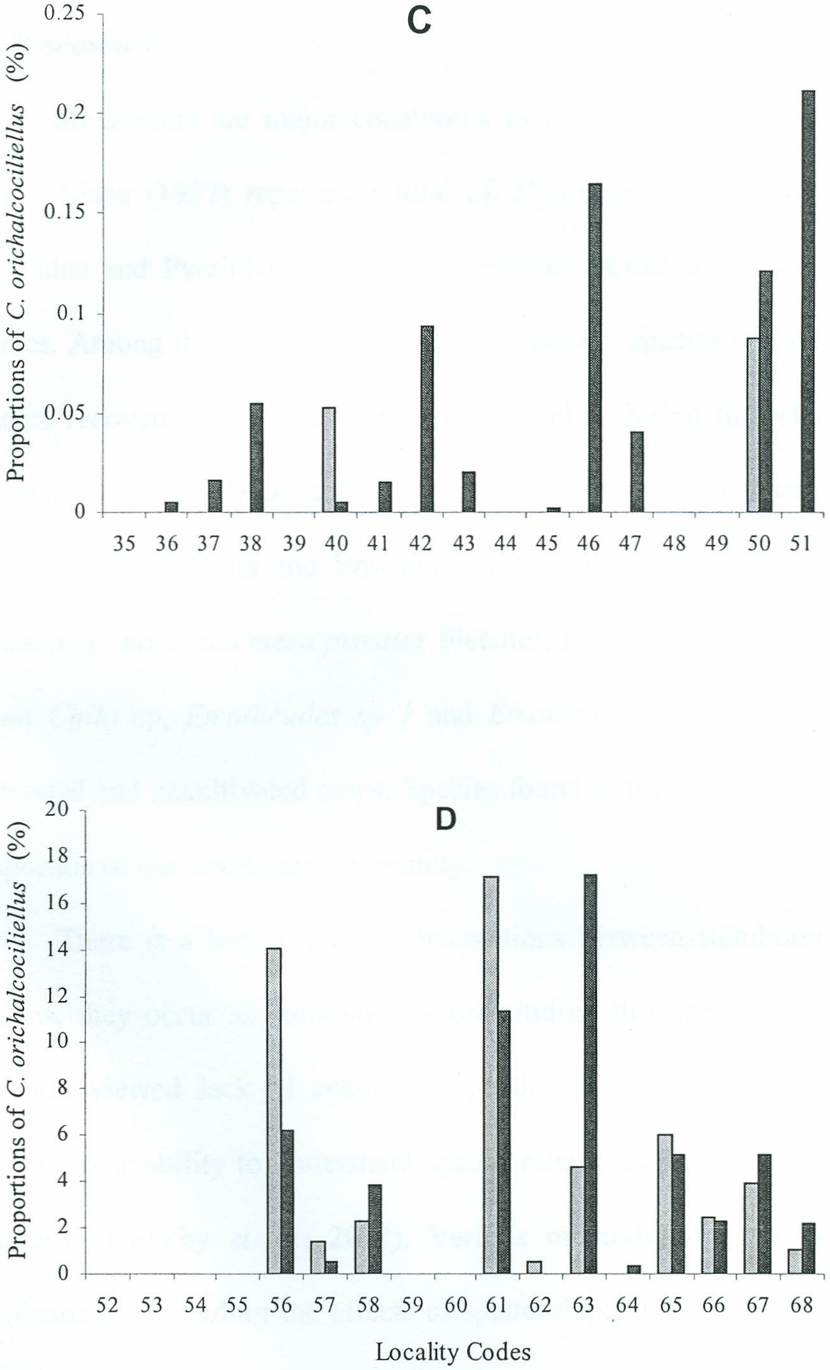
Explanatory variables	Estimate	Std. error	Z value	Prob. (> Z)
Intercept	-4.884e + 02	6.987e + 01	-6.990	2.75e – 12***
Rainfall	-5.248e - 02	8.465e - 03	-6.200	5.64e – 10***
Evapotranspiration	6.101e - 01	8.882e - 02	6.869	6.46e – 12***
Evapotranspiration^2	-1.913e - 04	2.806e - 05	-6.817	9.32e – 12***
Altitude	-1.538e - 03	2.193e - 04	-7.013	2.34e – 12***
Moisture index	7.728e + 01	1.151e + 01	6.716	1.87e – 11***

Degrees of freedom: 67 Total (i.e. Null); 55 Residual; Null deviance: 1381.39; Residual deviance: 183.49; AIC: 247.85; Number of Fisher scoring iterations: 8; Significance codes: 0 ***; 0.001**; 0.01*, 0.05`

Normality test for both the observed (W = 0.3101; p = 0.000) and predicted (W = 0.3520; p = 0.000) proportions showed strong evidence against normality. Observed and predicted values were subjected to arcsine transformation for analysis of which the model explained 79.1% of the variance. Unlike other stemborer species, fitted proportions of *C. orichalcociliellus* exceeded the observed values in most of the localities except in Mt Kenya 2 (n^0 40; 0.1%); Shimba 2 (n^0 56; 7.8%); Mombasa 4 (n^0 57; 1.0%); Shimba 1 (n^0 61; 5.7%); Garsen 2 (n^0 65; 0.9%) and Malindi 1 (n^0 66; 0.1%). Apart from Malindi 1 where there is a mixed population of *P. merkeri* and *P. maximum* in the uncultivated neighbourhood, *P maximum* and *S. arundinaceum* dominated other localities where observed proportions exceeded the fitted proportions.

Figure 9: Comparison of the observed and predicted proportions of *C.orichalcociliellus* in different localities surveyed in the country based on the logistic polynomial regression model. Graphs are ordered in terms of elevations; **A**, > 1885; **B**, 1350 – 1884; **C**, 730 – 1349; **D**, < 730m asl; ░ - Observed, ▓ predicted




C
Proportions of C. orichalcociliellus (%)
0.25
0.2
0.15
0.1
0.05
0
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51
D
Proportions of C. orichalcociliellus (%)
20
18
16
14
12
10
8
6
4
2
0
52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68
Locality Codes

CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1. Discussion

Stemborers are major constraints to maize and sorghum production in tropical Africa. Maes (1997) reported a total of 21 stemborer species in Africa belonging to Noctuidae and Pyralidae families of which *C. partellus* (Pyralidae) is the only exotic species. Among the several lepidopteran stemborer species reported in Africa, four main species recovered in maize and sorghum fields during this study included *B. fusca, S.calamistis, C. partellus* and *C. orichalcociliellus*. Other species; *S. cretica* Lederer, *Sesamia oriaula* Tams and Bowden*, S nonagriodes* Lefebvre and *Eldana saccharina, Sesamia sp. nov.*, *Sciomesa piscator* Fletcher, *Busseola phaia* Bowden, *Busseola sp* near *phaia Chilo* sp, *Ematheudes sp 1* and *Ematheudes sp 2* were also recovered in both cultivated and uncultivated crops. Species found in the cultivated crops constituted minor proportion of the stemborer community.

There is a long history of interactions between stemborer species and in many regions, they occur as communities constituting different proportions. Ecologists have typically viewed lack of spatial independence in ecological data as a problem that obscure their ability to understand spatial relationship among insects, stemborers being included (Timothy *et al.*, 2002). Various methods have therefore been devised for eliminating or avoiding the effects of spatial dependence in measuring biotic responses. However, over the last 20 years, ecologists have begun to realise that there is important biological information in the spatial dependence of biotic responses, and have become increasingly interested in examining spatial relationships directly (Timothy *et al.*, 2002).

In this study, effects of explanatory variables on individual species spatial proportions were separated irrespective of their interactions. Both logistic polynomial regression and interpolation results showed that proportions and distributions of stemborer pests (*B. fusca, S. calamistis*, *C. partellus* and *C. orichalcociliellus*) are limited by interactions among environmental parameters; altitude, maximum temperature, minimum temperature, evapotranspiration, rainfall and moisture index.

Correlation test to compare intensity of association among the above environmental parameters showed strong inverse correlation between altitude and maximum temperature, minimum temperature and evapotranspiration. This corroborates results presented by Thornthwaite (1948) on the adiabatic lapse rate (ALR), in which he reported that for every 100m rise in altitude, there would be a decrease in average temperature by about 0.5^0C. These inverse associations of environmental variables justify why altitude was excluded among the characterisation parameters during the spatial interpolation. In logistic polynomial regression where only significant variables ($p < 0.05$) were included in the final quadratic model, altitude and moisture index appeared to influence ecological suitability for some stemborer species. These two approaches finally showed more or less the same spatially suitable area for establishment of different stemborer species except for *S. calamistis* in which the model explained only 25.8% of the total ecologically suitable range.

This study showed that *B. fusca* and *C. partellus* are the most widely distributed species, and this corroborates results presented by Overholt *et al*. (2001). The exotic *C. partellus* dominated lowland areas of the Coast and Severe water stress regions, while the native *B. fusca* dominated high altitude areas mainly Moist high, and Cool & Dry high tropics. The other native members of the stemborer community *S. calamistis* and *C. orichalcociliellus* also occurred in defined ecological areas with *S. calamistis* occurring in all ACZs within 2400m asl. Nye (1960) mentioned similar altitude range (0 to 2,439m asl) as suitable for the establishment of *S. calamistis*. Though *S. calamistis* was present in all ACZs, it constituted less than 8% of the stemborer community in almost all localities surveyed except in Moist low tropics where it constituted more than 10% due to favourable interactions between altitude, rainfall, evapotranspiration, minimum temperature and moisture index. *Chilo orichalcociliellus* unlike the other native species was only present in one ACZ; Moist low tropics, where it constituted about 5% of the complex. The other species recovered including *S. nonagrioides* and *E saccharina* were recovered only in moist low tropics and severe water stress regions.

Through logistic polynomial regression, it is evident that spatial distributions of different stemborer species are restricted to defined areas by interactive influence between different environmental variables. This does not necessarily mean that stemborer species have completely different ecological requirements as their population overlap some ACZs. There are environmental ranges that accommodate different stemborer species resulting in the observed spatial overlaps across different ACZs. These overlaps, together with variation in climatic conditions during the LR and SR growing seasons explain the observed variability in infestation levels between the seasons. In such areas, stemborer species with competitive advantage dominates the complex as evident among the widely distributed stemborer species; *C. partellus* and *B. fusca*.

Chilo partellus was first reported in Africa in Malawi in 1930's (Tams, 1932) and has successfully colonised many areas often displacing the indigenous species and subsequently becoming predominant. In Kenya it was first reported in 1950's (Nye, 1960) and by late 1960's it had increased its dominance along the Coastal region an area originally colonised by *C. orichalcociliellus* and *S. calamistis* (Mathez, 1972). Later studies by Warui and Kuria (1983) in 1978–1981, showed that *C. orichalcociliellus* and *C. partellus* were equally abundant and 10 years later (1991–1992), *C. partellus* reportedly had dominated accounting for more than 80% of the stemborer complex (Overholt *et al.*, 1994).

In this study, *C. partellus* is evidently important in Dry mid-altitude, Severe water stress and Moist low tropic zones where it constituted more than 65%. Its altitudinal occurrence across different ACZs falls within the range reported by previous workers who recovered *Chilo* species from maize at altitudes from 21 and 1,677m asl (Overholt *et al.*, 1994; Zhou *et al.*, 2001). However, Ingram (1958) showed that *C. partellus* could not survive above 1,220m asl in Western Uganda or above 1,524m asl on Eastern or Northern Uganda. Ingram's conclusion was based on the annual temperature difference (≈5^0C), which he considered as a limiting factor. This might not be true as in South Africa, *C. partellus* was found to colonise an area about 1,600m asl known to have harsh winter conditions (Kfir, 1997). Similarly, in this study *C. partellus* was recovered in regions with both averagely warm and cold temperature regimes revealing its ability to adapt and colonise most ACZs. Presenting elevation as a variable on its own to explain distributional trend of *C. partellus* grossly ignores the plasticity of its biology. This is supported by polynomial regression results, which showed that the ecologically suitable range for the establishment of *C. partellus* is a product of interaction between several climatic parameters; Pmm, Pmm^2, E0, $E0^2$, $Tmax^2$, Alt, Alt^2 Pmm/E0, $Pmm/E0^2$ and not altitude alone.

Busseola fusca the other important stemborer species dominated high elevation districts of Kiambu, Kericho, Nyeri, Narok, and Uasin-Gishu, which fall under the cool and dry highland zones. The establishment of *B. fusca* in this region is favoured by low temperature regimes (both maximum and minimum). *B. fusca* was relatively abundant in the southern half of moist mid-altitude zone making up to nearly two thirds of the community, a proportion that was diluted by high proportions of *C. partellus* in the north. The establishment of *B. fusca* in these zones is influenced by interaction between Tmax $Tmax^2$., Alt. and Alt^2 variables. These variables are fewer compared to the number of variables that interact to influence suitable ecological range for distribution of *C. partellus.* This probably explains why *B. fusca* has remained static in its distribution since 1950's (Nye, 1960; Guofa *et al.*, 2002).

Spatial interpolations together with logistic polynomial regression used in this study were based on the ranges of climatic variables of the sampled localities and may therefore not be applicable in areas beyond this range. Both statistical methods (spatial interpolation and logistic polynomial regression) provided similar information on the distribution characteristic of different stemborer species. Logistic polynomial regression model explained more than 75% of the variance for *B. fusca, C. partellus* and *C. orichalcociliellus* species and it was poor for *S. calamistis* (< 25%), suggesting the need to include other independent variables to improve the estimation of ecologically suitable range.

This study does not give clear evidence on the relationship between stemborer abundance and the neighbouring wild hosts upon which the management option could be proposed. It has been argued that the presence of alternative hosts of stemborers in the uncultivated neighbourhood is detrimental in serving as stemborer reservoir during non-cropping season (Schulthess *et al.*, 1997). This argument has been fronted based on the assumption that stemborer species are polyphagous (Khan *et al.*, 1997), information that is questioned by current findings (Le Ru *pers. com*), which suggest high specialisation among stemborer species. Assessment of wild hosts was subjective considering that moths particularly *B. fusca* and *S. calamistis* fly long distances in search for suitable hosts (Kfir, 1997). Unlike the distribution of stemborers species that were limited to ecologically suitable areas, most of the species from Cyperacea, Poacea and Typhacea families presented by Khan *et al.* (1997) and Overholt *et al.* (2001) as potential wild hosts were found in most of the localities surveyed. Apart from the *Cyperus* species, *Phragmites* species, *Echinochloa pyramidalis* and *Typha domingensis* that were restricted around swampy areas, other hosts were highly varied in their abundance and existed as mixed population in most of the localities.

5.2. **Conclusions**

The outcome of this study shows that distribution of respective stemborer species are affected by different climatic variables. Interactions among climatic variables are specific to each stemborer species and this results in spatial overlaps in potentially suitable areas for establishment respective species. These findings also explain the seasonal variability in species composition in some ACZs. Unfortunately, this outcome does not support the initially presented theory of stemborer exchange between the cultivated and uncultivated compartments. There was no strong relationship between stemborer population abundance and abundance of the potential wild hosts in the uncultivated areas.

Classically, the stemborers and other arthropods that colonize the cultivated crops (maize and sorghum) been considered to come from the wild habitats, and by principle are temporary in the cultivated fields. Several studies have been carried out in West, South, and East Africa to evaluate the exchange of stemborer between the two compartments. None of these studies could show an exchange of economically important stemborer species between these habitats due to lack of methodologies that would highlight displacement mechanisms.

Some of these works suffered from insufficient taxonomic expertise that subsequently weakened their conclusions. Even with the weak conclusions, outcomes of these studies have been used as a basis for promotion of the stimulo-deterrent diversionary ("push-pull") strategy in which the stemborers are supposedly prevented (pushed) from reaching cultivated crops by repellent unsuitable inter-crops and attracted (pulled) by highly susceptible trap plants. This approach in principle ignores the general insect community structure, which comprises the phytophagous insects, their predators and parasitoids.

5.3. **Recommendations**

The development of sustainable integrated pest management is an integral part in improving cereal production in tropical Africa. This requires a thorough understanding of stemborer species diversity and population dynamics in different ecosystems. I therefore recommend;

- Study on stemborer species diversity with a focus on ecological preference and the dynamics of their populations in both cultivated and uncultivated fields as this will provide information on the stemborer species interaction with different plant species.
- Molecular markers should constitute the integral part of future stemborer studies as this will make it possible to trace gene flow and subsequent quantification of the exchange of stemborer populations between the wild and cultivated habitats

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APPENDICES

Appendix 1: Geographical positions, altitude and length of growing cycles for localities surveyed.

Name of locality	Geographical position system (GPS)		Altitude (m asl)	Length of growing cycle (months)
	Latitude	Longitude		
NYAHURURU	S 00°04.732'	E 36°34.266'	2456	6
NAROK 1	S 01°05.539'	E 36°07.027'	2367	6
MOLO	S 00°10.147'	E 35°37.643'	2332	8
ELDORET 1	N 00°34.888'	E 35°13.558'	2249	6
MERU 2	N 00°08.344'	E 37°28.296'	2228	6
KISII 1	S 00°46.216'	E 34°58.788'	2223	6
NAROK 2	S 01°00.636'	E 35°38.479'	2221	6
GATAMAIYU 1	S 01°00.057'	E 36°43.022'	2181	7
KITALE 2	N 01°11.738'	E 34°49.106'	2160	4
NYEMBENI	N 00°14.655'	E 37°54.423'	2147	8
KISUMU 1	S 00°21.681'	E 35°15.204'	1985	6
Mt KENYA 4	S 00°02.845'	E 37°03.376'	1979	6
MACHAKOS 2	S 01°29.347	E 37°16.611'	1978	6
RIFT 2	S 00°39.892'	E 36°23.154'	1930	6
KITALE 1	N 00°47.455'	E 34°49.508'	1917	6
RIFT 4	S 00°19.399'	E 36°09.034'	1888	6
NGONG 1	S 01°25.386'	E 36°42.015'	1885	4
RIFT 1	S 00°57.437'	E 36°33.474'	1884	6
LOITOKITOK 2	S 02°55.764'	E 37°30.986'	1869	4
CHERANGANI 1	N 01°20.797'	E 35°15.239'	1864	4
Mt KENYA 3	S 00°24.417'	E 37°00.813'	1774	6
RIFT 5	N 00°06.560'	E 35°54.025'	1748	3
TAITA 1	S 03°23.626'	E 38°20.339'	1729	6
NAMANGA 1	S 02°05.990'	E 36°47.662'	1698	4
Mt KENYA 1	S 00°55.793'	E 37°09.343'	1639	4
ICIPE	S 01°13.209'	E 036°53.775'	1625	4
MERU 1	S 00°23.030'	E 37°36.636'	1606	4
KISII 2	S 00°54.790'	E 34°31.740	1583	3
MOMBASA 1	S 01°50.161'	E 37°15.338'	1582	4

Appendix 1: Continues…

Name of locality	Geographical position system (GPS)		Altitude (m asl)	Length of growing cycle (months)
	Latitude	**Longitude**		
KAKAMEGA	N 00°13.516'	E 34°53.793'	1430	6
NAMANGA 2	S 02°32.054'	E 36°48.968'	1416	3
SIAYA	N 00°08.077'	E 34°19.002'	1372	3
GARISSA 1	S 01°07.185'	E 37°35.879'	1363	3
KITUI 2	S 01°19.482'	E 38°03.684'	1363	4
KERIO 1	N 00°30.812'	E 35°34.564	1333	4
LOITOKITOK 1	S 02°43.109'	E 37°31.169'	1331	3
KISUMU 4	N 00°35.775'	E 34°27.165'	1283	3
HOMA BAY	S 00°27.844'	E 34°33.112'	1250	3
TAITA 2	S 03°26.292'	E 38°21.955'	1180	4
Mt KENYA 2	S 00°43.030'	E 37°16.038'	1179	3
KITUI 1	S 01°24.114'	E 37°48'047'	1160	3
MOMBASA 2	S 02°05.453'	E 37°29.388'	1153	3
KISUMU 2	S 00°10.357'	E 34°54.804'	1143	3
RIFT 6	N 00°35.168'	E 36°00.921	1084	3
GARISSA 2	S 00°55.672'	E 38°05.676'	994	3
MOMBASA 3	S 02°21.894'	E 37°53.528'	989	3
KITUI 3	S 01°47.349'	E 38°10.234'	980	3
KYUSO	S 00°28.181'	E 38°15.876'	918	3
TAVETA	S 03°23.431'	E 37°42.935'	839	3
LODWAR 2	N 02°09.092'	E 35°29.792'	807	3
RIFT 3	S 01°45.837'	E 36°03.991'	781	3
MOMBASA 7	S 02°40.627	E 38°11.715'	739	3
GARISSA 3	S 00°48.247'	E 38°31.647'	679	3
TAITA 3	S 03°24.917'	E 38°32.075'	610	3
GARISSA 4	S 00°43.421'	E 39°00.902'	431	3
TURKANA	N 03°32.290'	E 35°51.632'	420	3
SHIMBA 2	S 04°08.843'	E 39°26.963'	417	3
MOMBASA 4	S 03°43.246'	E 39°01.474'	400	3
MOMBASA 5	S 03°52.804'	E 39°29.993'	210	3
GARISSA 5	S 00°26.468'	E 39°36.964'	164	3

Appendix 1: Continues…

Name of locality	Geographical position system (GPS)		Altitude (m asl)	Length of growing cycle
	Latitude	**Longitude**		
BURA	S 01°02.007'	E 39°53.988'	148	3
SHIMBA 1	S 04°11.463'	E 39°31.921'	111	3
MOMBASA 8	S 04°32.502'	E 39°07.831'	103	3
MOMBASA 6	S 04°19.196'	E 39°32.471'	43	3
LAMU	S 02°19.857'	E 40°38.605'	43	3
GARSEN 2	S 02°16.006'	E 40°06.812'	40	3
MALINDI 1	S 03°08.054'	E 40°08.098'	33	3
MALINDI 2	S 03°35.439'	E 039°51.814'	32	3
GARSEN 1	S 02°42.805'	E 40°08.544'	30	3

Appendix 2: Surveyed locality codes and their respective annual average climatic conditions

Locality codes (n^0)	Name of locality	Altitude (m asl)	Tmin (^{0}C)	Tmax (^{0}C)	Rainfall (mm)	Evapotranspiration (PE)	Moisture index (P/PE)
1	NYAHURURU	2456	7.72	20.60	940	1267	0.808
2	NAROK 1	2367	9.39	24.07	678	1333	0.507
3	MOLO	2332	8.05	21.04	1145	1246	0.981
4	ELDORET 1	2249	10.05	24.13	1103	1435	0.815
5	MERU 2	2228	8.03	18.94	912	1331	0.699
6	KISII 1	2223	9.74	24.33	1621	1317	1.255
7	NAROK 2	2221	9.35	24.70	841	1339	0.627
8	GATAMAIYU 1	2181	9.95	21.32	1165	1295	0.915
9	KITALE 2	2160	13.52	27.76	1603	1539	1.064
10	NYEMBENI	2147	7.72	17.91	1245	1312	0.966
11	KISUMU 1	1985	10.45	24.73	1552	1341	1.198
12	Mt KENYA 4	1979	10.05	23.01	750	1445	0.528
13	MACHAKOS 2	1978	10.00	20.51	902	1292	0.671
14	RIFT 2	1930	10.32	25.40	731	1388	0.539
15	KITALE 1	1917	12.50	26.83	1358	1557	0.909
16	RIFT 4	1888	8.88	25.19	760	1348	0.590
17	NGONG 1	1885	10.27	21.90	902	1308	0.688
18	RIFT 1	1884	9.39	22.05	1003	1296	0.789
19	LOITOKTOK 2	1869	9.59	20.40	878	1178	0.698
20	CHERANGANI 1	1864	12.65	26.94	947	1600	0.620
21	Mt KENYA 3	1774	11.26	24.05	1011	1471	0.696
22	RIFT 5	1748	11.52	27.29	1046	1484	0.709
23	TAITA 1	1729	14.08	25.36	1095	1334	0.781
24	NAMANGA 1	1698	12.95	24.56	452	1390	0.314
25	Mt KENYA 1	1639	13.28	25.20	996	1521	0.652
26	ICIPE	1625	13.16	25.15	850	1471	0.576
27	MERU 1	1606	13.63	25.30	1180	1616	0.741
28	KISII 2	1583	13.34	26.50	1266	1462	0.871
29	MOMBASA 1	1582	13.70	25.41	671	1464	0.445
30	KAKAMEGA	1430	12.73	27.10	1650	1514	1.120
31	NAMANGA 2	1416	13.69	25.25	583	1374	0.409
32	SIAYA	1372	15.68	29.05	1339	1606	0.842

Appendix 2: Continues…

Locality codes (n^0)	Name of locality	Altitude (m asl)	Tmin (^{0}C)	Tmax (^{0}C)	Rainfall (mm)	Evapotranspiration (PE)	Moisture index (P/PE)
33	GARISSA 1	1363	14.89	26.98	835	1611	0.514
34	KITUI 2	1363	15.35	27.27	882	1614	0.545
35	KERIO 1	1333	17.44	32.69	775	1775	0.447
36	LOITOKTOK 1	1331	14.45	26.46	728	1415	0.498
37	KISUMU 4	1283	14.55	28.41	1467	1607	0.934
38	HOMA BAY	1250	15.46	28.19	1143	1579	0.729
39	TAITA 2	1180	13.54	24.68	1105	1305	0.829
40	Mt KENYA 2	1179	15.20	27.92	961	1660	0.583
41	KITUI 1	1160	15.91	28.16	839	1636	0.508
42	MOMBASA 2	1153	16.18	28.70	656	1582	0.403
43	KISUMU 2	1143	15.70	28.86	1241	1604	0.780
44	RIFT 6	1084	17.37	32.95	587	1799	0.334
45	GARISSA 2	994	16.83	29.82	732	1707	0.434
46	MOMBASA 3	989	15.90	28.46	660	1536	0.418
47	KITUI 3	980	17.60	29.93	617	1655	0.371
48	KYUSO	918	18.50	30.85	545	1800	0.313
49	RIFT3	914	18.96	31.83	597	1744	0.342
50	TAVETA	839	17.16	30.48	541	1472	0.359
51	MOMBASA 7	739	16.88	29.06	682	1516	0.438
52	GARISSA 3	679	19.76	31.87	639	1794	0.361
53	TAITA 3	610	16.28	27.52	928	1405	0.651
54	GARISSA 4	431	20.68	32.56	575	1812	0.321
55	TURKANA	420	23.69	4.65	187	2254	0.083
56	SHIMBA 2	417	22.25	30.53	1133	1528	0.778
57	MOMBASA 4	400	20.13	30.49	587	1503	0.383
58	MOMBASA 5	210	21.62	30.20	951	1522	0.646
59	GARISSA 5	164	22.25	34.08	317	1854	0.173
60	BURA	148	22.27	33.75	381	1783	0.214
61	SHIMBA 1	111	21.90	30.32	1129	1514	0.783
62	MOMBASA 8	103	22.79	32.34	613	1702	0.365
63	MOMBASA 6	43	22.02	30.43	1212	1512	0.845

Appendix 2: Continues…

Locality codes (n^0)	Name of locality	Altitude (m asl)	Tmin (^{0}C)	Tmax (^{0}C)	Rainfall (mm)	Evapotranspiration (PE)	Moisture index (P/PE)
64	LAMU**	43	23.41	30.38	941	1651	0.598
65	GARSEN 2	40	21.33	30.75	995	1491	0.690
66	MALINDI 1	33	22.88	29.68	919	1604	0.601
67	MALINDI 2	32	22.71	30.11	1008	1574	0.673
68	GARSEN 1	30	22.07	29.34	783	1586	0.508

Appendix 3: Average stemborer field infestation and species composition (%) for the localities surveyed during the LR and SR growing seasons of 2003.

Locality Codes (n^0)	No. of plants checked for infestation	No. infested stems sampled	Field infestation (%)	Total larvae recovered	Stemborer species composition (%)			
					B. fusca	*S. calamistis*	*C. partellus*	*C. orichal.*
1	2058	165	8	518	83.01	16.99	0.00	0.00
2	1151	115	10	255	100.00	0.00	0.00	0.00
3	2027	304	15	478	100.00	0.00	0.00	0.00
4	713	335	47	411	100.00	0.00	0.00	0.00
5	1224	257	21	586	96.93	3.07	0.00	0.00
6	1855	223	12	282	98.94	1.06	0.00	0.00
7	1232	222	18	447	99.33	0.67	0.00	0.00
8	4872	341	7	304	97.70	2.30	0.00	0.00
9	908	291	32	606	99.50	0.17	0.33	0.00
10	2478	198	8	216	99.54	0.46	0.00	0.00
11	6258	250	4	346	95.66	0.00	4.34	0.00
12	4657	419	9	734	97.41	2.32	0.27	0.00
13	1716	360	21	714	99.02	0.98	0.00	0.00
14	7694	385	5	454	99.78	0.22	0.00	0.00
15	1400	210	15	217	98.62	0.00	1.38	0.00
16	1523	365	24	769	97.79	1.82	0.39	0.00
17	2041	490	24	1195	96.49	2.43	1.09	0.00
18	3385	575	17	941	98.72	0.32	0.96	0.00
19	1096	252	23	637	88.85	0.16	10.99	0.00
20	720	50	7	50	100.00	0.00	0.00	0.00
21	3664	769	21	808	89.36	0.74	9.90	0.00
22	706	106	15	141	100.00	0.00	0.00	0.00
23	2369	592	25	709	87.17	12.69	0.14	0.00
24	504	15	3	15	26.67	26.67	46.67	0.00
25	2520	756	30	1326	44.87	6.94	48.19	0.00
26	751	128	17	196	65.82	13.27	20.92	0.00
27	3071	491	16	570	94.74	4.74	0.53	0.00
28	1827	73	4	77	77.92	1.30	20.78	0.00
29	4544	454	10	817	48.96	19.71	31.33	0.00
30	1610	97	6	212	98.58	1.42	0.00	0.00
31	979	402	41	571	9.28	11.91	78.81	0.00

Appendix 3: Continues…

Locality Codes (n^0)	No. of plants checked for infestation	No. infested stems sampled	Field infestation (%)	Total larvae recovered	Stemborer species composition (%)			
					B. fusca	*S. calamistis*	*C. partellus*	*C. orichal.*
32	439	39	9	103	49.51	4.85	45.63	0.00
33	781	289	37	900	0.22	7.22	92.56	0.00
34	1481	237	16	319	33.23	14.73	52.04	0.00
35	72	19	27	94	78.72	1.06	20.21	0.00
36	3822	229	6	366	5.46	18.58	75.96	0.00
37	1976	336	17	745	30.47	2.68	64.97	0.00
38	507	147	29	690	14.64	1.30	84.06	0.00
39	1580	253	16	210	38.57	7.14	54.29	0.00
40	1547	588	38	1881	4.68	3.51	91.76	0.05
41	1405	155	11	393	0.51	1.78	97.71	0.00
42	2772	499	18	1448	1.24	2.00	96.75	0.00
43	1215	389	32	1158	11.05	1.38	87.56	0.00
44	189	23	12	35	62.86	37.14	0.00	0.00
45	1000	200	20	535	0.37	2.43	97.20	0.00
46	958	239	25	426	4.69	4.46	90.85	0.00
47	816	114	14	279	1.79	2.15	96.06	0.00
48	921	286	31	935	0.21	0.21	99.57	0.00
49	487	49	10	119	3.36	14.29	82.35	0.00
50	1462	570	39	1144	3.50	0.00	96.42	0.09
51	2792	475	17	578	1.73	14.01	84.26	0.00
52	1653	364	22	320	0.63	6.88	92.50	0.00
53	412	91	22	977	0.00	0.10	99.90	0.00
54	158	41	26	343	0.00	2.92	97.08	0.00
55	364	80	22	86	1.16	44.19	54.65	0.00
56	1732	381	22	592	0.00	8.95	77.03	14.02
57	1869	299	16	417	0.00	6.00	92.57	1.44
58	1649	445	27	942	0.00	8.39	89.38	2.23
59	1926	250	13	535	0.00	2.24	97.76	0.00
60	638	128	20	366	0.00	2.46	97.54	0.00
61	1034	300	29	439	0.23	17.31	65.38	17.08
62	608	304	50	764	0.00	10.99	88.48	0.52

Appendix 3: Continues…

Locality Codes (n^0)	No. of plants checked for infestation	No. infested stems sampled	Field infestation (%)	Total larvae recovered	Stemborer species composition (%)			
					B. fusca	*S. calamistis*	*C. partellus*	*C. orichal.*
63	1166	385	33	347	0.00	10.37	85.01	4.61
64	582	175	30	220	0.00	0.00	100.00	0.00
65	381	305	80	861	0.00	3.37	81.65	6.04
66	1546	417	27	908	0.00	12.33	85.24	2.42
67	1321	383	29	662	0.15	11.18	83.38	3.93
68	609	286	47	1055	0.00	0.00	98.96	1.04

Appendix 4: Comparison of proportions (%/100) of the observed and fitted values of different stemborers species in surveyed localities.

Locality	*B. fusca* (%/100)		*S. calamistis* (%/100)		*C. partellus* (%/100)		*C.orichal.* (%/100)	
codes (n^0)	Observed	Fitted	Observed	Fitted	Observed	Fitted	Observed	Fitted
1	0.83	9.91E-01	0.17	0.06	0.00	4.52E-06	0.00	2.03E-06
2	1.00	9.90E-01	0.00	0.08	0.00	1.18E-04	0.00	2.94E-07
3	1.00	9.87E-01	0.00	0.01	0.00	1.58E-05	0.00	2.20E-06
4	1.00	9.85E-01	0.00	0.04	0.00	1.48E-04	0.00	5.84E-03
5	0.97	9.88E-01	0.03	0.02	0.00	3.34E-04	0.00	3.84E-06
6	0.99	9.84E-01	0.01	0.00	0.00	4.43E-05	0.00	2.87E-04
7	0.99	9.85E-01	0.01	0.05	0.00	5.62E-04	0.00	1.37E-06
8	0.98	9.78E-01	0.02	0.03	0.00	2.24E-04	0.00	2.59E-06
9	1.00	9.93E-01	0.00	0.02	0.00	1.34E-04	0.00	4.48E-04
10	1.00	9.87E-01	0.00	0.00	0.00	3.18E-04	0.00	1.40E-05
11	0.96	9.56E-01	0.00	0.00	0.04	7.92E-04	0.00	2.16E-03
12	0.97	9.44E-01	0.02	0.03	0.00	1.75E-02	0.00	4.17E-04
13	0.99	9.48E-01	0.01	0.04	0.00	1.09E-02	0.00	1.60E-08
14	1.00	9.49E-01	0.00	0.04	0.00	1.80E-02	0.00	5.85E-05
15	0.99	9.64E-01	0.00	0.02	0.01	6.37E-03	0.00	2.16E-03
16	0.98	9.31E-01	0.02	0.02	0.00	2.31E-02	0.00	2.18E-05
17	0.96	9.04E-01	0.02	0.04	0.01	2.09E-02	0.00	4.17E-07
18	0.99	9.03E-01	0.00	0.02	0.01	1.35E-02	0.00	1.33E-06
19	0.89	9.05E-01	0.00	0.04	0.11	3.30E-02	0.00	8.22E-14
20	1.00	9.52E-01	0.00	0.07	0.00	3.16E-02	0.00	1.43E-03
21	0.89	8.36E-01	0.01	0.02	0.10	8.64E-02	0.00	1.09E-03
22	1.00	9.11E-01	0.00	0.02	0.00	7.98E-02	0.00	8.84E-04
23	0.87	8.26E-01	0.13	0.13	0.00	5.03E-02	0.00	4.26E-07
24	0.27	7.59E-01	0.27	0.05	0.47	2.69E-01	0.00	6.28E-06
25	0.45	6.94E-01	0.07	0.05	0.48	2.65E-01	0.00	6.50E-04
26	0.66	6.67E-01	0.13	0.06	0.21	2.79E-01	0.00	6.01E-04
27	0.95	6.39E-01	0.05	0.03	0.01	3.39E-01	0.00	1.11E-04
28	0.78	6.74E-01	0.01	0.02	0.21	1.42E-01	0.00	1.08E-03
29	0.49	5.98E-01	0.20	0.07	0.31	4.45E-01	0.00	2.20E-04
30	0.99	3.91E-01	0.01	0.00	0.00	2.06E-01	0.00	4.59E-03
31	0.09	2.39E-01	0.12	0.06	0.79	7.46E-01	0.00	4.20E-06
32	0.50	4.72E-01	0.05	0.03	0.46	4.34E-01	0.00	9.83E-05

Appendix 4: Continues…

Locality codes (n^0)	*B. fusca* (%/100)		*S. calamistis* (%/100)		*C. partellus* (%/100)		*C.orichal.* (%/100)	
	Observed	Fitted	Observed	Fitted	Observed	Fitted	Observed	Fitted
33	0.00	2.41E-01	0.07	0.05	0.93	8.21E-01	0.00	2.92E-04
34	0.33	2.62E-01	0.15	0.06	0.52	7.78E-01	0.00	2.67E-04
35	0.79	8.77E-01	0.01	0.14	0.20	5.30E-01	0.00	8.48E-08
36	0.05	1.59E-01	0.19	0.07	0.76	7.83E-01	0.00	5.32E-05
37	0.30	2.03E-01	0.03	0.01	0.65	6.01E-01	0.00	1.66E-04
38	0.15	1.38E-01	0.01	0.04	0.84	7.58E-01	0.00	5.47E-04
39	0.39	2.23E-02	0.07	0.03	0.54	7.82E-01	0.00	1.13E-06
40	0.05	6.01E-02	0.04	0.03	0.92	9.34E-01	0.00	5.03E-05
41	0.01	5.42E-02	0.02	0.04	0.98	9.33E-01	0.00	1.55E-04
42	0.01	6.44E-02	0.02	0.05	0.97	9.17E-01	0.00	9.31E-04
43	0.11	6.23E-02	0.01	0.02	0.88	8.38E-01	0.00	2.00E-04
44	0.63	3.49E-01	0.37	0.06	0.00	8.62E-01	0.00	6.62E-08
45	0.00	1.79E-02	0.02	0.04	0.97	9.61E-01	0.00	2.24E-05
46	0.05	8.09E-03	0.04	0.03	0.91	9.65E-01	0.00	1.65E-03
47	0.02	1.60E-02	0.02	0.06	0.96	9.44E-01	0.00	4.09E-04
48	0.00	1.28E-02	0.00	0.08	1.00	9.55E-01	0.00	1.41E-07
49	0.03	2.43E-02	0.14	0.08	0.82	9.27E-01	0.00	3.89E-06
50	0.03	3.44E-03	0.00	0.06	0.96	9.47E-01	0.00	1.21E-03
51	0.02	3.53E-04	0.14	0.03	0.84	9.81E-01	0.00	2.11E-03
52	0.01	8.92E-04	0.07	0.06	0.93	9.71E-01	0.00	9.55E-08
53	0.00	2.38E-05	0.00	0.03	1.00	9.79E-01	0.00	3.00E-04
54	0.00	2.85E-05	0.03	0.05	0.97	9.75E-01	0.00	4.36E-08
55	0.01	5.67E-02	0.44	0.27	0.55	5.63E-01	0.00	2.09E-39
56	0.00	5.07E-06	0.09	0.15	0.77	7.28E-01	0.14	6.16E-02
57	0.00	3.69E-06	0.06	0.07	0.93	9.66E-01	0.01	4.84E-03
58	0.00	1.02E-07	0.08	0.10	0.89	8.96E-01	0.02	3.86E-02
59	0.00	8.89E-07	0.02	0.03	0.98	9.27E-01	0.00	1.17E-08
60	0.00	4.84E-07	0.02	0.03	0.98	9.25E-01	0.00	4.32E-06
61	0.00	1.69E-08	0.17	0.06	0.65	8.07E-01	0.17	1.14E-01
62	0.00	6.14E-08	0.11	0.05	0.88	9.32E-01	0.01	2.71E-04
63	0.00	4.78E-09	0.10	0.04	0.85	7.47E-01	0.05	1.72E-01
64	0.00	4.63E-09	0.00	0.08	1.00	8.97E-01	0.00	3.23E-03
65	0.00	5.56E-09	0.03	0.06	0.82	8.64E-01	0.06	5.17E-02

Appendix 4: Continues…

Locality	*B. fusca* (%/100)		*S. calamistis* (%/100)		*C. partellus* (%/100)		*C.orichal.* (%/100)	
codes (n^0)	Observed	Fitted	Observed	Fitted	Observed	Fitted	Observed	Fitted
66	0.00	2.47E-09	0.12	0.08	0.85	9.07E-01	0.02	2.31E-02
67	0.00	3.13E-09	0.11	0.08	0.83	8.63E-01	0.04	5.14E-02
68	0.00	1.91E-09	0.00	0.06	0.99	9.52E-01	0.01	2.22E-02