Evaluation of the impact of *Cotesia flavipes* Cameron (Hymenoptera :Braconidae) and indeginous parasitoids on stemborer populations in southwestern Kenya.

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DECLARATIONS

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

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DEDICATION

This work is dedicated to my parents Jashon Ogedah Ogilo and Irene Aoko Ogedah who died during the course of this study.

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ABSTRACT:

Data obtained from regular field samples throughout the life cycle of *Chilo partellus* in three experimental sites; Ungoye, Mbita point and Kuja river, were used to construct life tables. Key factor analysis was conducted to determine the key mortality factors.

Results showed little variation in the total inter-generation mortality expressed as 100rx at all the three developmental stages of *C.partellus*. The mean values obtained ranged from 89.35%-98.1%, 86.1%-99.8% and 91.7%-96.03% for Kuja river, Mbita point and Ungoye respectively. The most common cause of mortality was classified as disappearance whereas parasitism contributed minimally to the *C.partellus* mortality at all the sites. Disappearance at Ungoye was the key mortality factor and was significantly correlated with the total generation mortality.

The regressions of each mortality factor on log density for each age interval was also computed for the Ungoye experimental site to test for density dependence. Mortality due to disappearance at the small instar stage (k2), mortality due to disappearance at the medium larval stage (k4) and mortality due to parasitism at the pupal stage (k7) showed positive correlations with their respective log density, indicating that mortality in these developmental stages acted in a density dependent fashion.

In the farmers fields in southwestern Kenya, *C. partellus* was found to be the predorminant stemborer species in all the seasons. *Cotesia sesamiae* was the dominant larval parasitoid, but the exotic parasitoid *C. flavipes* had a seasonal parasitism rate which ranged from 1.25% to 6.14%.

CHAPTER ONE

1. GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 General introduction.

Insect pests, particularly lepidopteran stemborers, constitute one of the major constraints to the production of sorghum and maize in the tropics. *Chilo partellus* (Swinhoe)(Pyralidae) is one of the most important gramineous stalk borers in Africa and South Asia. Early instar larvae of *C. partellus* feed on young leaves in the whorl, which can cause deadheart, while the more mature larvae bore into the stems. In severe cases of infestation, plant growth is retarded and flowering and grain production is drastically reduced. Yield losses of 18% (Warui and Kuria, 1983) and 44% (Mohyuddin & Attique, 1978) have been attributed to *C. partellus* in Kenya and Pakistan, respectively.

C. partellus is indigenous in Asia, but was accidentally introduced into Africa early this century (Overholt et al., 1994b). Chemical control of *C.partellus* is effective during a limited period when the first and second instars feed on the leaf tissues (Whitney, 1977). Insecticides, if correctly applied can result in effective control, but such control measures may not necessarily lead to increased grain yield (Coaker, 1956; Ingram, 1960).

The large numbers of wild grasses that are alternative hosts of stemborers serve as reservoirs for these stemborers during non-cropping seasons. Some authors have suggested that wild grasses should be destroyed to decrease the survival of

stemborers between seasons (Ingram, 1958). However, this strategy may not be practical because of labour constraints and concerns about the conservation of natural ecosystems. A strategy that has often been successful against the introduced pests is classical biological control whereby natural enemies of the pest or the pest's close relatives are collected and introduced into an area where the pest occurs. This method has been used most frequently against introduced pests which are presumed to have arrived in a new area without their natural enemies. The natural enemies are then sought in the area of origin of the pest. However, classical biological control can also be used against native pests that lack effective natural enemies or where natural biological control has been upset by the intensified agriculture. The major advantage of classical biological control is its sustainability. Once an exotic natural enemy is established in a new environment, it provides a permanent suppression of the pest population without further inputs.

The larval parasitoids *Cotesia flavipes, C.sesamiae, and C. chilonis,* which constitute what is known as the *Cotesia flavipes* complex, have been used in several attempts at the classical biological control of gramineous stem borer pests in many areas of the tropics. The earliest attempts at classical biological control using the *C. flavipes* complex appears to have been in 1951 when *C. sesamiae* was shipped from Kenya to Mauritius (Greathead,1971). However unconfirmed reports (Breniere et al., 1985) claimed the introduction of *C. flavipes* into Mauritius as early as 1917. *C. flavipes* gives effective control of certain stem borers in both its endemic area (Asia) as well as in areas into which it has been introduced (Betbeder-Matibet & Malinge

1967; Cock 1985). On the Indian Ocean islands of Mauritius and Reunion, *C. flavipes* established after it was apparently accidentally introduced along with it's stem borer host, *Chilo sacchariphagus* (Bojer)(Lepidoptera:Pyralidae), but the impact on host populations was not clear (Greathead, 1971; Williams, 1983; Rajabalee & Govendasamy, 1988). In Madagascar, where *C. flavipes* was introduced in 1960, parasitism of 60% of *C. sacchariphagus* larvae has been reported (Betbeder-Matibet & Malinge 1967).

Several attempts have been made to establish *C. flavipes* in Africa for the biological control of various gramineous stem borers. During the period from 1968 to 1972, *C. flavipes* was released in Uganda, Tanzania and Kenya by the Commonwealth Institute of Biological Control (CIBC) for regulation of *Chilo partellus* (CIBC 1968-1972). In South Africa, a major effort was also made to establish *C. flavipes* for the control of *C. partellus* (Skoroszewski & Van Hamburg 1987). In West Africa, *C. flavipes* was released against a complex of sugar-cane stem borers in Ghana (Scheibelreiter, 1980), and in Ivory Coast and Senegal against *Chilo zacconius* in rice (Breniere & Bordat, 1982). *C. flavipes* reportedly failed to establish in any of the areas it was released in Africa (Overholt, et al., 1994). The International Centre of Insect Physiology and Ecology (ICIPE) is currently involved in a further attempt to establish *C. flavipes* in Africa (Overholt, et al., 1994). Collections of *C. flavipes* from two regions in Pakistan, Rawalpindi (North Pakistan) and Sindh (South Pakistan), were imported into Kenya in 1991 and 1992, respectively. The material from Rawalpindi was used for laboratory experiments and field cage trials at Mbita Point field station

in southwestern Kenya in 1991 but was never intentionally released. Surveys of stem borers and their natural enemies prior to 1991 at Mbita Point resulted in no *C. flavipes* recoveries. However, surveys of stem borers in southwestern Kenya in 1994 recovered several *Cotesia sp.,* which were later verified to be *C. flavipes* (Omwega et al., 1995).

1.2 Literature Review.

1.2.1 Stemborer Distribution.

Many stemborers occur in Africa, but only a few species are economically important in maize, millet or sorghum which are the major cereal food crops in this continent (Overholt et al., 1994). Stemboring lepidopteran larvae belonging to the families Noctuidae and Pyralidae are among the most damaging pests of cereal crops throughout the African continent. They are the major pests of subsistence cereals such as maize and sorghum as well as plantation crops such as sugarcane (Polaszek & LaSalle, 1995).Two noctuid species *Busseola fusca* (Fuller) and *Sesamia calamistis* (Hampson), are widely distributed in the continent of Africa and reach damaging levels in some locations. *B.fusca* is a serious pest of maize at high elevations in East and southern Africa (Harris and Nwanze, 1992). In West Africa, *B.fusca* is abundant in the dryer savannah zone, especially in areas where sorghum is grown (Harris, 1962). *S. calamistis*, occurs throughout sub-saharan Africa but is only a serious pest in West Africa on cultivated cereals (Bosque-Perez & Mareck, 1990). *Sesamia cretica* is

found in North-eastern Africa, the middle east and in the Mediterranean areas of Europe attacking sorghum (Tams & Bowden, 1953).

The pyralids *Eldana saccharina*, and *Chilo partellus* are also widely distributed in sub-saharan Africa. *E. saccharina* is considered a major pest of maize and sugar-cane in West Africa (Scheibelreiter, 1980; Bosque-Perez & Mareck 1990). In Uganda, *E.saccharina* formerly attacked wild host plants (grasses) but has since 1970 widened its host range to include maize, sorghum and sugar-cane (Atkinson, 1979). *C. orichalcociliellus* which has been reported from the coastal region of Kenya and Madagascar (Mathez 1972; Warui & Kuria 1983) as an important pest has also changed its pest status with the advent introduction of the exotic stemborer *C. partellus* (Overholt et al., 1994b).

C. partellus is the only exotic stemborer in Africa, having been introduced from Asia early this century (Overholt et al., 1994b). This stemborer was first recorded from Malawi in 1932 (Tams, 1932). Thereafter, it was recorded in Uganda in 1953 (Ingram, 1958) and in South Africa in 1958 (Van Hamburg, 1979). It is now found in most areas (below 1500m) of the eastern and southern parts of the African continent (CAB, 1989), where it is now an important pest of sorghum and maize.

1.2.2 Life history and pest status of *Chilo partellus*

Early instar larvae of *C. partellus* feed initially by scraping in leaf whorls of growing plants, producing characteristic "window-paning" and "pin-holes". Later, the larvae tunnel into the stems and may kill the central leaves and growing point

producing "deadhearts". The larvae also bore into maize cobs and feed on the developing grains. Plants thus affected have poor growth, reduced yield and are more susceptible to wind damage and secondary infections.

Yield losses of 18% in maize due to damage caused by *C.partellus* and *C. orichalcociliellus* have been recorded in Kenya (Warui & Kuria, 1983). Seshu Reddy & Sum,(1991) also reported a maximum grain yield reduction and stalk damage in maize (cv. Katumani) due to *C. partellus* at 20 days after plant emergence, while there was an insignificant larval effect on yields in plants infested at 60 days after emergence. Jepson (1954) reported 40% to 100% infestation by *B. fusca* in Tanzania, while in Ethiopia movement of *B. fusca* larvae into the base of sorghum heads resulted in undersized heads and a grain loss of 15% (Megenasa, 1982). In Uganda a 56% loss of grain yield resulted when sorghum was infested with *C. partellus* 20 days after plant emergence (Starks, 1969), whereas in Kenya losses have ranged between 2% and 88% (Seshu Reddy, 1988).

1.2.3 Stemborer management:

Attempts to control stemborers in the past have been based either on cultural practices, such as residue management and manipulation of planting dates (Kfir, 1990;Seshu Reddy, 1985),or by the use of insecticides, carbamates in particular (Van den Berg & Van Rensburg, 1992;Van Rensburg, 1990). However, chemical control of stemborers is hindered by the feeding behaviour of the larvae. Applications are only

effective during a limited period when the first and second instars feed on the leaf tissues (Whitney, 1977).

1.2.4 Biological control:

During the last half of this century, there have been several attempts of biological control of cereal stemborers in Africa and the neighbouring Indian ocean islands (Bordat, 1983; Greathead, 1971; Overholt, 1993; Skoroszewski & Van Hamburg, 1987) whereby *C. flavipes* had been released. *C. flavipes* is a gregarious endoparasitoid that is thought to be indigenous to the Indo-Australian region where it attacks several species of pyralid and noctuid stemborers (Mohyuddin et al., 1981; Nargakatti & Nair, 1973; Beg & Inayatullah, 1980; Shami, 1987; Goraya et al., 1982). During the period from 1968 to 1972, *C. flavipes* was released in Uganda, Tanzania and Kenya by the Commonwealth Institute of Biological Control (CIBC) for the regulation of *C.partellus* (CIBC, 1968-1972). In South Africa, a serious effort was also made to establish *C. flavipes* for the control of *C. partellus* (Skoroszweski & Van Hamburg, 1987). In West Africa, *C. flavipes* was released against a complex of sugar cane stemborers in Ghana (Scheilbreiter 1980) and in Ivory Coast and Senegal against *Chilo zacconius* in rice (Breniere & Bordat, 1982). *C. flavipes* reportedly failed to establish in any of the areas where it was released in the mainland Africa (Overholt et al., 1994). On the Indian Ocean islands of Mauritius and Reunion, *C.flavipes* established after it was apparently introduced accidentally along with its

stemborer host *Chilo saccariphagus*, but the impact on host populations is not clear. (Greathead, 1971; Williams, 1983; Rajabalee & Govendasamy, 1988).

The International Centre of Insect Physiology and Ecology (ICIPE) has been involved in a further attempt to establish *C.flavipes* in Africa (Overholt et al., 1994). At the Kenyan coast, *C. flavipes* was recovered three years after it's release thus providing clear evidence that the exotic parasitoid was now established. Further investigations have shown that it has spread from the original release sites to other locations (Overholt, et. al., 1996). Surveys of stemborers after *C. flavipes* accidental release in southwestern Kenya recovered several *Cotesia* species some of which were later verified to be *C. flavipes.* Further morphological and electrophoretic studies, in conjunction with the mating compatibility of the field and laboratory populations of *C.flavipes,* have provided clear evidence that *C. flavipes* has been established in continental Africa (Omwega et al., 1995).

1.2.5 Indigenous natural enemies

A complex of native natural enemies attacking stemborers in Africa has been reported. Using serological studies in South Africa, several species of ants and spiders were shown to predate on *E. saccharina* eggs and larvae, although their impact on the pest was generally low (Leslie, 1988). In Uganda, Mohyuddin & Greathead (1970) reported that four species of ants ; *Tetramorium guineense, Phediole megacephala, Carciocondyla badonei and C. emeryi,* destroyed almost 90% of eggs and first instar larvae of *C. partellus* and *B. fusca.*

Native stemborer parasitoids in Africa include those that attack eggs, larvae, and pupae. However, these parasitoids in most cases do not seem to be able to maintain populations below economically acceptable levels (Williams, 1983; Oloo, 1989; Overholt et al., 1994b), although Oloo and Ogedah (1990) and Kfir (1992) reported that the parasitoids had expanded their host ranges to include the exotic stemborer. Conlong (1994) argued that the indigenous parasitoids may have had a greater impact on the stemborer populations in wild grass communities than in the crops. This was mainly because of the fact that stemborer's growth in wild grasses was slower than in maize (Bowden, 1976), which therefore resulted in a wider temporal window of susceptibility to stage specific parasitoids. Also wild grass communities tended to be long-lived compared with ephemeral annual crops.

1.2.6 Classical biological control

Biological control was defined as the action of natural enemies (living organisms: parasitoids, predators and pathogens) to maintain a pest population at density levels lower than that which would occur in the absence of these enemies by DeBach, (1964). Natural enemies could be utilized in three ways; (1) augmentation of species through the direct manipulation of their population, as by insectary mass production and periodic colonization, (2) conservation through the manipulation of the environment to preserve natural enemies, and, (3) importation of exotic species and their establishment in a new habitat (classical biological control). Classical biological control, the introduction and permanent establishment of exotic natural

enemies for long term pest regulation, is an accepted technique of pest suppression, and in many countries is the first choice to combat introduced pests. The underlying premise of biological control is that the populations of organisms are regulated by natural enemies, and that introduced pest species have escaped regulation because they have been separated from their coevolved natural enemies. Control is thus achieved by introducing natural enemies from the area of origin of the pest (Waage and Greathead, 1988). Recent estimates of percentage success of classical biological control vary. Braconids, have been succeseful against lepidoptera (54%) whereas ichneumonids have been proportionately more successful against Symphyta (46%) (Greathead, 1986).

In an attempt to regulate the densities of stemborers in Africa, *C. flavipes* a gregarious larval endoparasitoid of several noctuid and pyralid stemborer larvae has been imported into Kenya from Pakistan by the International Centre of Insect Physiology and Ecology (ICIPE) (Overholt et al., 1994).

Recent reports indicate that this parasitoid is now established in Kenya (Omwega et al., 1995; Overholt et.al., 1997). There is a need therefore to evaluate the role of this recently established natural enemy on stemborer populations in Kenya. Evaluating the impact of natural enemies on their hosts could be divided into two categories. The first one involves separate host populations: one population with a particular natural enemy; the other without it. When the resulting densities and mortalities in the population are compared, the differences are attributed to the natural enemy (Luck et al., 1988). Although evaluations of this type do quantify the impact of

the natural enemy in terms of the rate of mortality that is caused by an agent and the consequent overall reduction in host density, they do not provide descriptions of other sources of the mortality that act together with the natural enemy. (Bellows et al., 1992).

The second category involves the use of life tables whose main advantage is that it allows the mortality caused to the host by the agent to be quantified and also to be compared with other sources of the mortality acting on the population. It also allows the ecological role a natural enemy plays in a particular system to be determined (Bellows et al., 1992).

1.2.7 Life Tables:

A life table is a means to systematically and numerically describe mortality according to specific age groups within a population. Put in another way, it is nothing more than an account of the survival of a pest as it develops from the egg stage to the adult stage. Life tables allow the ecological role a natural enemy plays in a particular system to be quantified and to determine whether it is a source of regulation contributing to stability (Bellows et al., 1992).

The emphasis of ecological life tables concerned with animal populations is the identification and quantification of a species' population dynamics (Varley and Gradwell, 1960; Harcourt, 1969; Southwood, 1978). In addition, survivorship curves obtained from life tables can help to identify stages of an insect pest vulnerable to specific control practices (Price, 1975).

Deevay (1947) was the first researcher to adopt the life table format to the study of natural populations of animals, and Morris and Miller (1954) presented the first detailed life table for a natural population of an insect (Harcourt, 1969). Since then, life tables have been constructed for many insect populations (Price, 1975) and many workers follow the general format proposed by Harcourt (1969).

Southwood (1978) describes two basic types of life tables; age specific or horizontal life tables, and time specific or vertical life tables. These life tables describe the fate of a real cohort of individuals belonging to a single generation of a population with distinct non-overlapping generations. Age specific life tables can be analyzed by key factor analysis to identify the primary or the 'key' cause of change in population density (Varley & Gradwell, 1960). Age specific life tables are applicable to species with discrete generations and dynamic age distributions (Southwood, 1978). A time specific life table describes the fate of an imaginary cohort found by determining the age structure of a random sample of individuals from the population at a point in time. Time specific life tables are appropriate for species with overlapping generations and a stable age distribution. Analysis of time specific life tables describes changes in population density over time.

Construction of life tables requires a careful consideration of sampling intervals and procedures to reliably estimate the population density of as many life stages as possible. The total number of individuals that pass through a particular stage in each generation is determined from estimates of stage specific density (Southwood, 1978). It is sometimes possible to directly measure the total number entering a stage

(Varley et al., 1974). More often the number of individuals is determined from a series of density estimates made from successive samples of the population and analyzed by various graphical or statistical methods (Southwood, 1978).

Life table data are most useful when a sequence of life tables during a number of generations are available for the same population. Analysis of such series can reveal the major causes of population change and can identify relationships between mortality rates and the density (Knutson, 1987). A Key factor analysis, introduced by Morris (1959), uses a series of life tables to determine the mortality sources most likely responsible for the observed changes in population density. This factor is defined as the "key factor". The effect or "killing power" of a mortality factor during each stage is conveniently expressed as a k-value which is the difference between the logarithms of the population density before and after the mortality acts. Since sources of k values are assumed to act in sequence, the sum of k values equals the total generation mortality, K (Varley and Gradwell, 1960, 1968).

Thus, k value = log N1 - log N2

and total generation mortality = K = k1+k2+k3+k4+k5+...etc.

where N1 = Population density before mortality

N2 = Population density after mortality.

The graphical method of key factor analysis (Varley & Gradwell, 1960) plots the individual k-values and total K against time and over as many generations as possible. The age specific mortality (k) is visually compared to determine the k values that appear to contribute the most to variations in total mortality K. This

submortality, expressed by its k value, is considered to be the key factor (Varley & Gradwell, 1960; Southwood, 1978).

Podoler & Rogers (1975) proposed a quantitative procedure to identify the key factor for those situations where a visual examination of the plotted k values fails to clearly define a key factor. The k values are plotted on the y axis against the total mortality K on the x axis and the regression coefficient (b) is calculated. The k value having the greatest slope (b) is identified as the key factor because it contributes the most to the changes in K. In addition, the relative importance of mortalities other than the key factor can be determined by comparing the values of their regression coefficients (Podoler & Rogers, 1975).

Census data summarised in life tables can be analyzed to describe relationships between the mortality rate and population density. Varley and Gradwell (1970) described four types of interactions between mortality and density. A density dependent mortality factor kills an increasing proportion of the population as the population density on which it acts increases or there is a proportionate increase in fecundity or fertility with increasing density. An inverse-density dependent mortality kills a decreasing proportion with increasing population density or there is a proportionate increase in fecundity or fertility with increasing density. The demonstration of density-dependent mortality in naturally occurring animal populations is important as it is commonly accepted that only this type of relationship can regulate density (Varley & Gradwell, 1970).

Varley and Gradwell (1968) proposed a method of life table analysis which identifies density-dependence, inverse density-dependence, delayed density dependence and density independent mortality. The relationship between the rate of a specific mortality factor and population density is determined by regression of its k value on the logarithm of population density on which the mortality acts. The result is a straight line relationship for the individual mortality factor k described by:

$k = a + b (\text{Log } N)$ where

k = k value factor for the specific mortality

a = intercept

b = slope of the regression and

N = population density on which the mortality factor acts.

A regression coefficient of $b = 0$ indicates density independent mortality. Inverse density dependent mortality is demonstrated graphically by plotting k values against log host density and serially joining the points. An anticlockwise or spiral graph is a proof of inverse density dependence (Varley & Gradwell, 1970).

However, as Varley & Gradwell (1970) caution, the regression of k values on log density can be statistically invalid if density is computed from the percent survival. The result is that regression of y/x (dependent variable) on x (independent variable) and errors in the estimation of x (density) can themselves result in an apparent

correlation. Analysis of the relationship between the population density before (N1) and the density after (N2) the action of the mortality avoids this difficulty since N1 and N2 are estimated independently. A regression of log N2 (independent variable) on log N1 (dependent variable) which is significantly different from a slope of 1 demonstrates a density dependent relationship (Varley and Gradwell, 1968, 1970; Southwood, 1978). However, even this test may be invalid as regression analysis requires that the independent variable (log N2) be measured without error (Kidd & Jervis, 1996). Recognising that errors in insect census data are very large, Varley and Gradwell (1968) proposed a formal proof of density dependence. A regression of log N1 on log N2 and a regression of log N2 on log N1 are calculated and plotted on the same graph by reversing the x and y coordinates of one of the regressions. A third line is drawn through the mean value of x (ordinate values) and y (abscissa values) with a slope of 1. Proof of density dependence is shown when the slopes of both regression lines differ significantly from 1 and both lines lie on the same side of the third line with a slope of 1 (Varley & Gradwell, 1968, 1970; Luck, 1971; Southwood, 1978). While this procedure meets the statistical assumptions of regression analysis, the demonstration of density dependence from census data was difficult and the failure to do so in no way proved the absence (Southwood, 1978).

1.2.8 Rationale for the study

In 1991 and 1992 the International Centre of Insect Physiology and Ecology imported *Cotesia flavipes* from two areas in Pakistan, Rawalpindi (north

Pakistan) and Sindh (south Pakistan). The material from Rawalpindi was used for laboratory experiments and field cage studies in Mbita Point in southwestern Kenya but it was never intentionally released. The material from Sindh was later released in the coastal area of Kenya in 1993 (Overholt et al.,1994). However Omwega et al., 1995 reports the establishment of *C. flavipes* in Southwestern Kenya. It was therefore an opportunity to understand the impact of this exotic parasitoid on target stemborers populations.

1.2.9. Main objective

The general objective of this work was to quantify the role of *C. flavipes* and other indeginous parasitoids in the regulation of stemborer populations in southwestern Kenya.

Specific objectives:

1. To evaluate the role of *C. flavipes* and indigenous parasitoids in the regulation of stemborer populations through the construction of life tables.
2. To determine the seasonal and geographic distribution of stemborers in southwestern Kenya.

1.3 General Materials And Methods

1.3.1 Study sites

This study was conducted in southwestern Kenya in three localities during both the long (lr) and the short rainy seasons (sr) for the period 1994-1996; Mbita Point (lr 1995, sr 1995, & lr 1996); Kuja River (sr 1995, & lr 1996) and Ungoye (sr 1994, lr 1995, sr 1995, & lr 1996).

A field measuring 40m * 50m was prepared at each of the three experimental sites and planted with maize variety Katumani Composite B. The crop was planted at the recommended spacing of 75cm * 30cm and fertilizer treatment at planting time (NPK,200 Kg/ha) was used. Top dressing (CAN, 200Kg/ha) was applied about 20 days after plant emergence. Thereafter the plants were thinned to one plant per hill. All the other necessary agronomic practices were followed to ensure a good crop stand except for the application of insecticide.

The plots were stratified into nine sub plots each measuring 13m * 17m to facilitate sampling. These sub plots were separated from each other by a space measuring one metre on all sides.

CHAPTER TWO

2. ROLE OF *COTESIA FLAVIPES* AND OTHER INDIGENOUS PARASITOID ON THE STEMBORER POPULATION.

2.1 Introduction

Stemborers constitute one of the major constraints to efficient maize and sorghum production in the developing world (Ampofo, 1986). Most of the stemborers, including the noctuids *Busseola fusca* (Fuller) and *Sesamia calamistis* Hampson, and the pyralid *Chilo orichalcociliellus* Strand are native species in Africa. *Chilo partellus* is one of the major stemborer pests in Kenya (Overholt et al.,1994a). This pest was introduced into Africa in the early 1930`s (Tams, 1932) from Asia and now occurs throughout the eastern, central and southern parts of the African continent (Harris,1990).

Cotesia sesamiae, which is an indigenous larval parasitoid has not been able to maintain the pest population density at a level acceptable to the farmers (Oloo,1989; Overholt et al., 1994a). *Cotesia flavipes* which has been used succesfully in other parts of the world was introduced into Kenya from Pakistan in an attempt to reduce the severity of the stemborer problem (Overholt et al.,1994b).

Omwega et al.,(1995), have reported the establishment of *C. flavipes* in southwestern Kenya. However, the impact of *C. flavipes* on stemborer populations in this region is unknown.

Bellows et al. (1992), described two categories for evaluating the impact of natural enemies on their hosts; the first category involves separate host

populations; one population with a particular natural enemy; the other without it. When the resulting densities and mortalities in the populations are compared,the differences are attributed to the natural enemy. However, these types of evaluation do not provide descriptions of other sources of the mortality that act together with the natural enemy. The second category involves the construction and analysis of life tables for the affected populations. Here the mortality caused by an agent may be compared with other sources of the mortality acting on the population and contributions of contemporaneous factors separately quantified. Life tables also allow the ecological role a natural enemy plays in a particular system (i.e. whether it is a source of regulation contributing to the stability) to be determined.

The objective of this study was to provide information on the role of the exotic parasitoid *C. flavipes* and indigenous parasitoids on stemborer populations in southwestern Kenya.

2.2 Materials and Methods

Sampling at weekly intervals for the larval and pupal stages of the borers started soon after crop emergence and continued until harvest. During each sampling session, 20 plants were chosen at random. The sample rows and the plants within the rows were selected by using random numbers. These plants were uprooted and checked for stemborer eggs and then dissected to recover the immature stages of the borers. Both dead and live larvae and pupae were recovered. Live borers were placed individually in vials with natural diet and held

in the laboratory for possible parasitoid emergence. Dead stemborers were also held for possible parasitoid emergence. The stage of the plant, the stemborer life stage, the location of the stemborer in the plant, and the health status of the stemborer at the time of collection were all recorded during the dissections. A list of all the natural enemies encountered in the fields was compiled and population estimates plotted to provide information on their seasonal distribution.

The field samples did not yield sufficient number of eggs to account for the number of larvae recovered during samplings and therefore the egg data was not used in the life table analysis.

It was not easy to separate the various larval instars. Consequently, the data was pooled into four age categories; small (first and second instars), medium (third instar), large (fourth and fifth instars), and pupal stages.

The graphical method of Southwood and Jepson (1962) was used to calculate recruitment into various life stages. Due to the variation in different life stages and also due to other mortality factors, it was necessary to standardize population estimates that were obtained by dividing the estimated area under the curve by its developmental time obtained at 25 degrees centigrade under laboratory conditions.

Partial ecological life tables for each season were constructed for the first generation of the dominant borer according to the method described by Morris and Miller (1954) to determine the impact of *Cotesia flavipes* and indigenous parasitoids. Life tables were constructed for the first generation as this is the

generation reported by earlier workers to be the most damaging to maize and sorghum in East Africa (Whitney,1977). Moreover the first generation is more or less discrete whereas overlap occurs between generations later in the season (Stark, 1969). Mortality was partitioned into two causes; parasitism whereby the parasitoids are identified and disappearance which covers all other undetermined losses to predators, dispersal, disease or abiotic factors.

Podoler & Rogers (1975) regression method of key factor analysis was used to identify k values most closely associated with variations in generation mortality (K).

In order to detect possible density dependence, individual k values were regressed on the log 10 density upon which they acted. Where a relationship appeared to exist, a proof of density dependence test was carried out to ascertain whether density dependence was real or spurious (Southwood, 1967;Varley & Gradwell, 1968; Luck, 1971).

2.3 Results

2.3.1 Life table analysis

The recovered stemborers were *Chilo partellus, Busseola fusca, Eldana saccharina, and Sesamia calamistis. Chilo partellus* was the dominant borer in all the three study sites during all the sampling seasons (Figures 1-9).

Life tables for *C. partellus* populations in Mbita Point, Ungoye, and Kuja River for the long and short rain seasons during 1994-96 are shown in tables 1-9.

The real generation mortalities (100rx) for each age category are summarised in tables 10, 11, & 12. The lowest mean mortality occurred at the pupal stage with 0%; 1.3%; and 3.49% for Kuja River, Mbita Point and Ungoye sites, respectively. The results showed little variation in the total inter-generation mortality expressed as total 100rx at all the three sites (Tables 10-12). The mean mortality values obtained ranged from 89.35% - 98.1% ; 86.1% - 99.8% and 91.7% - 96.03% for Kuja River, Mbita Point and Ungoye sites, respectively.

2.3.2 Key factor analysis and density relationships:

The life tables which were used to derive various k values results are summarised in tables 13,14, & 15. Due to the few number of generations in Kuja River and Mbita Point, key factor analysis was not done. However, the key factor analyses for the Ungoye site was computed.

On visual examination using the Varley and Gradwell (1960) method, k4 which represented mortality due to disappearance at the medium larval stage, showed the most similar trend to change in K (total generation mortality) (Figure 16). Thus, dissapearance at the medium larval stage appeared to be the key factor causing population change. Mortalities due to parasitism at the medium larval stage (k3a and k3b) were small in all the areas ranging from 0.002 (k3a) recorded at Ungoye, 0.005, 0.05, and 0 for k3b recorded for MPFS, Ungoye and Kuja river, respectively. However, when the Podoler & Rogers (1975) method of key factor analysis was performed, k4, k2 (representing mortality due to disappearance at the

small instar stage), and k7 (representing mortality due to parasitism at the pupal stage),(Figs. 10,13 & 15) showed a positive correlation with K. However, k4 had the highest slope (b=0.674) confirming its role as the key factor. Nevertheless, none of the slopes were found to be statistically significant at P=0.05.

The regression of kx on log density for each lx interval was also computed for the Ungoye site data to test for density dependence (Figs.18-22). Mortality due to disappearance at the small instar stage (k2), mortality due to disappearance at the medium larval stage (k4) and mortality due to parasitism at the pupal stage (k7) showed positive correlations with their respective log densities; indicating that mortality in these stages was acting in a density dependent fashion.

2.4 Discussion and Conclusion

The partial ecological life tables which have been presented clearly indicate that the highest mean generational mortality of *C. partellus* occurred in the medium larval stage; 44.9%, 65.5% and 47.7% for Kuja river, Mbita Point, and Ungoye sites, respectively. This mortality was attributed to "disappearance" which represented mortality due to predation, disease, emigration and other unknown biotic and abiotic factors.

The real total generation mortality ranged from 89.35%-98.1%; 86.1%-99.8% and 91.7%-96.03% for Kuja river, Mbita Point, and Ungoye sites, respectively, suggesting that from the initial cohort, only a few *C. partellus* survived to adult stage under field conditions.

Using the Varley and Gradwell (1960) method of key factor analysis, k4 which represented mortality due to disappearance at the medium larval stage showed a more similar trend of change to K (total generation mortality). In other words variations in k4 between generations closely followed variations in the overall mortality (K) indicating that k4 was the key factor. It should be emphasised that identification of a key factor does not necessarily point to the factor or factors that may regulate the population density (DeBach et al., 1976; Southwood, 1967). Furthermore, it does not identify which factors were primarily responsible for maintaining the characteristic density of the population or what the density would be if a particular factor was removed. k3a and k3b, which represented mortality at the medium larval stage by *C. flavipes* and *C. sesamiae*, respectively, are minimal in all the areas indicating that the larval parasitoids contributed minimal mortality to *C. partellus* populations in these areas; thus they do not appear to be important mortality factors of *C. partellus* in southwestern Kenya. However, this could change with time. In Madagascar where *C. flavipes* was released against *C. saccariphagus* in sugar cane, maximum levels of parasitism of 60% were not reached until six years after release (Betbeder-Matibet & Malinge, 1967).There is a possibility of this occurring in this region. However, the impact of natural enemies is not necessarily related to their status as key factors. Many natural enemies do not appear as key factors in life tables of their host populations (Bellows et al., 1992). Cock (1986) argues that since any attack by parasitoids usually leads to the death of the host, and not normally easy to count directly, estimation of parasitised hosts

may be lower than those attacked, resulting in an underestimation of the effect of parastism in population regulation. Thus, the result on the impact of parasitism in this region may be an underestimation of the role of these mortality agents.

The Podoler and Rogers (1975) method of key factor analysis was also performed to further confirm the key mortality factor. Mortality due to disappearance at the medium and small larval instar stages (k4 and k2 respectively) and mortality due to parasitism at the pupal stage (k7) showed a positive correlation with K. However k4, had the highest slope (b=0.674) confirming its role as the key factor.Nevertheless none of the slopes were found to be statistically significant. Since k values and K were not statistically independent of each other, no conclusions could be drawn from the level of significance of such regressions.

An important ingredient in the analysis of the impact of various mortality factors on natural populations was to determine which, if any, of them acted in a density dependent manner and thus contributed to the stability of the population. Density dependence was ascertained by plotting k values on log density for each age interval (Southwood,1978). On the basis that each k value was a measure of proportional mortality, positive relationships for any of these plots would indicate that mortality was acting in a density dependent fashion (Kidd & Jervis, 1996). The slope of the line, the regression coefficient, is determined and this will give a measure of how the factor acts. The closer the regression coefficient is to 1.0, the greater the stabilizing effect of the regulatory factor (Southwood, 1978).

Mortality due to disappearance at the small instar stage (k2), at the medium stage (k4), and parasitism at the pupal stage (k7) showed a positive correlation with their respective log density indicating that mortality in these stages was acting in a density dependent fashion. Nevertheless k4 with a slope of 0.529 showed a greater stabilizing effect than the rest. However none of the regressions were found to be statistically significant.

Table 1. PARTIAL ECOLOGICAL LIFE TABLE FOR THE FIRST GENERATION OF *CHILO PARTELLUS* ON MAIZE CROP AT KUJA DURING THE SR`95

x	lx	dxF	dx	100qx	100rx
Small larvae	47	Parasitism	0	0	0
		Disappearance	23	48.9	48.9
		Total	23	48.9	48.9
Medium larvae	24	Parasitism	0	0	0
		Disappearance	17	70.8	36.2
		Total	17	70.8	36.2
Large larvae	7	Parasitism	0	0	0
		Disappearance	2	28.6	4.25
		Total	2	28.6	4.25
Pupae	5	Parasitism	0	0	0
		Disappearance			

lx - number surviving to age x

dx - number dying in age x

dxF - Cause of mortality

100qx - mortality represented as a percentage of the original cohort (real mortality)

100rx - mortality represented as a percentage of the stage it is acting on. (apparent mortality.

Table 2. **PARTIAL ECOLOGICAL LIFE TABLE FOR THE FIRST GENERATION OF *CHILO PARTELLUS* ON MAIZE CROP AT KUJA RIVER DURING THE LONG RAINS 1996:**

x	lx	dxF	dx	100qx	100rx
Small larvae	117	Parasitism	0	0	0
		Disappearance	50	42.7	42.7
		Total	50	42.7	42.7
Medium larvae	67	Cotesia flavipes	1	1.49	0.85
		Cotesia sesamiae	2	2.98	1.7
		Disappearance	62	92.5	52.9
		Total	63	94.0	53.7
Large larvae	4	Parasitism	0	0	0
		Disappearance	2	50	1.7
		Total	2	50	1.7
Pupae	2	Parasitism	0	0	0
		Disappearance			
		Total			

Table 3. PARTIAL ECOLOGICAL LIFE TABLE FOR THE FIRST GENERATION OF *CHILO PARTELLUS* ON MAIZE CROP AT MPFS DURING THE LR `95

x	lx	dxF	dx	100qx	100rx
Small larvae	366	Parasitism	0	0	0
		Disappearance	36	9.83	9.83
		Total	36	9.83	9.83
Medium larvae	330	C. sesamiae	4	1.20	1.09
		Disappearance	271	82.1	74.0
		Total	275	83.3	75.1
Large larvae	55	Parasitism	0	0	0
		Disappearance	5	9.09	1.36
		Total	31	9.09	1.36
Pupae	50	Dentichasmius	9	18.0	2.45
		Pediobius	2	4.0	0.45
		Disappearance	0	0	0
		Total	11	18.0	2.80

Table 4. **PARTIAL ECOLOGICAL LIFE TABLE FOR THE FIRST GENERATION OF *CHILO PARTELLUS* ON MAIZE CROP AT MPFS DURING THE SR`95**

x	lx	dxF	dx	100qx	100rx
Small larvae	442	Parasitism	0	0	0
		Disappearance	83	18.7	18.7
		Total	83	18.7	18.7
Medium larvae	359	Cotesia sesamiae	3	0.83	0.7
		Disappearance	326	90.8	73.8
		Total	329	91.6	74.4
Large larvae	30	Parasitism	0	0	0
		Disappearance	25	83.3	6.78
		Total	25	83.3	6.78
Pupae	5	Parasitism	0	0	0
		Disappearance			
		Total			

Table 5. PARTIAL ECOLOGICAL LIFE TABLE FOR THE FIRST GENERATION OF*CHILO PARTELLUS* ON MAIZE CROP AT MPFS DURING THE LR OF `96

x	lx	dxF	dx	100qx	100rx
Small larvae	102	Parasitism	0	0	0
		Disappearance	29	28.4	28.4
		Total	29	28.4	28.4
Medium larvae	73	Parasitism	0	0	0
		Disappearance	48	65.8	47.0
		Total	48	65.8	47.0
Large larvae	25	Parasitism	0	0	0
		Disappearance	0	40.0	9.8
		Total	10	40.0	9.8
Pupae	10	*P. furvus*	1	6.6	0.9
		Disappearance	0	0	0
		Total	1	6.6	0.9

Table 6. PARTIAL ECOLOGICAL LIFE TABLE FOR THE FIRST GENERATION OF *CHILO PARTELLUS* ON MAIZE CROP AT UNGOYE DURING THE SR OF `94

x	lx	dxF	dx	100qx	100rx
Small larvae	242	Parasitism	0	0	0
		Disappearance	65	26.8	26.8
		Total	65	26.8	26.8
Medium larvae	177	*C. flavipes*	1	0.56	0.4
		C. sesamiae	22	12.4	9.0
		Disappearance	118	66.6	48.8
		Total	141	79.6	58.3
Large larvae	36	Parasitism	0	0	0
		Disappearance	13	36.1	5.37
		Total	13	36.1	36.1
Pupae	23	Parasitism	3	13.04	1.23
		Disappearance	0	0	0
		Total	3	13.04	1.23

Table 7. PARTIAL ECOLOGICAL LIFE TABLE FOR THE FIRST GENERATION OF *CHILO PARTELLUS* ON MAIZE CROP AT UNGOYE DURING THE LR `95

x	lx	dxF	dx	100qx	100rx
Small larvae	914	Parasitism	0	0	0
		Disappearance	428	46.8	46.8
		Total	428	46.8	46.8
Medium larvae	486	*C. flavipes*	1	0.20	0.1
		C. sesamiae	4	0.82	0.4
		Disappearance	399	82.0	43.7
		Total	404	83.2	44.2
Large larvae	82	Parasitism	0	0	0
		Disappearance	31	37.8	3.39
		Total	31	37.8	3.39
Pupae	51	Parasitism	15	29.4	1.64
		Disappearance	0	0	0
		Total	15	29.4	1.64

Table 8. PARTIAL ECOLOGICAL LIFE TABLE FOR THE FIRST GENERATION OF *CHILO PARTELLUS* ON MAIZE CROP AT UNGOYE DURING THE SR`95

x	lx	dxF	dx	100qx	100rx
Small larvae	135	Parasitism	0	0	0
		Disappearance	5	3.7	3.7
		Total	5	3.7	3.7
Medium larvae	130	*Cotesia flavipes*	1	0.7	0.74
		Cotesia sesamiae	29	22.3	21.48
		Disappearance	37	28.5	27.4
		Total	67	51.5	49.6
Large larvae	63	Parasitism	0	0	0
		Disappearance	40	63.4	29.6
		Total	40	63.4	29.6
Pupae	23	Parasitism	14	60.8	10.3
		Disappearance	0	0	0
		Total	14	60.8	10.3

Table 9. PARTIAL ECOLOGICAL LIFE TABLE FOR THE FIRST GENERATION *CHILO PARTELLUS* ON MAIZE CROP AT UNGOYE DURING THE LR OF`96

x	lx	dxF	dx	100qx	100rx
Small larvae	126	Parasitism	0	0	0
		Disappearance	48	38.0	38.0
		Total	48	38.0	38.0
Medium larvae	78	Parasitism	0	0	0
		Disappearance	49	62.8	38.8
		Total	49	62.8	38.8
Large larvae	29	Parasitism	0	0	0
		Disappearance	19	65.5	15.07
		Total	19	65.5	15.07
Pupae	10	*P. furvus*	1	10.0	0.79
		Disappearance	0	0	0
		Total	1	10.0	0.79

Table 10 **REAL GENERATION MORTALITY (100rx) OF *CHILO PARTELLUS* AT KUJA RIVER**

	Generations		
Stage	1	2	Mean S.E
Small larvae	42.7	48.9	45.8 ± 1.03
Medium larva	53.7	36.2	44.9 ± 4.3
Large larva	1.7	4.25	2.9 ± 0.43
Pupa	0	0	0
TOTAL	98.1	89.35	93.6

Table 11. REAL GENERATION MORTALITY (100rx) OF *CHILO PARTELLUS* AT MPFS

	Generations			
Stage	1	2	3	Mean S.E
Small larvae	9.83	18.7	28.4	18.9 ± 2.52
Medium larva	75.1	74.4	47.0	65.5 ± 4.36
Large larva	1.36	6.78	9.8	5.98 ± 0.57
Pupa	3.0	0	0.9	1.3 ± 0.36
TOTAL	89.3	99.8	86.1	91.7

Table 12. **REAL GENERATION MORTALITY (100rx) OF *CHILO PARTELLUS* AT UNGOYE.**

Stage	Generations 1	2	3	4	Mean	S.E
Small larvae	26.8	46.8	3.7	38.0	28.8 ±	4.0
Medium larva	58.3	44.2	49.6	38.8	47.7 ±	1.8
Large larva	5.3	3.39	29.6	15.1	13.3 ±	2.7
Pupa	1.23	1.64	10.3	0.79	3.49 ±	0.9
TOTAL	91.7	96.03	93.2	93.49	93.3	

Generation 1, 1994 Short rain season
Generation 2, 1995 Long rain season
Generation 3, 1995 Short rain season
Generation 4, 1996 Long rain season.

Table 13. Summary of *k*-values obtained from partial mortality budgets of *Chilo partellus* for two generations studied at Kuja river, 1995-1996.

Life stage		Mortality factor	Generations 1	2
Small instar	k1	Parastism	0	0
	k2	Disappearance*	0.29	0.24
Medium	k3b	*C. sesamiae*	0	0.006
	k4	Disappearance	0.54	1.13
Large	k5	Parasitism	0	0
	k6	Disappearance	0.15	0.30
Pupae	k7	Parasitism	0	0
	k8	Disappearance	0	0
Total (K)			0.98	1.676

Season 1, 1995 Short rain season.
Season 2, 1996 Long rain season.
*Disappearance includes losses due to predation, emigration and all other unknown causes.

Table 14. Summary of *k*-values obtained from partial mortality budgets of *Chilo partellus* for three generations studied at MPFS,1995-1996.

Life stage		Mortality factor	Generations 1	2	3
Small instar	k1	Parastism	0	0	0
	k2	Disappearance*	0.04	0.09	0.145
Medium	k3b	*C. sesamiae*	0.005	0.007	0
	k4	Disappearance	0.747	1.036	0.465
Large	k5	Parasitism	0	0	0
	k6	Disappearance	0.04	0.778	0.222
Pupae	k7	*D.busseolae*	0.086	0	0.045
	k7	*P.furvus*	0.017	0	0
	K8	Disappearance	0	0	0
Total (K)			0.935	1.911	0.877

Season 1, 1994 Short rain season.
Season 2, 1995 Long rain season.
Season 3, 1995 Short rain season.
Season 4, 1996 Long rain season.
*Disappearance includes losses due to predation, emigration and all other unknown causes.

Table 15. Summary of *k*-values obtained from partial mortality budgets of *Chilo partellus* for four generations studied at Ungoye, 1994-1996.

Life stage		Mortality factor	Generations 1	2	3	4
Small instar	k1	Parasitism	0	0	0	0
	k2	Disappearance*	0.135	0.274	0.016	0.208
Medium	k3a	*C.flavipes*	0.002	0.00089	0.003	0
	k3b	*C. sesamiae*	0.05	0.003	0.109	0
	k4	Disappearance	0.477	0.747	0.145	0.429
Large	k5	Parasitism	0	0	0	0
	k6	Disappearance	0.195	0.206	0.437	0.462
Pupae	k7	*P.furvus*	0.06	0.151	0.407	0.045
	k8	Disappearance	0	0	0	0
Total (K)			0.919	1.382	1.117	1.144

Season 1, 1994 Short rain season.
Season 2, 1995 Long rain season.
Season 3, 1995 Short rain season.
Season 4, 1996 Long rain season.
*Disappearance includes losses due to predation, emigration and all other unknown causes.

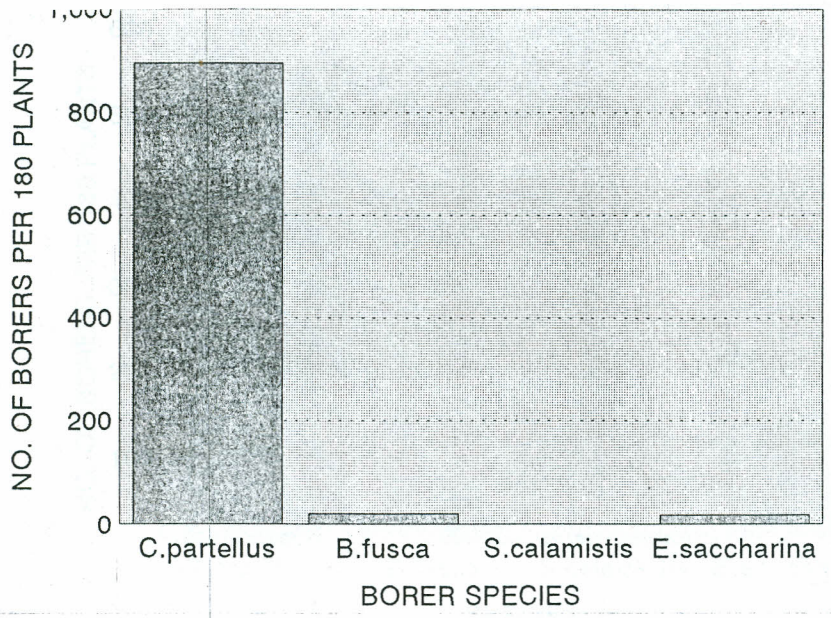


Figure 1. Species abundance at Ungoye during the long rains 1995

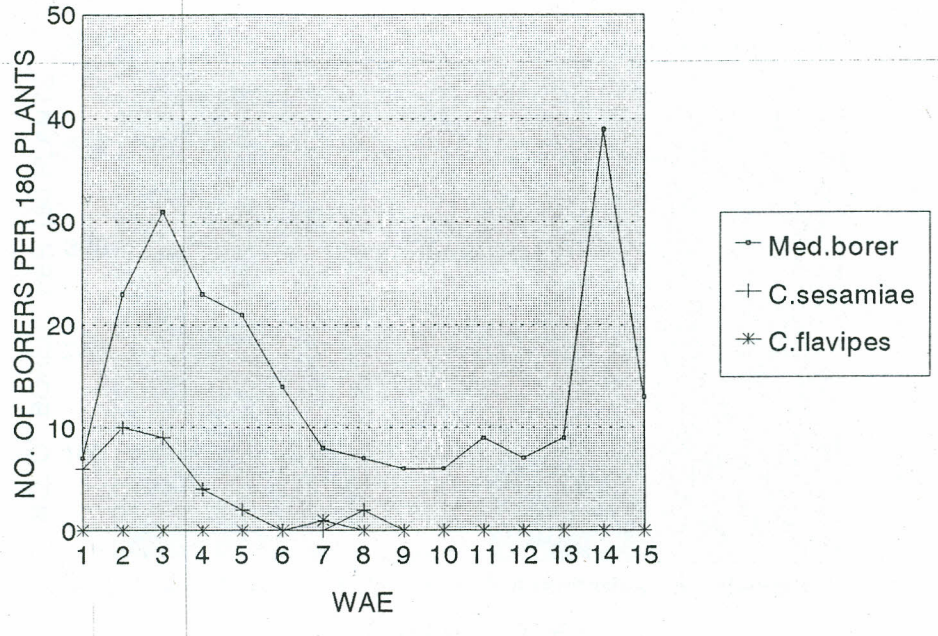


Figure 2. Incidence of medium and large stem borers and Cotesia sp. in Ungoye during short rains 1994.

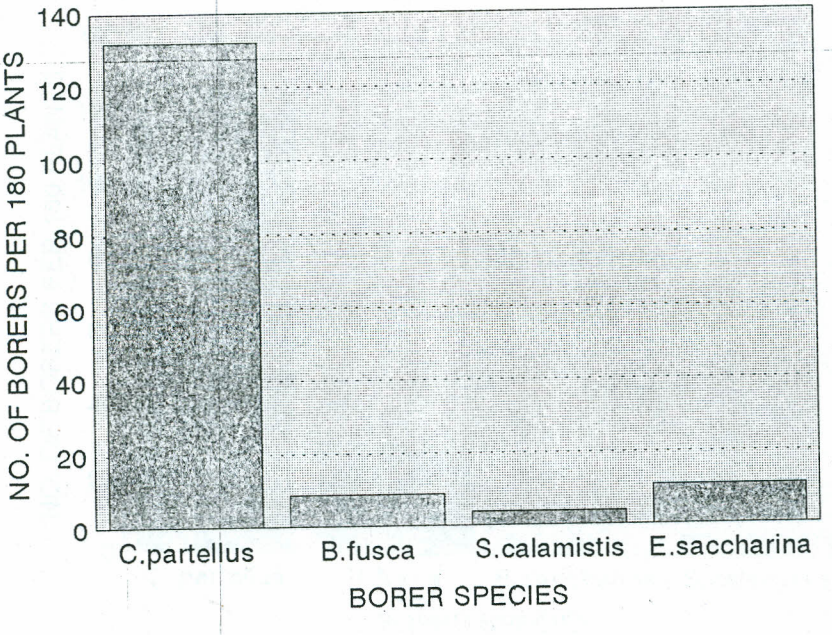


Figure 3. Species abundance in MPFS during the long rains 1996.

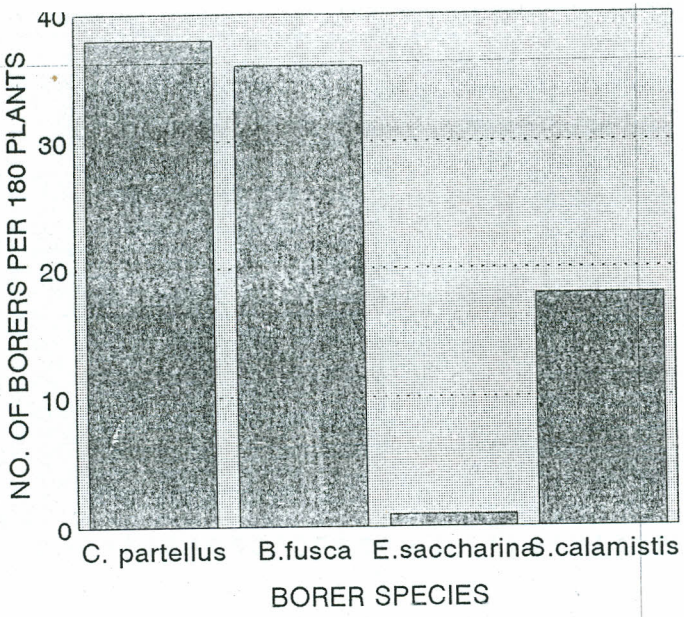


Figure 7. Species abundance in Kuja river during the short rains 1995.

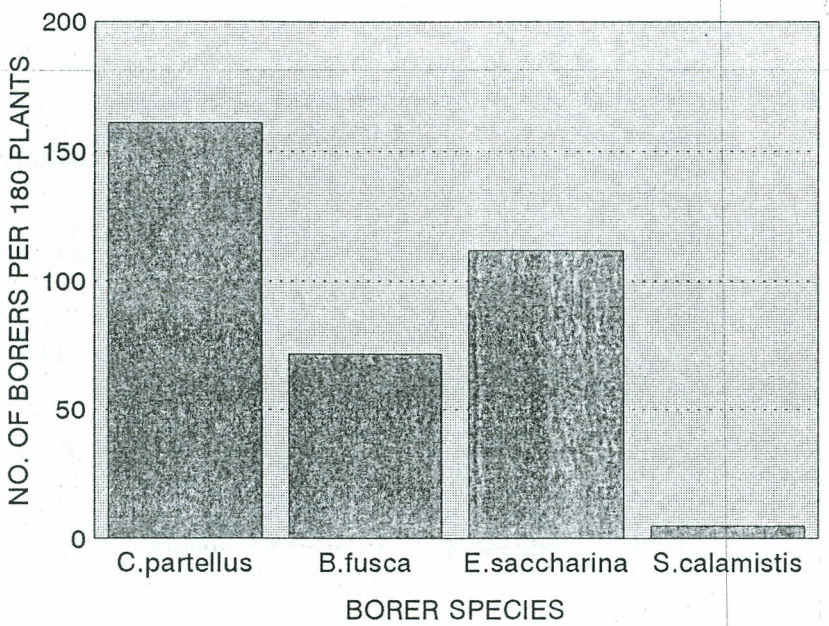


Figure 8. Species abundance in Ungoye during the long rains 1996

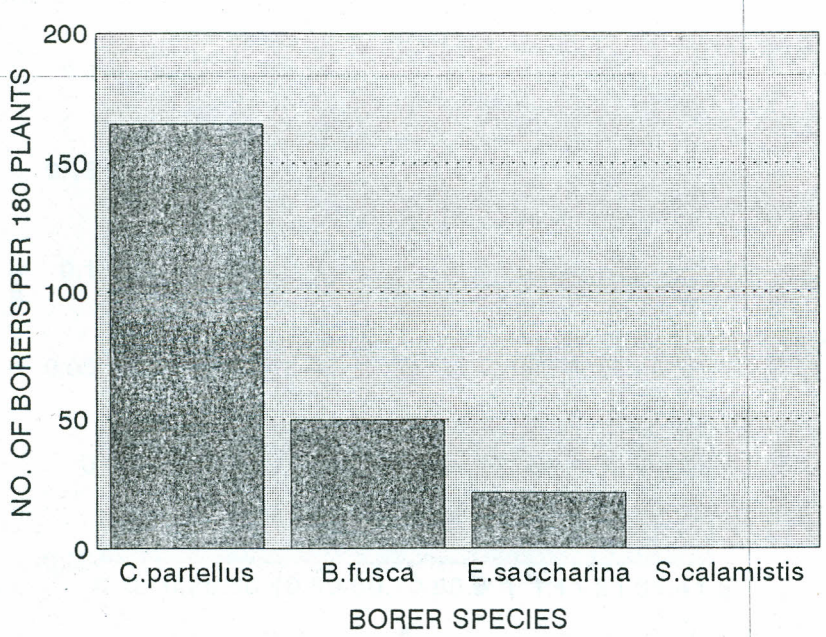


Figure 9. Species abundance in Ungoye during the short rains 1995.

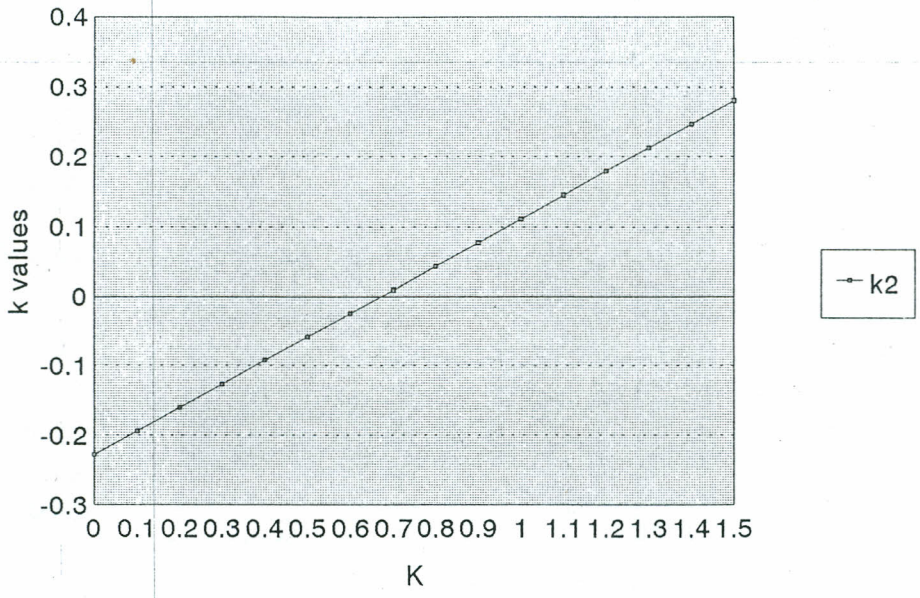


Figure 10. Key factor analysis for Ungoye (k2)
y = - 0.228 + 0.339X
r = 0.338

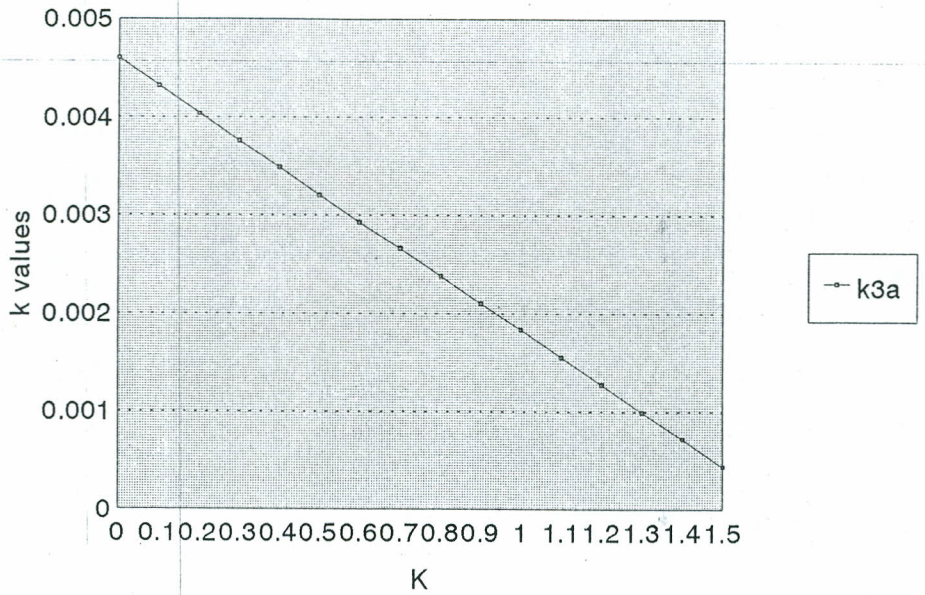


Figure 11. Key factor analysis method Ungoye (k3a)
y = 0.0046 - 0.002X
r = 0.161

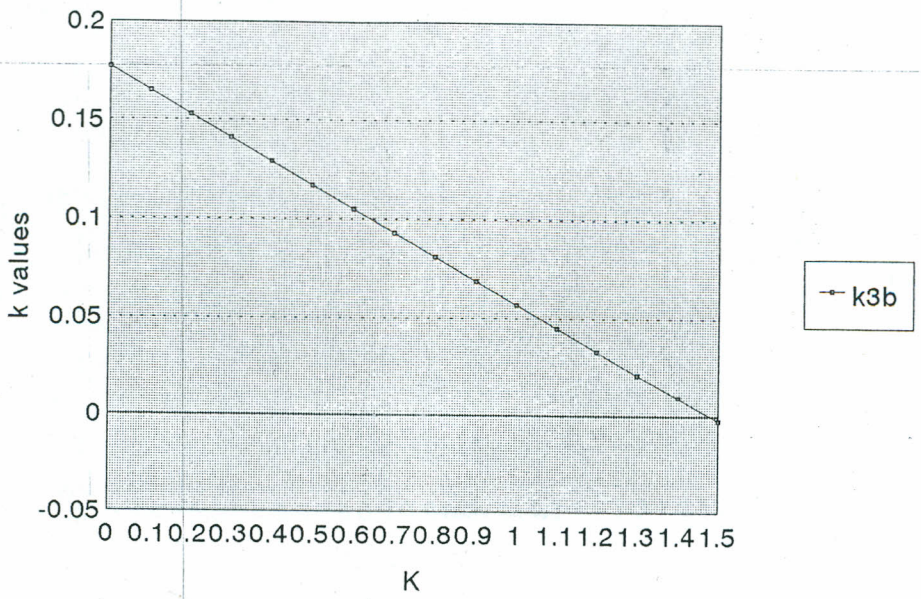


Figure 12. Key factor analysis Ungoye (k3b)
y = 0.1769 - 0.119X
r = 0.197

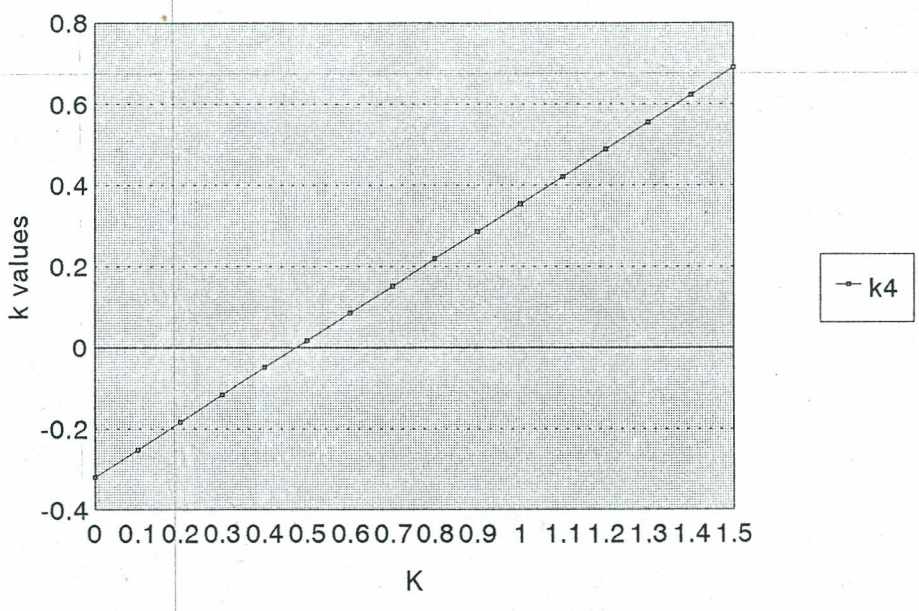


Figure 13. Key factor analysis Ungoye (k4)
y = - 0.320 + 0.674X
r = 0.269

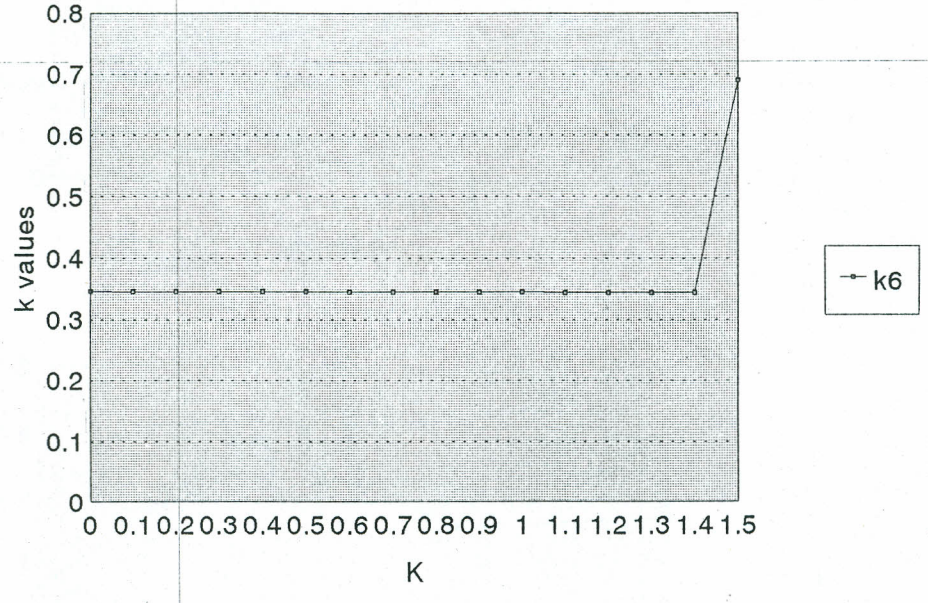


Figure 14. Key factor analysis Ungoye (k6)
y = 0.347 - 0.019X
r = 0.0006

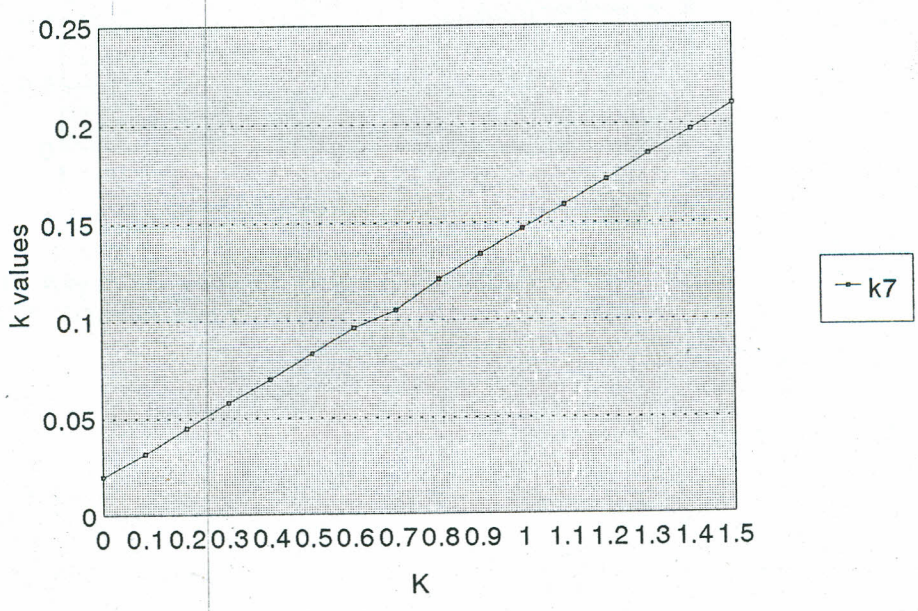
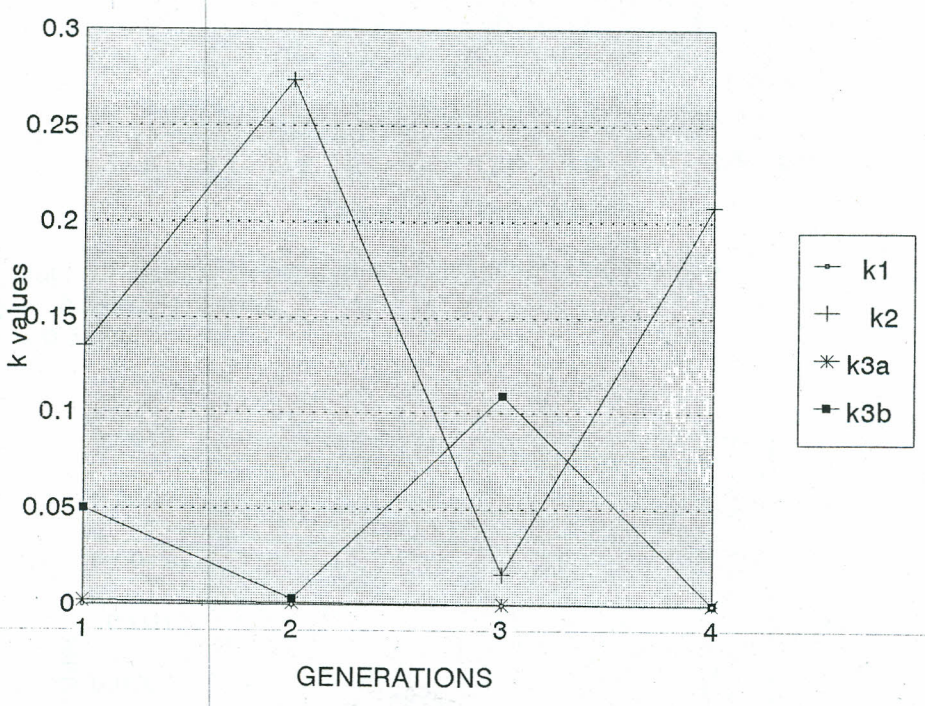


Figure 15. Key factor analysis Ungoye (k7)
y = 0.02 + 0.127X
r = 0.02



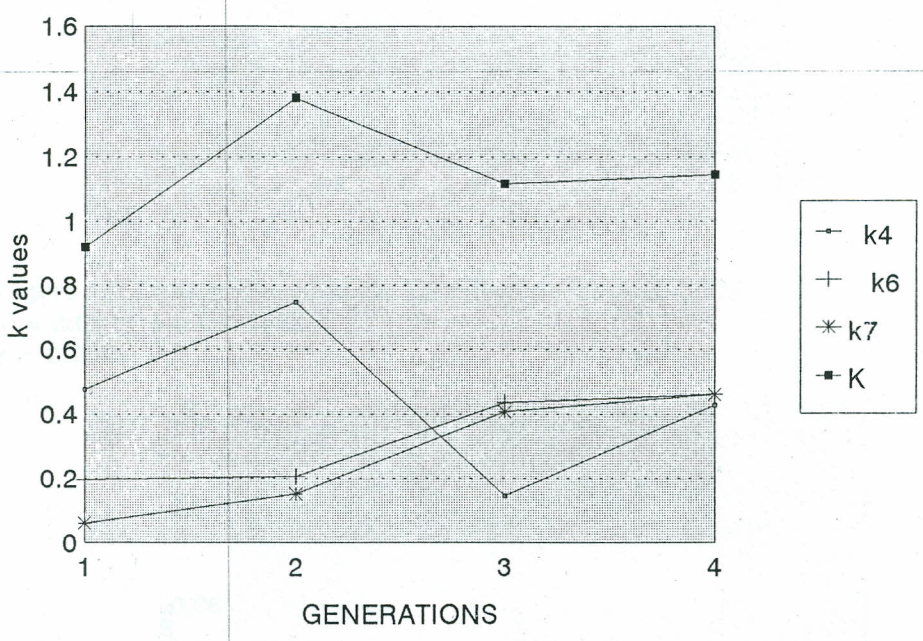


Figure 16. Key factor analysis Ungoye 1994-1995
Varley and Gradwell method(1960)

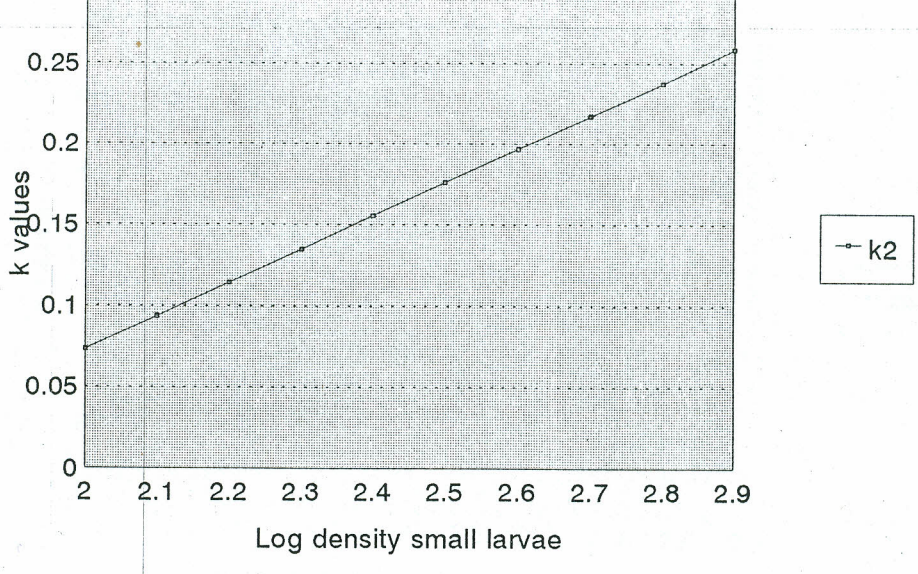


Figure 17. Density dependence identification Ungoye (k2)
y = -0.33895 + 0.206X
r = 0.517

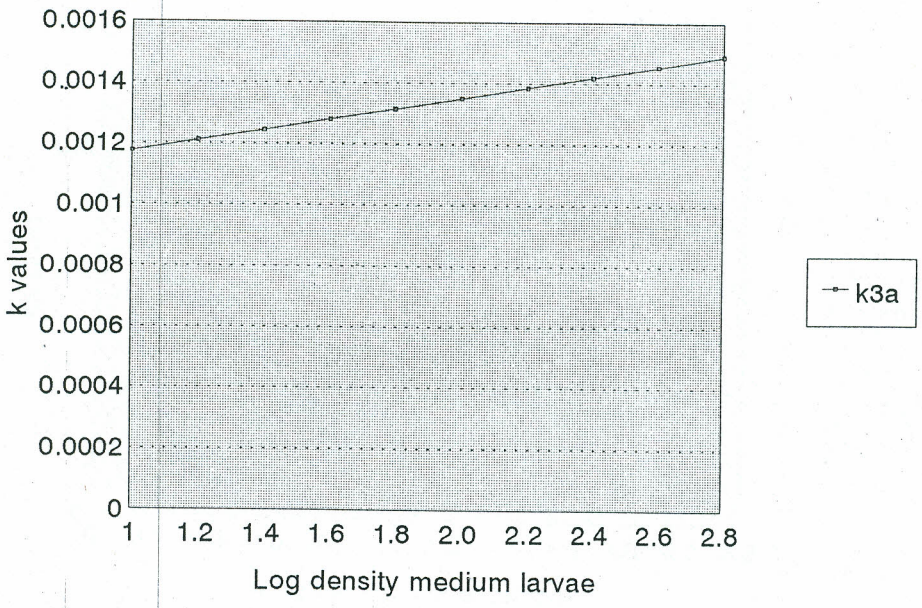


Figure 18. Density dependence identification Ungoye (k3a)
y = 0.0010 + 0.000175X
r = 0.002

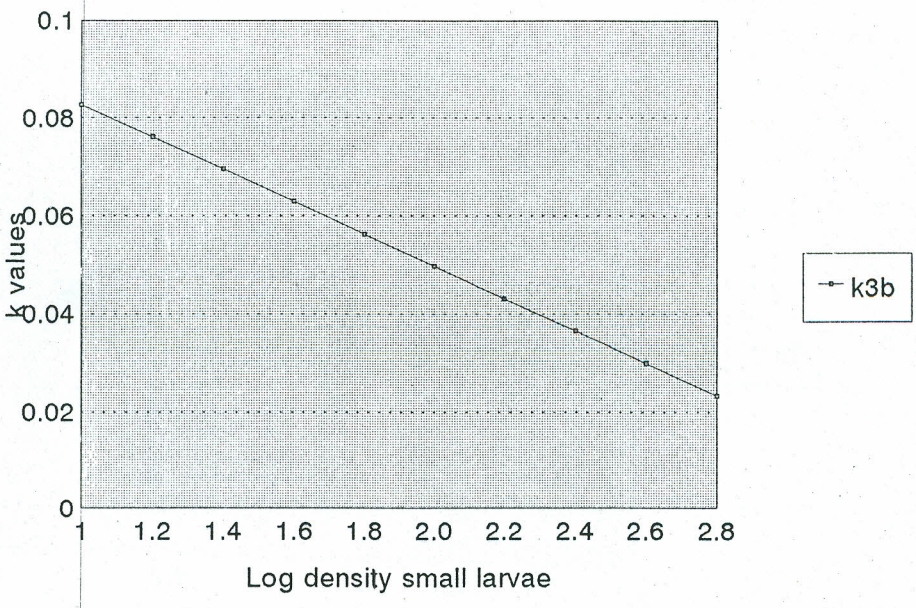


Figure 19. Density dependence identification Ungoye (k3b)
y = 0.1157 - 0.033X
r = 0.049

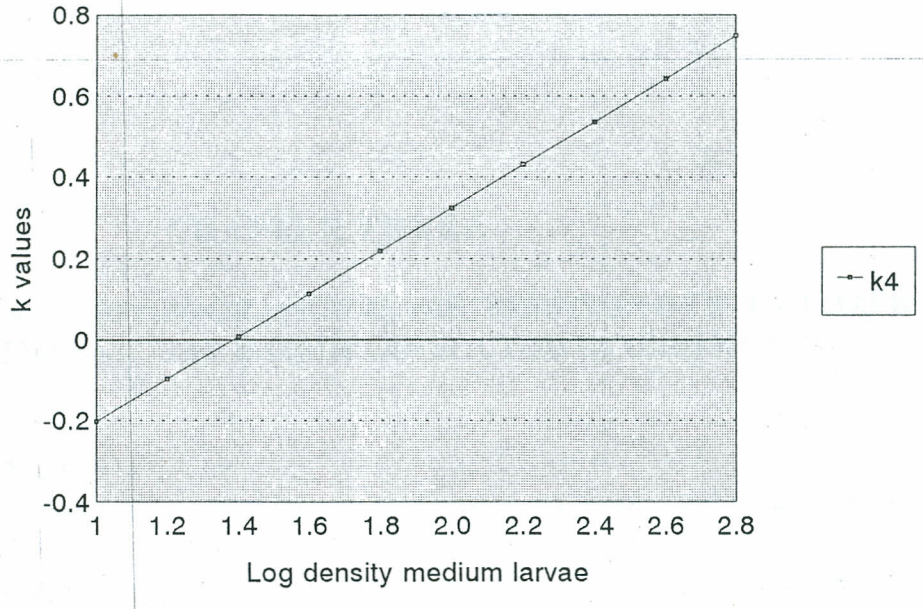


Figure 20. Density dependence identification Ungoye(k4)
y = -0.733 + 0.529X
r = 0.524

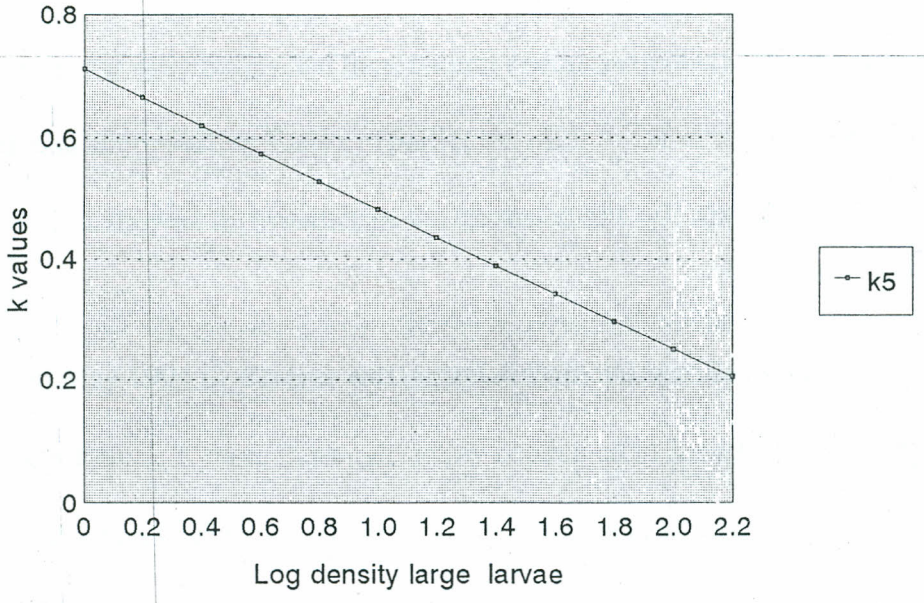


Figure 21. Density dependence identification Ungoye (k5)
y = 0.711 - 0.23X
r = 0.049

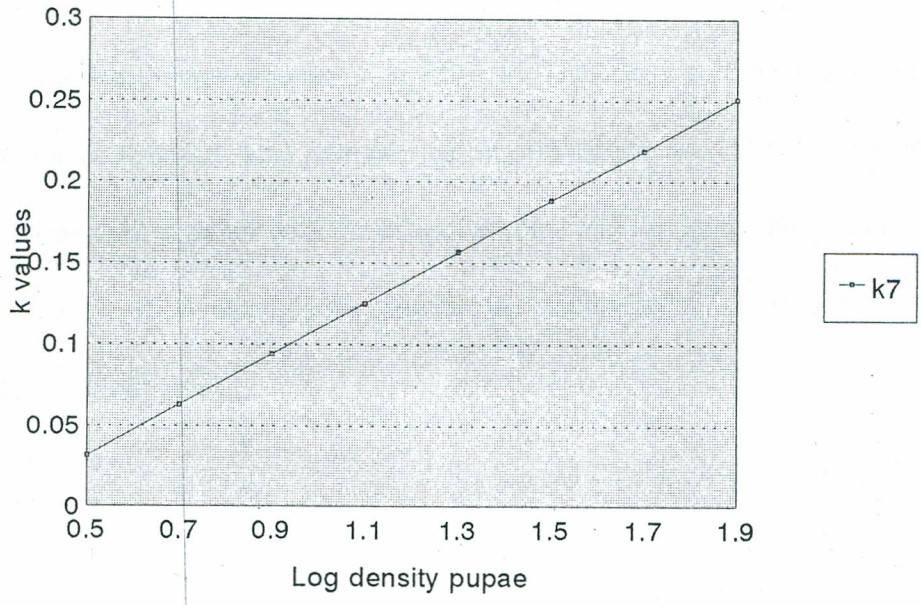


Figure 22. Density dependence identification Ungoye (k7)
y = -0.046 + 0.156X
r = 0.049

CHAPTER THREE

SEASONAL AND GEOGRAPHICAL DISTRIBUTION OF STEMBORERS AND THEIR NATURAL ENEMIES IN SOUTHWESTERN KENYA.

3.1 Introduction:

Chilo partellus, Busseola fusca, Sesamia calamistis, and *Eldana saccharina* occur in southwestern Kenya which has an elevation of 1100m above sea level. *C. partellus* is the most abundant species at some of the sites while *B. fusca* predominates in other sites. (Overholt et al.,1996).

Surveys of stem borers and their natural enemies conducted in western Kenya in general, and southwestern Kenya in particular, prior to the introduction of *Cotesia flavipes* in 1991 showed no evidence of the existence of *C. flavipes* (Oloo, 1989; Oloo and Ogedah, 1990).

However, in May 1994 *C. flavipes* was collected from unidentified stemborers in southwestern Kenya. A more thorough survey conducted in June/July 1994 recovered *C. flavipes* at seven locations in the same area (Omwega et al.,1995).

ICIPE maintained a colony of *C. flavipes* at Mbita Point Field station in southwestern Kenya for field cage experiments in 1991, which is about 50 km north of the area where *C. flavipes* was found but no intentional releases were made. It is possible that individuals escaped from either the laboratory colony or from the cages and became established. This is supported by Omwega et. al., 1995 who reported that the allozyme data together with the lack of evidence of the establishment of *C. flavipes* prior to 1994, strongly suggest that the established *C. flavipes* is from this recently imported stock.

It was therefore the aim of this study to ascertain the distribution of this parasitoid in southwestern Kenya, calculate levels of parasitism and also to examine the distribution of stem borers in relation to their natural enemies in this region.

3.2 Materials and Methods:

Subsistence farms were identified at random in some parts of southwestern Kenya bordering the areas where *C. flavipes* was recovered. Monthly samplings of maize and sorghum were done in each of these farms starting immediately after plant emergence until harvest. Ten plants were chosen at random from each of the fields using random numbers, but in the cases where a plant did not appear to be infested with stemborers, the nearest infested plant was chosen. Thus in each sampling session, a minimum of 10 plants or a maximum of 20 plants were collected in each farm. These plants were dissected and the larvae recovered, recorded and held in the laboratory for possible larval parasitoid emergence. The pupae were not held in the laboratory because the focus of the study was on larval parasitoids in general and *Cotesia sp.* in particular which do not attack the pupal stages. Both the stemborers and the larval parasitoids recovered were identified to species level. A list was then prepared to show the seasonal abundance of these stemborers, their larval parasitoids and their geographic distributions. Percent parasitism rates for each locality were calculated. Further analysis was also performed using the 2*2 contigency table to test for independence between the parasitism rate of the two larval parasitoids *C. sesamiae* and *C. flavipes* within the season. Since some of the

parasitism rates were found to be on the lower side (less than 5) a correction factor was applied using theformula:

$$X^2 = \frac{N(|ad-bc|-0.5n)^2}{(a+b)(c+d)(a+c)(b+d)}$$

Where N = Total number of parasitoids recovered in both seasons.

a = No. of *C. sesamiae* recovered during the short rains

b = No. of *C. sesamiae* recovered during the long rains

c = No. of *C. flavipes* recovered during the short rains.

d = No. of *C. flavipes* recovered during the long rains.

The null hypothesis was that the rate of parasitism is the same regardless of the season.

3.3 Results:

3.3.1. Seasonal distribution of stemborers in southwestern Kenya.

Results of the surveys which were conducted during 1994 short rains season, 1995 long and short rainy seasons and 1996 long rainy season are presented in table 16.

Chilo partellus, Busseola fusca, Sesamia calamistis and *Eldana saccharina* were recovered in this region. *C. partellus* was the most abundant stemborer encountered

during the short and long rainy seasons accounting for most of the stemborers recovered, while *S.calamistis* was the least recovered.

Table 16. Species composition of stemborers 1994-1996 in farmers fields Southwestern Kenya.

	LONG RAINS					SHORT RAINS				
Year	Cp	Bf	Sc	Es	Total	Cp	Bf	Sc	Es	Total
1994	-	-	-	-		75(93.75)	2(2.5)	-	3(3.75)	80
1995	22(100)	-	-	-	-22	222(81.3)	30(10.9)	1(0.3)	20(7.32)	273
1996	169(74.1)	58(25.4)	-	1	228	-	-	-	-	-

Abbreviations:

Cp *Chilo partellus*

Bf *Busseola fusca*

Sc *Sesamia calamistis*

Es *Eldana saccharina*

Percentages are in parenthesis

3.3.2 Parasitoid abundance and percent parasitism rates.

During the surveys carried out in this study, only two larval parasitoids were recorded, *Cotesia sesamia* and *Cotesia flavipes* (Table 17). Both parasitoids were recovered during all the surveys except for the 1995 long rainy season. The seasonal rates

of parasitism rose from 5% during the short rains of 1994 to 21.49% during the long rains 1996, and 1.25% to 6.14% during the same seasons for *C.sesamiae* and *C. flavipes,* respectively (Table 18).

Table 17. List of larval parasitoids recovered from farmers fields during surveys in southwestern Kenya.

Season	Location	Borer	C.sesamiae	C. flavipes
SR'1994	Ungoye	*	1	-
"	North Bugumbe	*	3	1
SR'1995	Kabondo	*	1	4
"	Kadem Kiwiro	*	7	-
"	Wachara	*	1	-
"	Amoyo	*	2	-
LR'1996	Homa Bay	*	-	3
"	Kwabwai	*	-	1
"	Kehancha	*	4	-
"	Kabondo	B.fusca	6	-
"	Kabondo	C.partellus	-	1
"	Kwabwai	C.partellus	2	4
"	Kwabwai	B.fusca	1	-
"	Homa Bay	B.fusca	34	-
"	Kendu Bay	unknown	1	-
"	Migori	C.partellus	-	1
"	Masaba	C.partellus	1	-
"	Bukira	C.partellus	-	4
"	Bukira	B.fusca	5	-

Table 18. Percent parasitism rates recorded for larval parasitoids in southwestern Kenya.

SEASON	NO. OF BORERS	NO. OF *C.sesamiae*	% PARASITISM *C.sesamiae*	No. OF *C. flavipes*	% PARASIT *C.flavipe*
SR'1994	80	4	5	1	1.25
LR'1995	22	0	0	0	0
SR'1995	273	11	4.02	4	1.46
LR'1996	228	49	21.49	14	6.14

Abbreviation: LR Long rains

SR Short rains

3.3.3 Independence between the parastism rate and the season.

Further analysis was performed to ascertain if there was any relationship between the parasitism rates of *C. sesamiae* and *C. flavipes* and the season.

Using the formula in section 5.3.2, X^2 was found to be 0.002.

The totals used to calculate the chi-square was obtained from table 19.

$$X^2 = \frac{83(|210-245|-41.5)^2}{(64)(19)(20)(63)} = 0.002$$

The Chi-square table gave 3.84 at P=0.05 level of significance when X^2 had one degree of freedom which is higher than the tabulated X^2 value of 0.002.

Table 19 Parasitism rates of C.flavipes and C. sesamiae per season.

Season	C.sesamiae	C.flavipes	TOTALS
SHORT RAINS	15	5	20
LONG RAINS	49	14	63
TOTALS	64	19	83

3.4 Discussion

The results indicated that the exotic parasitoid *C. flavipes* had spread to most parts of southwestern Kenya. This was in agreement with the earlier works reported by Omwega et al.,1995. Parsitoids were recovered in all the seasons except during the 1995 long rains. This was because the samplings were conducted late and therefore fewer borers were recovered. This subsequently led to no parasitoids recovery.

C. flavipes was only recovered from *C.partellus* whereas *C. sesamiae* was recovered from both *B. fusca* and *C. partellus*. This finding agreed with earlier works by Ngi-Song et al., 1995 who reported that *C. flavipes* did not develop on *B. fusca*. From

their dissections of parasitized *B. fusca* larvae, they found that the parasitoid eggs were encapsulated in the host larva. The inability of *C. flavipes* to develop in *B. fusca* may hamper the spread and colonization of this parasitoid where *B.fusca* was predorminant.

The percent parasitism which was found in farmers fields was higher than that attributed to the same parasitoids in the life table studies, and this points out the short comings of relying on percent parasitism as an indicator of natural enemy efficacy. Percent parasitism has been found to be a poor measure of the impact of parasitoids on host population dynamics for a number of reasons. First, as Van Dreische (1983) pointed out, the number and timing of samples taken are usually inadequate for the task. To assess a parasitoid's contribution to host population mortality, it is the percentage attacked for the generation which must be determined and this may be best done within the context of a complete life table study of the host population. Furthermore, the total parasitoid impact should be viewed as all host deaths resulting from the presence of the parasitoid, not just hosts utilized for the parasitoid reproduction.

The Chi-square value (X^2) calculated for the test of independence to ascertain if there was any relationship between the rates of parasitism and the season, was not found to be significant at $P>0.05$ level of significance. Thus, the null hypothesis of independence between the parasitism rates and the season cannot be rejected. This therefore suggests that the season had no relationship to the parasitism of the two larval parasitoids, *C.sesamiae* and *C.flavipes*.

CHAPTER FOUR

6.0 SUMMARY AND SUGGESTIONS FOR FUTURE WORK.

The partial ecological life table analysis showed that the highest mean generational mortality of *C. partellus* occurred in the medium stages; 44.9%, 65.5%, and 47.7% for Kuja river, Mbita Point and Ungoye sites respectively. This mortality was attributed to disappearance, and was found to be the key mortality factor. The larval parasitoids, *C.sesamiae,* and *C.flavipes* did not contribute a great deal to the mortality of *C.partellus* in southwestern Kenya.

Mortality due to disappearance at the small instar stage (k2), motality due to disappearance at the medium stage (k4) and mortality due to parasitism at the pupal stage (k7) all acted in a density dependent manner. However, k4 showed a greater stabilizing effect than the other factors.

The percent parasitism rates in farmers fields for the larval stemborers in southwestern Kenya ranged from 5% to 21.49% (from sr'1994 to lr'1996) and from 1.25% to 6.14% for the same period for *C.sesamiae* and *C.flavipes,* respectively.

There is therefore need to carry out further studies on the population dynamics of *C.partellus* in this region to ascertain the role that the exotic parasitoid might play in future. It is gratifying to note from this study that *C.flavipes* population has spread and parasitism levels are rising with time. It will be interesting to find out whether this trend continues in the future in this region and hence the need for such a study.

There is also need to carry out a more detailed study on the role of indigenous parasitoids and predators affecting all the stages of the stemborers (including the egg stages) to further understand their impact on the population of stemborers in this region.

REFERENCES:

Ampofo, J.K.O. (1986) Maize stalk borer (Lepidoptera:Pyralidae) damage and plant resistance.Environ. Entomol.15:1124-1129.

Atkinson, P.R. (1979) Distribution and natural hosts of *Eldana saccharina* Walker in Natal, its oviposition sites and feeding patterns. Proceedings of the South African Sugar Technologists' Association 53: 111-115.

Beg, M.N. & Inayatulla, C. (1980) Studies on Apanteles flavipes a parasite of graminaceous borers. Pakistan J. Agric. Res. 1, 50-53.

Bellows T.S. Jr.,R.G. Van Driesche & J.S.Elkington (1992). Life table construction and analysis in the evaluation of natural enemies. Ann. Rev. Entomol. 37: 587-614.

Betbeder-Matibet, M. & P. Malinge (1967). Un succes de la lutte biologique: controle de *Proceras sacchariphagus* Boj., "Borer ponctue" de la canne a sucre a Madagascar par un parasite introduit, *Apanteles flavipes* Cam. Agronomie Tropicale 22: 1196-1220.

Bleszynski, S. (1970) A revision of the world species of *Chilo zinken* (Lepidoptera: Pyralidae). Bulletin of the British Museum of Natural History, Entomology 25: 101- 195.

Bordat, D. (1983) Mis au point de l'elevage de masse d'*Apanteles chilonis* (Matsumura, 1912) et d' *Apanteles flavipes* (Cameron 1891)(Hymenopteres Braconidae) sur trois lepidopteres Pyralidae foreurs des gramineea *Chilo zacchonius* (Bleszynski, 1970) *Chilo partellus* (Swinhoe 1884) et *Diatraea saccharalis* (Fabricius 1794) dans un objectif de lutta biologique. These, Universite' des sciences et Techniques du Languedoc, Academie de Montpellier 1-184.

Bosque-Perez, N.A. & Mareck, J.H. (1990) Distribution and composition of Lepidopterous maize in Southern Nigeria. Bull. Entomol. Res. 80: 363-368.

Bowden, J. (1976) Stem borer ecology strategy and control. Ann. Appl. Biol. 84, 107-134.

Breniere, J., & Bordat, D. (1982). Intere et difficultes de la lutta biologique par introdution de'entomophages-cas des foreurs du riz en Afrique. Agronomie Tropicale 37, 203-206.

C.A.B. (1989) Distribution maps of pests. Series A, Map no. 184. International Institute of Entomology, London.

C.I.B.C. (1968-1972) Annual reports of the Commonwealth Institute of Biological Control, London.

Coaker, T.H. (1956) An experiment of stem borers control on maize. East Afric. J. 21:220-221.

Cock,M.J.W.(1986). Requirements for biological control: An ecological perspective. Biocontrol News and Information 7, 7-12.

Conlong, D.E. (1994) A review and perspectives for the biological control of the African sugarcane stalkborer *Eldana saccharina* Walker (Lepidoptera:Pyralidae). Agric.,Ecosys. and Environ., 48: 9-17.

DeBach, P., (1964) Biological control of insect pests and weeds. Chapman and Hall. London.

DeBach,P.,Huffaker,C.B.,MacPhee,A.W.,(1976). Evaluation of the impact of natural enemies. **In:** Theory and practice of Biological Control,ed. C.B.Huffaker, P.S. Messenger, pp255-85.,New York Academic 788pp.

Deevey, E.S. Jr. (1947) Life tables for natural populations of animals. Quart. Rev. Biol. 22:283-314.

Goraya, A.A.,Mushtaque, M.,& Attique, M.R. (1982) Suitability of *Apanteles flavipes* (Cameron)(Hym: Braconidae) as a biocontrol agent for graminaceous stem-borers in Pakistan. Proceedings of the eighteenth Annual Convention of the Pakistan Society of Sugar Technology, Rawalpindi, September 4-5: 177-182.

Greathead, D.J. (1971) A review of the biological control in the Ethiopian region. Technical Communication, Commonwealth Institute of Biological control 5: 1-162.

Greathead, D.J., (1986) Parasitoids in classical biological control. In Insect Parasitoids (Eds J. Waage and D.Greathead),Academic Press, London, pp.289-318.

Harcourt, D.G. (1969) The development and use of life tables in the study of insect populations. Ann. Rev. Entomol. 14: 175-196.

Harris. K.M. (1962) Lepidopterous stem borers of cereals in Nigeria. Bull. Entomol. Res. 11:467-477.

Harris,K.M., (1990) Bioecology and Chilo species. Insect Sci. applic. 11:467-477.

Harris, K.M. & Nwanze K.F. (1992) *Busseola fusca* (Fuller), the African maize stalk borer: A handbook of information. Information bulletin 33. ICRISAT Pantacheru, India and CABI Oxon U.K. 84p.

Ingram, W.R. (1958) The Lepidopterous stalk-borers associated with graminae in Uganda. Bull. Entomol. Res. 53:139-171

Ingram W.R. (1960) Experiments on the control of stalk borer in sorghum in Uganda. East Afric. Journ. 25:184-187.

Jepson,W.F. (1954) A critical review of the world literature on the lepidopterous stalk borers of tropical graminaceous crops. London, U.K.: Commonwealth Institute of Entomology. 1-127.

Kidd, N.A.C., & M.A. Jervis (1996). The role of natural enemies in insect population dynamics. **In** Jervis, M.A., & Kidd, N.A.C. (Eds.) Insect natural enemies 351-361., Chapman & Hall.

Kfir, R. (1990) Prospects for cultural control of the stalk borers *Chilo partellus* (Swinhoe) and Busseola fusca (Fuller), in summer grain crops in South Africa. Jour. Entomol. Soc. S. Afric. 53:41-47.

Kfir, R. (1992) Seasonal abundance of the stem borer *Chilo partellus* (Lepidoptera:Pyralidae) and its parasites on summer grain crops. Jour. Econ. Entomol. 85, 518-529.

Knutson, A.E.(1987) Population dynamics and natural enemies of the southwestern corn borer (Lepidoptera:Pyralidae) in the Texas high plains, Texas A & M University P.hd Thesis.

Leslie, G.W. (1988) The identification and importance of predators of Eldana saccharina (Lepidoptera:Pyralidae). Proceedings of the South African Sugar Technologists' Association 62:124-128.

Luck, R.F. (1971). An appraisal of two methods of analyzing insect life tables. Can. Entomol. 103: 1261-1271.

Luck, R.F., B.M. Shepard, & P.E. Kenmore (1988) Experimental methods for evaluating arthropod natural enemies. Ann. Rev. Entomol 33:367-391.

Mathez, F.C. (1972) *Chilo partellus* Swinhoe, *Chilo orichalcociliellus* Strand (Lepidoptera: Crambidae)and *Sesamiae calamistis* (sic) Hmps.(Lepidoptera:Noctuidae) on maize in the coast province, Kenya. Mitteilungen der Schweizerischen Entomologischen Gesellachaft 45(4):267-289.

Megenesa, T. (1982) Insect pests of sorghum in Ethiopia. IN: Proceedings of the Regional Workshop on sorghum in Eastern Africa, 17-21 Oct. 1982, Nazareth and Debre Zeit, Ethiopia, Sorghum improvement project. pg. 54-64.

Mohyuddin, A.I. & Greathead, D.J. (1970) An annotated list of the parasites of graminaceous stem borers in East Africa, with a discussion of their potential in biological control. Entomophaga 15,241-274.

Mohyuddin, A.I. & Attique, M.R. (1978) An assessment of loss caused by *Chilo partellus* to maize in Pakistan. PANS 24: 141-144.

Mohyuddin, A.I. & lnayatulla, C. (1981) Host selection and strain occurence in *Apanteles flavipes* (Cameron)(Hymenoptera:Braconidae) and its bearing on biological control of graminaceeous stem-borers (Lepidoptera:Pyralidae). Bull. Entomol. Res. 71:575-581.

Morris, R.F. & C.A. Miller (1954). The development of life tables for the spruce bud worm . Can. Jour. Zool. 32:283-301.

Morris, R.F., (1959) Single factor analysis in population dynamics. Ecology 40: 580-588.

Nagarkatti, S. & Nair, K.R. (1973) The wild and cultivated Graminaeae and Cyperaceae on populations of sugar cane borers and their parasites in North India. Entomophaga 18: 419-430.

Ngi-Song, A.J., Overholt, W.A., & Ayertey,J.N. (1995) Suitability of African gramineous stemborers for development of *Cotesia flavipes* and *C.sesamiae* (Hymenoptera:Braconidae). Environmental Entomolgy 24:(4) 978-983.

Oloo, G.W. (1989) The role of local natural enemies in population dynamics of *Chilo partellus* (Swinh.)(Pyralidae) under subsistence farming systems in Kenya. Insect Science and its Applications. 10 No.2 pp.243-251.

Oloo,G.W.& Ogedah, K. (1990) The incidence of *Chilo partellus* (Swinh.)(Pyralidae) and the contribution of natural enemies to its mortality under intercropping system in Kenya. Tropical Pest Management 36(3):244-248.

Omwega, C.O., Kimani, S.W. Overholt,W.A. & Ogol, C.K.P.O.(1995) Evidence of the establishment of *Cotesia flavipes* (Hymenoptera: Braconidae) in continental Africa. Bull. Entomol. Res. 85(4):525-530.

Overholt, W.A., (1993) Release of beneficial insects in Kenya. Discovery and Innovation 5(3), 199-200.

Overholt, W.A., Ogedah, K., & Lammers P.M. (1994a) Distribution and sampling of *Chilo partellus* (Swinhoe)(Lepidoptera:Pyralidae) in maize and sorghum at the Kenya coast. Bulletin of Entomological Research 84: 367-378.

Overholt, W.A., Ngi-Song A.J., Kimani, S.W., Mbapila,J.,Lammers P.M. and Kioko, E. (1994b) Environmental considerations of the introduction of *Cotesia flavipes* Cameron (Hymenoptera; Braconidae) for biological control of Chilo *partellus* (Swinhoe)(Lepidoptera: Pyralidae) in Africa. Biocontrol News and Information 15(2):19N-24N.

Overholt W.A., Ochieng'J.O., Lammers, P. & Ogedah, K. (1994) Rearing and field release method for *Cotesia flavipes* Cameron (Hymenoptera: Braconidae), a parasitoid of tropical gramineous stem borers. Ins. Sci. Applic. 15(3):253-259.

Overholt, W.A.,Ngi-Song A.J.,Omwega C.O., Kimani-Njogu S.W., Mbapila J.,Sallam M.N., & Ofomata V. (1996) An ecological approach to biological control of gramineous stemborers in Africa: The introduction and establishment of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae). In E.B. Radcliff and W.D. Hutchison (eds), *Ted Radcliff's Gopher state IPM site*, RL:http://www.ent.agri.umn.edu/academics/classes/ ipm/ipmsite.htm.Univ.of Minnesota, St. Paul, MN.

Podoler, H. & D. Rogers (1975) A new method for the identification of key factors from life table data. J. Anim. Ecol. 48: 85-115.

Polaszek,A. & LaSalle, J. (1995) The hyperparasitoids (Hymenoptera:Encrytidae,Eulophidae, Eurytomidae) of cereal stem borers (Lepidoptera:Noctuidae, Pyralidae) in Africa. African Entomolgy 3:(2) 131-146.

Price, P.W. (1975) Insect ecology. John Wiley and sons New York. 385pp.

Rajabalee, M.A. & Goverdasamy, M. (1988) Host specificity and efficiency of *Apanteles flavipes*(Cam)and *Apanteles sesamiae* (Cam.) (Hymenoptera:Braconidae) parasites of sugar cane moth borers in Mauritius. Revue Agricole et Sucriere de l'lle Maurice 67:78-80.

Scheilbreiter, G.K. (1980) Sugar-cane stem borers (Lepidoptera:Pyralidae and Noctuidae) in Ghana. Zeitshrift fur fur Angewandte Entomolgie 89:87-99.

Seshu Reddy, K.V. (1983) Sorghum stem borers in eastern Africa. Ins. sci. applic. 4:33-39.

Seshu Reddy, K.V. (1985) Integrated approach to the control of sorghum stem borers. In Proceedings of the International Sorghum Entomology Workshop, Texas A & M University, College station, TX, USA 205-215. ICRISAT.

Seshu Reddy, K.V.(1988) Assesment of on-farm yield losses in sorghum due to insect pests. Ins. Sci. Applic. 9 (6): 679-685.

Seshu Reddy, K.V. & Sum, K.O.S. (1991) Determination of economic injury level of the stem borer *Chilo partellus* (Swinhoe) in Maize, *Zea mays* L. Ins. Sci. Applic.12(1,2,3,):269-274.

Shami, S. Mohyuddin, A.I. (1987) Host selection by Indonesian strain of Apanteles flavipes(Cam.) and its suitability for various graminaceous borers in Pakistan. Proceedings of the 23rd Annual Convention of the Pakistan Society of Sugar Technology. 25-27 July, Rawalpindi. pp286-291.

Southwood, T.R.E. & Jepson, W.F. (1962) Studies on the populations of *Oscinella frit* L. (Dipt.:Choropidae) in the oat crop. J. Anim. Ecol. 31, 481-95.

Southwood, T.R.E. (1967) The interpretation of population change. Jour. Anim. Ecol. 36,519-29

Southwood, T.R.E. (1978). Ecological Methods . John Wiley and sons. New York 419pp.

Skoroszweski,R.W. & Van Hamburg, H. (1987) The release of *Apanteles flavipes* (Cameron)(Hymenoptera:Braconidae) against stalk-borers of maize and grain-sorghum in South Africa. Jour. Entmol. Soc. Southern Afric. 50:249-255.

Starks, K.J. (1969) Some cereal crop insects in east Africa. East Africa Agriculture and Forestry Organisation. Serere Res. Sta. Uganda,(Mimeo).

Tams W.H.T. (1932) New species of African Heterocera. Entomologist 65: 1241-49.

Tams W.H.T. & Bowden J. (1953) A revision of the African species of *Sesamiae* Guenee and related genera (Agrotidae-Lepidoptera). Bull. Entomol. Res. 43:645-678.

Van Den Berg, J. & Van Reensburg, J.B.J. (1992) Chemical control of Chilo partellus (Lepidoptera: Pyralidae) larvae behind leaf sheaths of grain sorghum. Appli. Plant Sci. 6: 28-30.

Van Driesche R.G. (1983) Meaning of percent parasitism in studies of insect parasitoids. Environ. Entomol. 12(6) 1611-1622.

Van Hamburg, H. (1979) The grain-sorghum stalk-borer *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae): seasonal changes in adult populations in grain sorghum in the Transvaal. Jour. Entomol. Soc. Southern Africa 42: 1-9.

Van Rensburg, G.D.J. (1990) Comparison of chemical control approaches against the maize stalk borer, *Busseola fusca* (Lepidoptera: Noctuidae), in maize in South Africa. Phytophylactica 22:87-91.

Varley, G.C. & G.R. Gradwell (1960). Key factors in population studies. Journ. Anim. Ecol. 29:664-669.

Varley, G.C., & G.R. Gradwell (1968). Population models for the winter moth, pp.132-142, in T.R.E. Souhtwood (Ed.) Insect Abundance. 4th Symp. Roy. Entomol. Soc. London 160pp.

Varley, G.C. & G.R. Gradwell (1970). Recent advances in insect population dynamics. Ann.Rev. Entomol. 15: 1-24.

Varley, G.C., G.R. Gradwell, & M.P. Hassel (1974). Insect population Ecology: An analytical approach . Univ. California Press, Berkeley, CA. 212pp.

Waage, J.K. & Greathead, D.J. (1988) Biological control: challenges and opportunities. Philosophical Transactions of the Royal Society of London,B,318, 111-128

Warui, C.M. & Kuria J.N. (1983) Population incidence and the control of maize stalk-borers *Chilo partellus* (Swinhoe) and *Chilo orichalcociliellus* Stand and *Sesamiae calamistis* Hmps. in Coast Province, Kenya. Insect Science and its Application 4: 11-18.

Williams, J.R.(1983) The sugar cane stem borer (*Chilo saccariphagus*) in Mauritius. Revue Agricole et Sucriere de l`lle Maurice 62: 5-23.

Whitney,W.K. (1977) Insect and mite pests and their control. In food crops of the lowland tropics. (Ed. Leakey C.L.A. & Wills J.B.) Oxford University Press.