The impact of predators on maize stem borers in coastal Kenya

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Stellingen behorende bij het proefschrift:

The impact of predators on maize stem borers in coastal Kenya

1. Plaagreductie met behulp van inheemse natuurlijke vijanden moet de belangrijkste vorm van biologische bestrijding zijn voor boeren in de meeste agrarische systemen.
    Dit proefschrift.
    Luck, R.F., Shepard, B.M. and Kenmore, P.E. (1988). Experimental methods for evaluating arthropod natural enemies. Annual Review of Entomology 33, 367-391.

2. Het veelvuldig voorkomen van een predator betekent niet automatisch dat deze predator een hoge mortaliteit onder plaaginsecten veroorzaakt.
    Dit proefschrift.
    Whitcomb, W.H. (1981). The use of predators in insect control. In: Pimentel, D. (ed.), CRC Handbook of Pest Management in Agriculture, Vol. II, 105-123.

3. Boeren zullen eerder geneigd zijn om methoden ter beheersing van stengelboorders in te voeren wanneer er rekening gehouden wordt met de visie van de boeren en de praktische uitvoerbaarheid van de aanbevelingen.
    Dit proefschrift.

4. De invloed van inheemse natuurlijke vijanden op de mortaliteit van een plaag wordt vaak overschat omdat negatieve onderzoeksresultaten slechts zelden gepubliceerd worden.
    Dit proefschrift.

5. Het imago van milieuorganisaties zou aanzienlijk verbeteren, en daarmee hun invloed toenemen, als deze organisaties meer aandacht zouden besteden aan ontwikkelingen die een positieve invloed hebben op het milieu.

6. Het verbieden van het gebruik van bestrijdingsmiddelen in Nederland ter bescherming van de volksgezondheid heeft weinig zin zolang geïmporteerde landbouwprodukten niet strenger gecontroleerd worden op residuen van verboden middelen.

7. De wetenschap legt een allesomvattende claim op wat mensen nog denken en geloven mogen.
    A. van den Beukel (1990) De dingen hebben hun geheim, gedachten over natuurkunde, mens en God. Ten Have, Baarn.

8. Onbeduidende zaken kosten op vergaderingen de meeste tijd, omdat de meesten daar meer verstand van hebben dan van belangrijke zaken.

CONTENTS

PREFACE

The work described in this thesis was carried out between 1995 and 1999 while I was assigned by DGIS as an associate-expert in Entomology to the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya. I want to express my sincere thanks to everybody involved in the research described in this thesis and name a few people specifically.

In the first place, I am indebted to my promotor Joop van Lenteren and my co-promotor Arnold van Huis for their encouragement and support throughout the period. Their visits to Kenya were greatly appreciated and enjoyed! Many thanks also to Bill Overholt, my programme leader, who gave me the freedom, the means and the people to do my own research. I also want to thank him for trusting me with the management of the work at Muhaka: it was not always easy, but it was definitely a rich and valuable experience.

At Muhaka, many people assisted in one way or another in the research. J.C. Olela, Maurice Okomo, Silas Ojwang, Peter Owuor, Boaz Musyoka, Moses Mungai, the late Ricard Kenyatta, Sapaya Welembah, Ali Bakari, Mwanarusi Hamisi and the many casuals of the project did an enormous amount of work. They crossed swollen rivers, spent 24 hours in the field watching a few egg batches and even outran an angry cobra .... all in the name of science! I also want to thank Naphtali Dibogo, who conducted the interviews described in chapter 2. Other people at Muhaka included Stanley Wainaina, Douglas Kalume, Grace Kariuki, Peter Kijana, Binti Hamisi and numerous askaris. In one way or other, they all made working at Muhaka more pleasant.

I am also grateful for the help of the WAU-team in Nairobi. I especially want to name Gerphas Okuku, Joseph Okello and Josephine Osea who assisted in the experiments and did a fair amount of running up and down for me. Charles Omwega,

Chapter 1

GENERAL INTRODUCTION

MAIZE CULTIVATION IN EAST AND SOUTHERN AFRICA

Overview of maize production

Maize (*Zea mays* L.) is one of the most important food sources for much of the human population of Africa. The crop is primarily grown by subsistence farmers and provides, apart from food, also animal fodder and building material. In Kenya alone, 1.4 million hectares of maize were estimated to be under cultivation in the period of 1994 to 1998, with an average total grain production of 2.5 million tonnes per year (Table 1.1) (FAO, 1999). Average grain yields in Kenya were approximately 1.8 tonnes/ha in 1994 to 1998 (FAO, 1999), although in some areas, yields often do not reach even 1 tonne/ha (Saxena *et al.*, 1989; Waaijenberg, 1993; Grisley, 1997). Comparing the period 1994 to1998 with 1974 to 1978 shows that although the yield per ha and total production increased by 19% and 14%, respectively, the production per capita declined with 57% because the population doubled over the past 20 years (Table 1.1). In many years, yields are not sufficient to feed the increasing population, and since the 1980s Kenya has generally been a net importer of maize. Other countries in East Africa face similar problems, and average yields in these countries are usually even lower than in Kenya (Table 1.1).

Due to population pressure, many households are forced to move to land with lower yield potential, most of which fall in the transitional and semi-arid zones that are less suitable for maize growing (Waaijenberg, 1993; FEWS, 1996). Nevertheless, maize continues to be the dominant crop in these areas (FEWS, 1996). In the densely populated areas with high yield potential, maize is grown on the same plot year after

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year, leading to declining soil fertility and decreasing yields. Factors such as population pressure, decreasing popularity of drought-resistant crops, land constraints and stagnant maize yields contribute to a deterioration in food security for a large part of the population (FEWS, 1996).

Small-scale farmers are confronted with many constraints to maize production. Not only do they mention low and unreliable rainfall and soil infertility as major factors responsible for low yields, but also the lack of farm inputs such as seeds and fertiliser and infestation by insects (Saxena *et al.*, 1989; Waaijenberg, 1993; Grisley, 1997). Other factors such as an inadequate extension system (Saxena *et al.*, 1989) and poor distribution and market facilities (Waaijenberg, 1993) aggravate the situation.

Table 1.1. Area under maize production, yield per hectare, total production, total human population, production per capita and production losses due to stem borer damage (assuming 15% yield loss) of Kenya, Tanzania and Uganda and of the whole of Africa. Figures are averages of 1974 to 1978 and 1994 to 1998.

Country	Period	Area (ha x 10^6)	Yield (tonnes/ha)	Total production (tonnes x 10^6)	Total human population[a] (x 10^6)	Production (kgs) per capita	Production (kgs) loss per capita due to stemborers
Africa	1974-1978	1.86	1.46	2.71	413.89	5.36	0.99
	1994-1998	2.57	1.56	4.04	719.50	5.62	0.84
Kenya	1974-1978	1.50	1.47	2.22	13.74	161.57	24.07
	1994-1998	1.44	1.75	2.52	27.15	92.82	13.92
Tanzania	1974-1978	1.22	1.09	1.34	15.90	84.28	12.55
	1994-1998	1.72	1.40	2.40	30.03	79.92	12.03
Uganda	1974-1978	0.45	1.25	0.57	11.18	50.98	7.55
	1994-1998	0.58	1.38	0.80	19.69	40.63	6.10

[a] Total population based on figures for 1975 or 1995.

Maize growing at the southern coastal area of Kenya

Study area

The economic development of the coastal region has not kept pace with that of central and western Kenya. Although it was relatively prosperous in pre-colonial and

early colonial times, the opening up of the highlands by European settlers meant an inevitable shift of development towards the interior (Cooper, 1981). At the present time, the economy is primarily dependent on agriculture and tourism (Hoorweg *et al.*, 1991; personal observation).

Rainfall at the southern coastal area of Kenya (Kwale and Kilifi Districts) is concentrated in two periods: from April until July (long rainy season), and from October until November (short rainy season). Going inland, rainfall diminishes while the potential evapotranspiration increases. Average rainfall in the coastal area ranges from less than 700 mm to over 1400 mm per year (Jaetzold and Schmidt, 1983), with a mean annual temperature of 24°C (Figure 1.1). Soils vary with topography and geology, but most are characterised by low structural stability, sensitivity to erosion and a low to very low fertility (Jaetzold and Schmidt, 1983). In the region, different agro-ecological zones alternate over relatively short distances (Jaetzold and Schmidt, 1983). The coastal plain consists mainly of the coconut-cassava (CL3) and cashewnut-cassava (CL4) zones (classification by Jaetzold and Schmidt, 1983). The first zone is relatively humid and has potential for a variety of crops, although the seasonal character and the low reliability of rainfall severely restrict agricultural productivity. In the somewhat drier cashewnut-cassava zone possibilities for crop production are more restricted than in the coconut-cassava region (Hoorweg *et al.*, 1991). Maize is predominantly grown in a zone of approximately 35 km from the sea to the hinterland, which usually receives an annual rainfall of more than 800 mm. The long rainy season is the main growing season, as the short rains are often too poor and unreliable to guarantee a reasonable harvest (van Oosten, 1989; Hoorweg *et al.*, 1991).
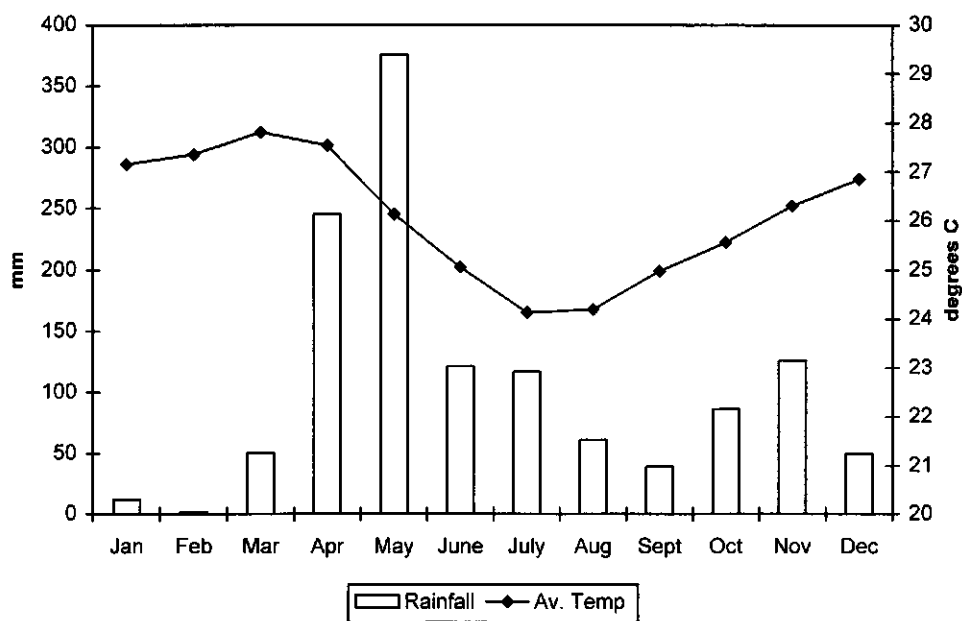
Figure 1.1. Rainfall and temperature patterns at the southern coastal area of Kenya. Data are averages from 1992 to 1998, obtained from the Kenyan Agricultural Research Institute in Mtwapa.

Production systems[1]

Maize is an important component of many cropping patterns, varying from simple sole cropping to complex mixtures of annual and perennial crops. In the study area, farmers concentrate their efforts on maize cultivation, although cassava and cowpea are also important crops. Both are planted in low densities in maize fields, either as intercrop or relay crop. Cassava is usually planted during the long rainy season and harvested just before next year's maize crop is sown. If cassava is planted during the short rainy season, then the maize in the long rainy season is sown in between the

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[1] Most of the information in this section has been obtained from reports by van Oosten (1989) and Waaijenberg (1993), or through personal observation.

cassava plants. Cowpea is generally planted as a relay crop in the long rainy season when maize plants reach maturity. Both the leaves and grains of cowpea are eaten.

Beside cassava and cowpea, a multitude of minor crops, including beans, greengrams, groundnuts, tomatoes, pumpkins, eggplants, cabbages and rice can also be found in the area. Coconuts play an important role in the coastal economy, with different parts of the tree being used as food, fuel and roofing material. Other fruit trees such as mango, cashew and citrus are of minor importance and receive little attention, although their produce may be sold when money is needed. Most food crops are produced for home consumption, and yields are usually not sufficiently high to form surpluses that can be sold.

Cultivation practices[1]

Less than a century ago, farmers at the southern Kenyan coast could still cultivate fresh bush land that gave high-yielding crops with a minimum of labour. Since then, fixed settlement, population growth and tree crops have increasingly limited the choice of sites for maize cultivation. Nowadays, fallows are short, often less than 2 years, which is too short to restore the original fertility of the soils. Due to the short fallow, weeds are more abundant and more labour is required for weeding. Fertiliser use is rare and yields are determined by the low soil fertility.

Land preparation usually starts in March or April, just before the first rains of the long rainy season. The vegetation, which generally consists of crop residues, dry herbs, grasses and one season old shrubs, is slashed or hoed just above the soil surface or burned. Veld burning, although officially prohibited, is a much-practised land preparation tool. Most farmers prepare their land with a hand hoe but in some areas land is ploughed by tractors or oxen. Tillage by hand hoe is irregular and superficial and produces a rough seed bed, which causes an early appearance of

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[1] Most of the information in this section has been obtained from reports by van Oosten (1989) and Waaijenberg (1993), or through personal observation.

weeds and an uneven germination of the crop. It also means that season after season the same weathered topsoil is used. For the short rainy season, the land is often not prepared but the same fields of the long rainy season are used again. Most farmers plant after the first heavy showers, using seeds that were kept from last season's harvest. Sowing is done by dropping several seeds in a hole dug with a hand hoe. The holes are made in a scattered pattern approximately 60 to 100 cm apart. The recommend line planting, with a distance of 75 cm between rows and 30 cm between plants in a row, and thinning of young maize plants to one plant per hill are seldom followed. Timely weeding, not later than 3 weeks after emergence (WAE) of maize, is a crucial cultivation practice. If the first weeding is carried out late, yield suffers or the crop may even fail.

Most farmers start weeding early but cannot mobilise enough labour to complete the whole field within a short period. A second weeding is generally carried out around 5 WAE, and some farmers even weed a third time to plant relay crops like cowpea or greengrams. Pesticides are not commonly applied but traditional methods of pest control, such as placing of ash, soil or plant extracts in the leaf whorl or uprooting infested plants, may be used (Chitere and Omolo, 1993; Grisley, 1997). Approximately 3 to 4 months after sowing, the maize is ready for harvesting. Some cobs are harvested early to provide soft maize for roasting, but most cobs are harvested when the ears are dry. Crop residues are left in the field or used as fodder or building material (Päts, 1996). The maize is stored in the husk in the loft of the house, often above the kitchen fire. The smoke deters weevils and the warm, dry air stops fungal ear rot. When the maize is to be used, the seed coat and germ are removed by pounding the moistened grains. The remainder is dried in the sun and winnowed. Then the maize is ground to flour in simple hand mills or taken to commercial electrical or diesel mills. Finally, it is consumed as "sima" or "ugali", a thick maize meal.

INSECT AND INSECT-VECTORED CONSTRAINTS TO MAIZE PRODUCTION

A range of insects is known to attack maize in East Africa, both in the field and in storage. Surveys carried out in the colonial days identified stem borers, leaf hoppers and armyworms to be the most damaging insects in the field (e.g. Le Pelley, 1959; Nye, 1960). In storage, larger grain borers, weevils and grain moths were the major pests (Table 1.2). Country-wide surveys have not taken place in recent years, but personal observation and discussions with farmers, newspaper and journal articles, as well as the focus of insect research institutions in East Africa let us believe that the list of insect pests has largely remained the same over the past 30 to 40 years.

Lepidopteran stem borers are generally considered to be the most geographically widespread, most frequently occurring and most damaging insect pests of maize in East Africa (Ingram, 1958; Nye, 1960; Youdeowei, 1989). Nearly all farmers have stem borers in their fields (Chitere and Omolo, 1993; Grisley, 1997) and yield losses range from 4 to 73% (for a review, see Seshu Reddy and Walker, 1990). Leafhoppers (*Cicadulina* spp.) can cause severe indirect damage by transmitting the maize streak virus (MSV). In the Kenyan highlands, 74% of farmers reported having MSV on their farm, and yield losses were estimated at 8% (Grisley, 1997) although higher losses may occur (Vogel *et al.*, 1993). Outbreaks of the African armyworm *Spodoptera exempta* Walker (Lepidoptera: Noctuidae) take place sporadically. However, if an outbreak occurs, destruction is so high that farmers are often compelled to replant their crops, risking failure if subsequent rains are poor (Youdeowei, 1989).

The larger grain borer (LGB) *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), is indigenous to Central America but is now well established in East Africa (Markham *et al.*, 1991). It causes high weight losses in farm-stored maize. In Tanzania, an average of 9% weight loss had occurred after five months in maize infested with LGB compared to 1% weight loss in LGB-free maize. Cobs with 70 to

Table 1.2. Insect pests of maize and their importance, recorded from East Africa (Kenya, Uganda, Tanzania).

Pest	Scientific name	Occurrence and damage	Reference
Field pests			
Major			
Stem borers	Chilo partellus (Swinhoe) Chilo orichalcociliellus (Strand) Sesamia calamistis Hampson Eldana saccharina Walker Busseola fusca (Fuller)	common, damage severe, 4-73% yield loss	1, 2, 3, 4, 6, 8, 12
Leaf hoppers	Cicadulina spp.	indirect damage severe by transmitting maize streak virus, 7-100% yield loss	1, 3, 11, 12
Common armyworm	Spodoptera exempta (Walker)	sporadic, but damage severe, 9% yield loss	1, 3, 6, 8, 10
Minor			
White/Chafer grubs	Heteronychus spp.	locally common, minor damage	1, 6, 8, 12
Cutworms	Agrotis spp. and others?	3%	1, 6, 8
False codling moth	Cryptophlebia leucotreta (Meyrick)	common, but only minor damage	1
Corn lanternfly	Peregrinus maidis (Ashmead)	common, but only minor damage	3
Maize aphid	Rhopalosiphum (Aphis) maidis (Fitch)	common, but only minor damage	2, 3
Coccinellid beetles	Epilachna similis (Thunberg)	sporadic, but may cause great damage	1, 3
Afro-Asian (Old World) bollworm	Heliothis armigera (Hübner)	sporadic, usually minor damage	1, 2, 3
Maize webworm	Marasmia trapezalis (Guenée)	sporadic, minor damage	1, 3
Termites	Microtermes spp.	?	3
	Macrotermes spp.	?	3
Storage pests			
Major			
Maize weevil	Sitophilus zeamais (Motschulsky)	common, severe damage to loose-stored maize	4, 5, 8, 9
Rice weevil	Sitophilus oryzae (L.)		5, 9
Larger grain borer	Prostephanus truncatus (Horn)	high losses, 9% after 5 months	4, 5, 8, 9
Minor			
Angoumois grain moth	Sitotroga cerealella (Olivier)	locally common, damage variable	1, 4, 5, 8
Rust red flour beetle	Tribolium castaneum (Herbst)	secondary pest, important in the presence of other pests	5
Confused flour beetle	Tribolium confusum J. du Val		5

References: 1=Nye, 1960; 2=Wheatley, 1961; 3=Bohlen, 1973; 4=Hill, 1983; 5=Hodges et al., 1983; 6=Walker, 1983; 7=Golob, 1988; 8=Youdeowei, 1983; 9=Golob and Hanks, 1990; 10=Broza et al. 1991; 11=Vogel et al., 1993; 12=Grisley, 1997.

80% grain damage, associated with 30 to 35% weight loss, were not unusual (Hodges *et al.*, 1983). In maize that is stored loose instead of on the cob, the weevils *Sitophilus zeamais* Motschulksy and *S. oryzae* (Linnaeus) are common (Golob and Hanks, 1990). In Tanzania, damage caused by *Sitophilus* spp. was less than that caused by LGB (Hodges *et al.*, 1983). The rust red flour beetle, *Tribolium castaneum* (Herbst) is a secondary pest that is unable to survive in intact maize grains but is successful on maize flour. Infestation by *T. castaneum* is enhanced by the presence of other storage insects, especially by those producing large quantities of maize dust such as *P. truncatus* and *Sitophilus* spp. (Hodges *et al.*, 1983). The grain moth *Sitotroga cerealella* (Olivier), originating from Europe but having spread over the whole world, appears to occur throughout East Africa (Nye, 1960; Hodges *et al.*, 1983; Youdeowei, 1989). It was not common in the Tabora region of Tanzania (Hodges *et al.*, 1983), but information on the occurrence and damage caused to maize storage in other areas is not available.

STEM BORERS AND THEIR CONTROL

This thesis focuses on the main insect pest in maize growing: the stem borer. In the following paragraphs, current knowledge of the biology, pest status and control of stem borers is summarised in order to provide background information to the research. Subsequently, the research problem and objectives are defined and an outline of the thesis is presented.

Biology of cereal stem borers
Distribution

In East Africa, a complex of 12 stem borer species has been reported from cereal crops, with *Chilo partellus* Swinhoe, *Chilo orichalcociliellus* Strand, *Busseola fusca* Fuller, *Sesamia calamistis* Hampson, *Sesamia cretica* Lederer and *Eldana*

saccharina (Walker) being the most important and widely distributed species (Nye, 1960; Youdeowei, 1989; Seshu Reddy, 1998). The current knowledge of taxonomy, economic importance, distribution and natural enemies of cereal stem borers in Africa has been put together by Polaszek (1998).

The exotic species *C. partellus* is the predominant stem borer at elevations below 1500 m. The species is indigenous to Asia and its first record in Africa was in Malawi in 1932 (Tams, 1932). Since the early 1950s, it has become well established as a pest throughout East and southern Africa (Sithole, 1989; Overholt *et al.*, 1994; Kfir, 1997b). Recent surveys indicate that in Malawi, Kenya, Uganda and Zambia, *C. partellus* accounted for over 75% of the stem borer population at lower altitudes (Overholt *et al.*, 1994; W.A. Overholt, personal communication). At higher altitudes, *B. fusca* is often the most abundant stem borer species (Sithole, 1989), although reports from South Africa suggest that *C. partellus* is gradually displacing *B. fusca* at higher elevations (Kfir, 1997a). *E. saccharina* is widespread south of the Sahara and is primarily known as a stem borer of sugarcane, although maize and other cereals are also attacked. *S. calamistis* is widespread but usually not abundant, while *S. cretica* occurs mainly in the savannah regions of Northeast Africa and northern Kenya. *C. orichalcociliellus* occurs at altitudes lower than 300 m, especially in coastal areas, but it is usually not found in only small numbers. Furthermore, there is evidence that it is being displaced by *C. partellus* (Overholt *et al.*, 1994).

The stem borer species encountered at the southern coastal area of Kenya, the area where the studies for this thesis were conducted, are *C. partellus*, *C. orichalcociliellus* and *S. calamistis*. In the early 1970s, *C. orichalcociliellus* was the predominant stem borer in the area, followed by *C. partellus* and *S. calamistis* (Mathez, 1972). Research carried out from 1978 to 1981 found that *C. orichalcociliellus* was the most abundant species during the long rains, whereas *C. partellus* and *C. orichalcociliellus* were equally abundant during the short rains (Warui and Kuria, 1983). In a more recent study, *C. partellus* was found to be the

most common species, usually accounting for more than 80% of the stem borers (Overholt *et al.*, 1994). There is no evidence that total stem borer densities have changed (Overholt *et al.*, 1994), and the apparent shift in the abundance of the two *Chilo* species suggests that the exotic stem borer may be displacing the indigenous species (Ofomata *et al.*, 2000). The abundance of *S. calamistis* remained fairly constant over time, and usually accounted for 7 to 12% of stem borers during the long rains and up to 23% of stem borers during the short rains (Warui and Kuria, 1983, Overholt *et al.*, 1994).

Life cycles

Chilo partellus moths emerge in the late afternoon and early evening. Mating occurs soon after emergence and on the two to three subsequent nights (Berger, 1989), egg batches of 10-80 overlapping eggs are laid on the undersides (Päts and Ekbom, 1994) or upper sides (Mathez, 1972) of leaves, often near midribs. The fecundity of *C. partellus* is reported to be approximately 434 eggs per female (Berger, 1989). Adults live for approximately two to seven days (Alghali, 1988) and normally do not disperse far from emergence sites. Eggs hatch in the early morning (6.00 to 8.00 h), four to eight days after being oviposited (Berger, 1989; Delobel, 1975). Young larvae ascend plants to enter the leaf whorls, where they start to feed. Older larvae tunnel into stem tissue and pupate after feeding for 2 to 3 weeks, unless they go into quiescence. Moths eclose from the pupae after 4 to 8 days. The life cycle is completed in 25 to 50 days when conditions are favourable (Harris, 1990). During the growing season, three or more successive generations may develop. Although the life cycle may be continuous when favourable conditions for host plant growth exist, it is usually interrupted by a cold or dry season. To overcome this period, the mature larvae enter diapause inside old stems or stubble (Scheltes, 1978) and pupate on the return of favourable conditions.

The life cycle of *Chilo orichalcociliellus* is largely similar to that of *C. partellus* (Mathez, 1972; Delobel, 1975). The fecundity of *C. orichalcociliellus* is approximately 475 eggs per female (Delobel, 1975). Ofomata *et al.* (2000) compared several characteristics of the two *Chilo* species and found that *C. partellus* had a higher fecundity than *C. orichalcociliellus* in the laboratory at 25°C and 28°C, but not at 31°C. In addition, more *C. partellus* than *C. orichalcociliellus* eggs survived to first instar larvae and *C. partellus* larvae developed faster than *C. orichalcociliellus*. *C. partellus* also terminated diapause faster than *C. orichalcociliellus*.

Female adults of *Sesamia calamistis* lay approximately 300 eggs in its lifespan of five to six days. The spherical eggs are laid in batches of 10 to 40 eggs (Bosque-Pérez and Dabrowski, 1989), usually in two to four adjoining rows between the lower leaf sheaths and stems (Mathez, 1972). Under field conditions, eggs hatch in five to six days. Shortly after hatching, larvae penetrate the stems directly or start feeding on the leaf sheath first (Holloway, 1998). *S. calamistis* larvae are also highly attracted to cobs. During the larval stage, which lasts for 30 to 60 days and usually involves five to six moults, larvae may successively attack a number of young stems. Pupation generally takes place in the stem or cobs (Bosque-Pérez and Schulthess, 1998) and the pupal period lasts for 10 to 12 days. In contrast to many other stem borers, *S. calamistis* breeds throughout the year and has no resting stage (Holloway, 1998). In the dry season, its can be found in mature grasses or in maize growing in small areas near water (Harris, 1962). In areas where *S. calamistis* is forced to feed on wild grasses to bridge the cropping season, larval survival and adult fecundity will be greatly reduced and as a result, stem borer densities will be low (Bosque-Pérez and Schulthess, 1998). The combined effect of fewer adults and reduced fecundity may explain the low incidence of *S. calamistis* in maize early in the first rainy season.

Injury and damage caused by stem borers

Most stem borer species produce similar injury symptoms on attacked gramineous plants. Newly hatched larvae feed initially by scraping in the leaf whorls of young plants, producing characteristic 'window-paning' and 'pinholes'. Later, the larvae tunnel into stems and may kill the central leaves and growing point, producing 'deadhearts' that will give no yield. The larvae also bore into the maize cobs and feed on the developing grains. Plants thus affected have poor growth and reduced yield and are more susceptible to wind damage and secondary infections (Seshu Reddy, 1998).

In East Africa, objective assessments of grain-yield losses attributable to stem borers are few. Youdeowei (1989) and Seshu Reddy and Walker (1990) gave estimates of 15 to 40% of potential yield, while losses of 18% were recorded in coastal Kenya (Warui and Kuria, 1983). Based on the level of 15% yield loss, the approximate production loss in tonnes of maize is estimated in Table 1.1.

Control strategies for cereal stem borers

Chemical control

Chemical application is the commonly recommended method for stem borer control, and research has shown its efficacy (Mathez, 1972; Warui and Kuria, 1983). However, pesticides must be applied frequently due to continuous infestation and the relatively short time larvae are exposed, which makes the method time-consuming and expensive. Chemical control is therefore not appropriate and often not feasible for the majority of small-scale farmers. Commercially produced alternative pesticides, for example based on products of the neem tree (*Azadirachta indica* A. Juss) or the bacteria *Bacillus thuringiensis* Berliner, have potential (Brownbridge, 1991; ICIPE, 1995), but these products are not yet readily available and may be costly (Mihm, 1994).

Cultural control

Some cultural control methods, such as intercropping with non-cereals and early planting, have been practised by farmers for centuries for various reasons (Minja, 1990; Waaijenberg, 1993). The efficacy of these cultivation practices against stem borers is often questionable. For example, Oloo (1989) and Skovgård and Päts (1996) demonstrated that the impact of intercropping maize and sorghum or maize and cowpea on stem borer populations is limited. Early planting alone is also unlikely to result in higher sustainable yields (Nwanze and Mueller, 1989). Methods such as placing ash or soil in the leaf whorl are practised locally (Grisley, 1997), but their efficacy has yet to be determined. Some effective cultural control strategies have been identified, but not all are feasible for subsistence farming systems. Management of crop residues such as burning or removing stems and stubble would reduce infestation in the following season (Ingram *et al.*, 1973) but farmers leave stems in the field purposely to increase soil fertility. Partial burning or exposing stems to the sun by horizontal placement causes high mortality of stem borer larvae (Gebre-Amlak, 1988; Päts, 1996) but farmers may consider this method too labour-intensive. Other effective yet labour-intensive methods include removal of infested plants, planting of trap or repellent crops (e.g. Khan *et al.*, 1997) and deep tillage. Deep tillage is often also not possible because tractors or oxen are not readily available or too expensive to hire or buy. Host plant resistance is promising, but agronomically and palatable maize varieties are not yet available. An extensive review of these and other cultural control methods is given by van den Berg *et al.* (1998).

Biological control

Indigenous natural enemies

A wide range of egg, larval and pupal parasitoids of stem borers has been identified, but there is little information available on the occurrence of predators,

nematodes and microbial pathogens (Bonhof *et al.*, 1997). The most abundant and widespread parasitoids in the East African region are the egg parasitoids *Telenomus* spp. and *Trichogramma* spp., the larval parasitoids *Cotesia sesamiae* and *Sturmiopsis parasitica* and the pupal parasitoids *Pediobius furvus* and *Dentichasmias busseolae* (for a review, see Bonhof *et al.*, 1997). Ants, spiders and earwigs are believed to cause high mortality on stem borer eggs and young larvae (Mohyuddin and Greathead, 1970; Girling, 1978; Oloo, 1989). However, additional studies that quantify predation on all stem borer life stages, as well as long-term studies on predator and stem borer populations and their interactions are long overdue. Nematodes and microbial pathogens have been reported to infect all life stages, but their impact is low under natural conditions (Odindo *et al.*, 1989). In general, indigenous natural enemies are not able to keep stem borer populations below economic injury levels (Oloo, 1989; Overholt *et al.*, 1994).

Classical biological control

Because of the low impact of indigenous natural enemies on stem borer populations, a biological control programme was initiated in 1968. Nine parasitoid species were released in Kenya, Uganda and Tanzania, but none of the species established (CIBC, 1968-1972) and stem borers continued to be an important pest (Sithole, 1989; Overholt *et al.*, 1994; Kfir, 1997b). In 1990, a second biological control programme began in Kenya. The exotic larval parasitoid *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) was released in the coastal area of Kenya in 1993. After establishment, it spread several hundred kilometres from the release sites and colonised new areas. The parasitoid's impact is still low, although parasitism has increased considerably since 1997 in comparison to the initial four years after release. *C. flavipes* has now also been released in other parts of Kenya, in Uganda, Zanzibar, Somalia and Mozambique, while further introductions in other countries are being planned (W.A. Overholt, personal communication).

In summary, the currently available cultural, varietal or chemical control methods are often not effective or feasible for small-scale subsistence farmers. The impact of the indigenous and exotic natural enemies is low, although the introduced parasitoid *C. flavipes* may become important in the future. The need remains for the development of a sustainable, low-cost and effective management strategy to control cereal stem borers in Africa.

PROBLEM DESCRIPTIONS, RESEARCH FOCUS, METHODOLOGY AND OUTLINE OF THESIS

Problem description

Life table studies in West Kenya indicate that mortality of stem borers can be very high under field conditions, with only 5% of the eggs producing moths (Oloo, 1989; Oloo and Ogeda, 1990). In the coastal region of Kenya, mortality is thought to be equally high (Mathez, 1972). Mortality of eggs and small larvae is often over 90%, but that of late instar larvae and pupae is much lower (Mohyuddin and Greathead, 1970; Mathez, 1972; Oloo, 1989; Oloo and Ogeda, 1990). Disappearance is nearly always the most important mortality factor of all life stages. Disappearance is usually attributed to predation (Mohyuddin and Greathead, 1970; Leslie, 1982; Kfir, 1988; Oloo, 1989) but this is a conjecture based on little research. Other factors that may cause disappearance, such as rainfall, solar radiation (desiccation) and cannibalism have so far received little attention. Consequently, there is a need to study both biotic and abiotic factors in more detail in order to gain a better insight into the causes of 'disappearance'.

Abiotic factors such as rainfall, wind and solar radiation may have influenced disappearance rates found in life table studies. Eggs and young larvae seem most vulnerable to these factors. Nuessly *et al.* (1991) found that wind and rain caused

considerable dislodgement of *Helicoverpa zea* (Boddie) eggs laid on leaf surfaces of cotton. Studies on rice leaf folder eggs did not show a clear relation between rainfall and dislodgement, unless wind speeds were very high (de Kraker, 1996). Disappearance of young larvae feeding in the leaf whorl may be influenced by heavy rainfall or strong wind, which could either drown the larvae or blow them off plants. Harcourt (1966) reported that rainfall is an important cause of mortality of the first two larval stages of *Pieris rapae* Linnaeus on cabbage. Van Huis (1981) found that rainfall during early infestation by *Spodoptera frugiperda* (J.E. Smith) in maize decreased the percentage of infested plants and also reduced the number of larvae per infested plant. He concluded that rainfall results in important reduction of the early instars of *S. frugiperda*. Disappearance of late instar larvae may indirectly be caused by solar exposure or desiccation. Early and late instar larvae leave the original host plant to search for new plants (Berger, 1992). These larvae are highly exposed to solar radiation and other adverse factors, especially while crawling on the ground.

The role of predators as mortality agents of stem borers in Africa is still poorly understood. A few quantitative studies were conducted in South Africa in the early 1980s (Leslie, 1982, 1988; Carnegie, 1991) but most other information is anecdotal (for a review, see Bonhof *et al.*, 1997; Bonhof, 1998). In East Africa, two small studies were conducted: a Petri dish study on consumption capacity of abundant predators (Dwumfour, 1990) and a study where predators were excluded from 10 plants carrying egg batches of *E. saccharina* (Girling, 1978). Information on predator species and abundance, as well as their interactions with stem borers, is limited to empirical observations. To obtain a proper understanding of the relationship between predators and stem borers, it is necessary to study both predator and stem borer populations across several seasons and locations. The high variation in disappearance found between different environments in previous studies (e.g. Mathez, 1972; Girling, 1978; Oloo, 1989) suggests that there may be possibilities to enhance predation through environmental manipulation such as weeding regimes or

wild habitat management, as natural vegetation is thought to provide shelter and alternative food for natural enemies (e.g. Altieri *et al.*, 1977; Altieri and Whitcomb, 1979).

Research focus

This study focuses on the important but previously uninvestigated mortality factors causing disappearance of cereal stem borers in Kenya. Special emphasis is given to the impact of predators, but the role of parasitoids and physical factors such as rainfall, wind and sunshine are also studied.

Methodology

Methods to evaluate predation have been reviewed extensively (e.g. DeBach and Huffaker, 1971; Grant and Shepard, 1985; Luck *et al.*, 1988). In our study, we used a combination of sampling, experimental and observational methods to assess the impact of predators on maize stem borers in the southern coastal region of Kenya. A number of reviews dealing with the evaluation of indigenous natural enemy impact (e.g. Luck *et al.*, 1988; Bellows *et al.*, 1992) stress the fact that no single method is without limitations. The use of various techniques serves to complement and cross-check results.

Outline of thesis

To provide background information to the research, farmers' perceptions of the importance, control measures and natural enemies of maize stem borers were obtained by means of interviews (Chapter 2). This information is also crucial for developing a stem borer control strategy that is appropriate for small-scale farmers in the region. Information on the natural enemies of cereal stem borers in East Africa is reviewed from published and unpublished records (Chapter 3). To explore the impact of the predator complex, abundance and temporal associations of stem borers and

predators were investigated (Chapter 4). The fate of naturally occurring *Chilo* spp. egg batches in maize and sorghum fields was followed to determine the role of parasitism, predation, disappearance and non-hatching on mortality of this relatively vulnerable life stage (Chapter 5). To unambiguously identify the major egg predators, direct observations of egg predation were made in maize fields during two seasons. Direct observations were complemented by laboratory assessments of prey acceptance, predation capacity and prey preference of a range of predator species (Chapter 6). A series of exclusion experiments was conducted to quantify the impact of the predator community on *C. partellus* eggs, small larvae (L1-L2), large larvae (L4-L5) and pupae (Chapter 7). The role of abiotic factors such as solar radiation and rainfall on disappearance of eggs and small larvae was studied using sheltered and unsheltered plants (Chapter 8). The thesis concludes with a general discussion (Chapter 9) where the outcome of the research is discussed and the possibilities to improve the management of stem borers is examined.

Chapter 2

FARMERS' PERCEPTIONS OF IMPORTANCE, CONTROL METHODS AND NATURAL ENEMIES OF MAIZE STEM BORERS AT THE KENYAN COAST

ABSTRACT

Resource-poor farmers at the Kenyan coast considered insect pests, and stem borers in particular, an important production constraint in maize growing. Knowledge of stem borer biology and possible sources of infestation was limited. Stem borer larvae and pupae were frequently seen but eggs and adults were less well-known. Farmers were not aware that the pest could survive in wild grasses and in dry stems, and nearly all farmers left dry stems and stubble in the field after harvest. Several methods for controlling stem borers were known, but only 32% and 56% of farmers in Kilifi and Kwale Districts, respectively, used any of the methods. Chemical control was the most popular control measure, being applied regularly by 19% and 38% of farmers in Kilifi and Kwale Districts, respectively. Traditional methods and cultural control methods were seldom used. Approximately 50% of farmers had heard of beneficial insects, with farmers collectively mentioning 17 predators of stem borers. Cocoons of the parasitoids *Cotesia flavipes* and the indigenous *Cotesia sesamiae* had been seen by 33% of respondents, but none knew what these were. The results of the present study stress the need to create awareness on the biology and ecology of stem borers and the role of natural enemies. Also, after effective control methods should be developed locally by farmers and researchers together, for example through the Farmers Field School approach.

INTRODUCTION

Since the 1980s, there has been a growing interest in initiating research from the farmers' perspective by documenting and analysing the effects of existing agricultural practices on pests (e.g. Altieri, 1984; Matteson *et al.*, 1984; Smit and Matengo, 1995; Päts, 1996). One of the most important insect pests in maize in East and southern Africa is the stem borer (Nye, 1960; Youdeowei, 1989). *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae) is the predominant stem borer species in lowland areas of the region (Overholt *et al.*, 1994; Kfir, 1997) and it is becoming increasingly important at higher elevations (Kfir, 1997a). Practices such as crop sanitation, wild host management, manipulation of planting date, the use of resistant varieties and the use of chemicals may have a considerable influence on stem borer populations. Destroying dry stems and stubble, for example, may considerably reduce stem borer populations in the new growing season. However, this method is seldom practised because the dry stems are used for many purposes (Päts, 1996). Stem borers can also overcome the dry season by staying active in wild host plants. The role of wild grasses in survival of stem borers is unclear. For many years, wild grasses were thought to act as reservoirs for stem borers (Usua, 1968; Joyce, 1976), and their destruction was encouraged (Ingram, 1958; Nye, 1960). Recent studies have, however, indicated that wild grasses can also act as trap plants, causing high mortality of stem borers (Khan *et al.*, 1997; Schulthess *et al.*, 1997). Wild grasses also play a role in the survival of stem borer parasitoids (W.A. Overholt, personal communication). Sowing early may decrease borer damage because the maize's most susceptible plant stage does not coincide with periods of peak egg and larval abundance of the stem borer. Early planting should be conducted on a large scale in order to be effective, and its practicability clearly depends on local (weather) conditions. The method may be useful in combination with other stem borer control methods, but alone it is unlikely to result in higher sustainable yields (Nwanze and Mueller, 1989). Chemicals can effectively reduce stem borer populations if applied

at the correct time (Mathez, 1972; Warui and Kuria, 1983), but their cost will be a major burden for many farmers (Saxena *et al.*, 1989). The use of chemicals may also interfere with the activity of natural enemies.

At present, very little information is available on the use of the above practices at the Kenyan coast. To develop a stem borer control strategy that is appropriate for resource-poor farmers in the coastal area, information is needed on maize growing practices and farmers' knowledge of stem borers, control methods and natural enemies.

MATERIAL AND METHODS

Study regions

The survey was conducted in Kwale and Kilifi Districts, Coast Province, Kenya (Figure 2.1). Maize production is predominantly practised in a zone of approximately 35 km from the sea to the hinterland that crosses the Agro-Ecological zones CL2 to CL4 (Jaetzold and Schmidt, 1983). Soils vary with topography and geology, but most are characterised by low structural stability, sensitivity to erosion and a low to very low fertility (Jaetzold and Schmidt, 1983). Maize is the most important crop, followed by cassava and cowpea. Most food crops are produced for home consumption, and yields are usually not high enough to form surpluses that could be sold (Van Oosten, 1989).

Sampling procedures

In each of the two Districts, three Divisions were chosen, and in each Division we selected two Locations. In each Location, two sub-Locations were selected in which one village was sampled. In this way, 12 villages were selected in each District. Selection of Divisions, Locations and sub-Locations was based on suitability of area
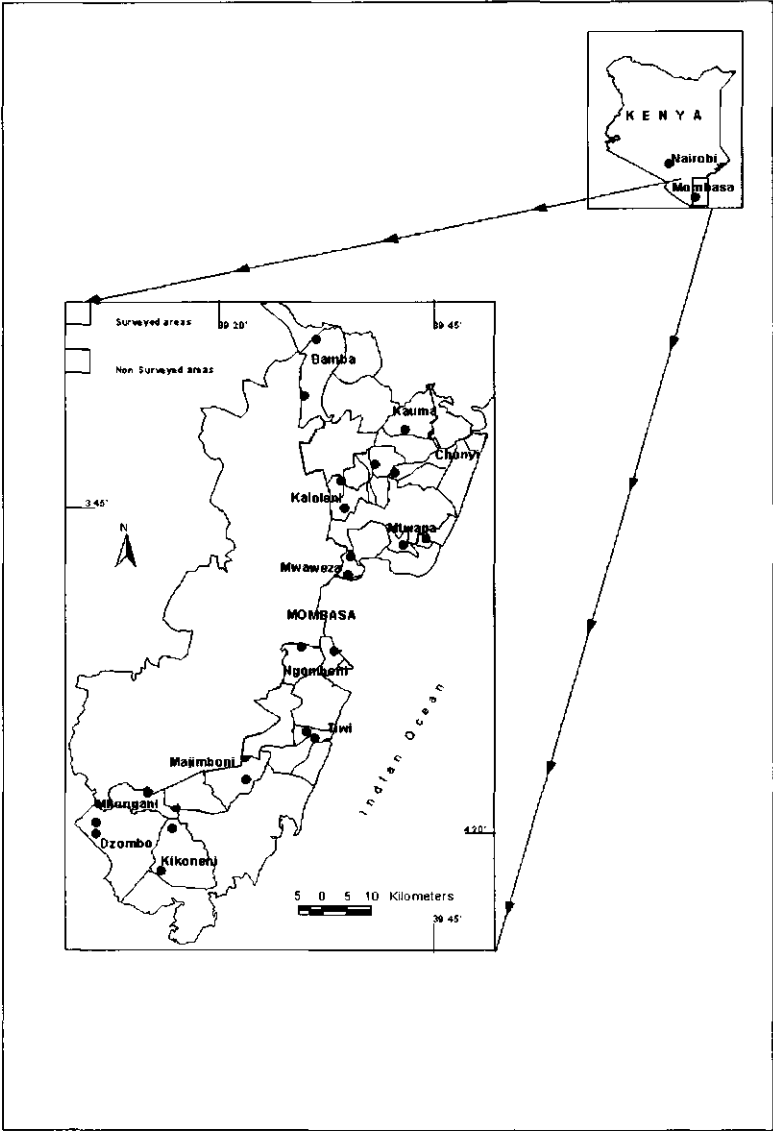
Figure 2.1.   Surveyed villages (indicated by dots) in 12 Locations (indicated by names) at the southern Kenyan coast.

Kwale District.	Msambweni Division:	Dzombo and Kikoneni Locations
	Kubo Division:	Mkongani and Majimboni Locations
	Matuga Division:	Tiwi and Ngombeni Locations
Kilifi District.	Bahari Division:	Mtwapa and Chonyi Locations
	Kaloleni Division:	Kaloleni and Mwaweza Locations
	Ganze Division:	Bamba and Kauma Locations.

for maize production (rainfall and soil type), accessibility and non-exposure previously to pest management projects. Social customs prevented us from directly addressing farmers (especially females) in fields and we therefore interviewed homestead heads at their houses. In each village, approximately 10% of the homestead heads were selected by picking the xth name (with x chosen randomly for each village) from a list with names of male and female homestead heads. All interviews were conducted by an enumerator in the Kiswahili language using a structured questionnaire.

Topics in the questionnaire related to maize growing practices, wild habitat management, stem borer knowledge, stem borer control practices and natural enemies. Questions were addressed to the household head but other members of the household often participated in the discussion. Information on stem borer life stages and specific predators (earwigs, ants, spiders, coccinellids, chrysopids, anthocorids and staphylinids) was obtained by showing the respondents vials containing these insects in alcohol. The farmer's knowledge of the insect and its function as well as the local name of the insect were recorded.

All quantitative data were analysed using the General Linear Model procedure after applying square-root transformation. Mean separations were carried out using the Student-Newman-Keuls test (SNK).

RESULTS AND DISCUSSION

General information on the interviewed farmers

A total of 240 household heads were interviewed, 62% being over 40 years old, and 33% being women. The level of education was low, with 50% of men and 62% of women having no formal education. Nearly all respondents (95%) were full-time farmers.

Maize growing and farming practices

Farm sizes in the study area ranged from approximately 0.5 ha to 12.0 ha, with 7% of farmers owning less than 0.1 ha, 70% owning 1.1 to 4.0 ha, 16% owning 4.1 to 8.0 ha and 7% owning more than 8.1 ha. Average farm sizes are shown in Table 2.1. The majority of farmers (80%) used only a small portion (0.1 to 2.0 ha) of their land for crop production. The area used for crop production was almost exclusively planted with maize (Table 2.1). In the long rainy season, all farmers grew maize but in the short rainy season 27% did not do so because of the unreliable rainfall and the high stem borer density. Unreliable rainfall was also a reason why nearly all farmers planted after the onset of the rains, although the lack of labour for planting was also an important factor. Local maize varieties were grown by 87% of the farmers. These varieties were especially popular because farmers felt they were high yielding, early maturing, drought resistant and not affected by storage pests. The improved varieties Pwani Hybrid 1, Pwani Hybrid 4 and Coast Composite were only planted by a few farmers.

Nearly all respondents (86%) left maize stems in the field after harvest to increase soil fertility or reported to do so because it is the common, traditional practice. In Kwale District, old stems were sometimes heaped on terraces to prevent soil erosion. Farmers removed stems to feed animals or to clear the land for a second crop. Only two farmers removed the stems to reduce the carry-over of stem borers to the next season's crop.

The average yield in the study area was highly variable and ranged from 827 to 1256 kg/ha per year between Divisions (Table 2.1). These estimates by farmers were far below the national average of 1662 kg/ha for 1996 (FAO, 1999). In the long rainy season of 1996, half of the farmers obtained the expected yield. In the short rainy season of 1996, this percentage decreased to only 10%. Unreliable rainfall (mentioned by 78 and 55% of farmers for the long rains' crop and short rains' crop, respectively), stem borer infestation (mentioned by 15 and 20%) and late planting

(mentioned by 0 and 14%) were major factors reducing the yield in 1996. Weather data for that year show that the rainfall pattern was very different from that in other years. Although the total amount of rainfall was normal (1300 mm), the distribution pattern was not. The long rainy season started early, before most farmers had finished land preparation. The rains also stopped early (in May), so the crop could not complete its development. The short rainy season failed almost completely, with only 120 mm rain. The unusual rainfall pattern in 1996 may explain why drought was mentioned as the main yield-reducing factor (for 1996) yet stem borers were generally considered to be more important.

Table 2.1. Farm and yield characteristics in six Divisions at the southern Kenyan coast.

| District | Division | Farm size | Surface (ha) used for | |
			crop production	maize production
Kwale	Msambweni	3.4 ± 0.3	1.4 ± 0.1	1.3 ± 0.1
	Kubo	4.1 ± 0.5	0.9 ± 0.1	0.8 ± 0.1
	Matuga	3.3 ± 0.6	0.9 ± 0.1	0.8 ± 0.1
Kilifi	Bahari	3.5 ± 0.3	1.6 ± 0.1	1.5 ± 0.1
	Kaloleni	3.3 ± 0.5	1.1 ± 0.2	1.1 ± 0.2
	Ganze	3.1 ± 0.4	1.0 ± 0.1	1.0 ± 0.1

| District | Division | Yield (kg/ha) | | |
		long rains 1996	short rains 1996	total 1996
Kwale	Msambweni	773.9 ± 57.6	263.7 ± 58.7	1106.7 ± 114.4 ab
	Kubo	628.1 ± 47.0	202.6 ± 35.4	826.9 ± 72.4 abc
	Matuga	581.7 ± 106.1	151.0 ± 39.8	688.1 ± 157.6 bc
Kilifi	Bahari	892.4 ± 62.2	342.0 ± 74.7	1256.0 ± 118.2 a
	Kaloleni	801.5 ± 98.1	83.0 ± 25.0	834.9 ± 107.3 abc
	Ganze	451.9 ± 52.2	186.4 ± 46.1	643.6 ± 73.2 c

Figures shown are untransformed averages and standard errors. Analysis was conducted on square-root transformed data. Figures within the same column followed by the different letters indicate significant differences ($p<0.05$) by Student Newman Keuls test.

Constraints to maize production

Insect pests, wildlife and drought were considered to be the major constraints to maize production. Insect pests were mentioned by 99% of farmers and were ranked most important by 54% (Figure 2.2). Drought was a common problem in both Districts but was generally considered to be less important than insect attack, possibly because it is seen as beyond the farmers' control (Waaijenberg, 1993). Likewise, low soil fertility may have been considered to be a 'fact' and therefore not often mentioned. In some areas, guinea fowls and rodents caused high damage by digging up seeds or young plants. Wildlife often caused considerable damage to the maturing crop. Other, less frequently mentioned and lower ranked constraints included shortage of labour or land, lack of farm inputs and a fungal disease locally known as 'Baridi' or 'Asili' (possibly southern leaf blight (*Exserohilum maydis*) or southern leaf spot (*Cochliobolus carbonum*)).
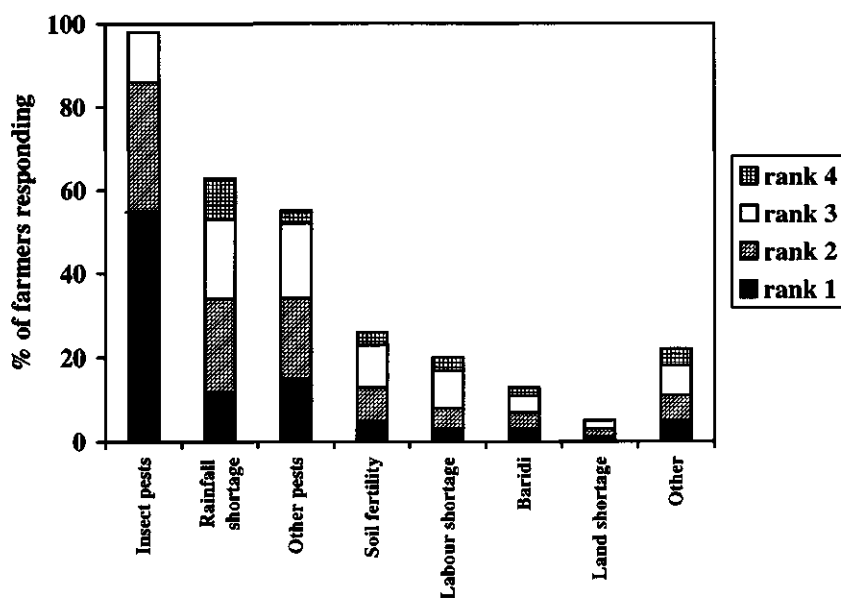
Figure 2.2. Constraints to maize production, as indicated by farmers. Baridi = fungal disease, possibly southern leaf blight or southern leaf spot.

Of the insect pests, stem borers were perceived as a problem by 97% of farmers (Figure 2.3). Armyworms (*Spodoptera* sp. or spp.) were local and sporadic pests, but their damage can be massive if an outbreak occurs (Youdeowei, 1989). Black beetles damaging roots and the lower part of the stem of young plants (possibly chafer grubs or *Heteronychus* spp. (Coleoptera: Scarabidae), were frequently reported by farmers in Kilifi District. In some villages, they were the most important pests. Leaf rolling caterpillars were mentioned in Kwale District but not in Kilifi District. Among storage pests, weevils (possibly *Sitophilus* spp. (Coleoptera: Curculionidae)), larger grain borers (*Prostephanus truncatus* (Horn) (Coleoptera: Bostrychidae)) and other storage borers (possibly *Chilo* spp. (Lepidoptera: Pyralidae) or the grain moth *Sitotroga cerealella* (Olivier) (Coleoptera: Gelechiidae)) were regarded as destructive (Figure 2.4). Identifying pests based on farmers' descriptions was sometimes difficult. One common name was often used for several insect species or families, and one species was also frequently known under several names.

Stem borer control methods

Thirty-six and 59% of farmers attempted to control stem borers in the two Districts (Table 2.2). Chemical control was the most used method, especially in areas with adequate rainfall to grow cash crops, good market possibilities, opportunity for off-farm employment and relatively good road connections. Bulldock (beta-cyfluthrin) and Dipterex (trichlorfon), two granular insecticides that are applied in the leaf whorl, were the most frequently used chemicals. Traditional methods, such as application of ash or soil in the whorl, were seldom used at the southern Kenyan coast, unlike in the Kenyan highlands (Grisley, 1997) and the Eastern Province of Kenya (J. Songa, personal communication). Possibly, knowledge of traditional methods may have been gradually lost with the increased use of pesticides, as was found by Atteh (1984) in Nigeria. The more prestigious status of chemicals may also

have influenced the farmers to under-report the knowledge and use of traditional methods.
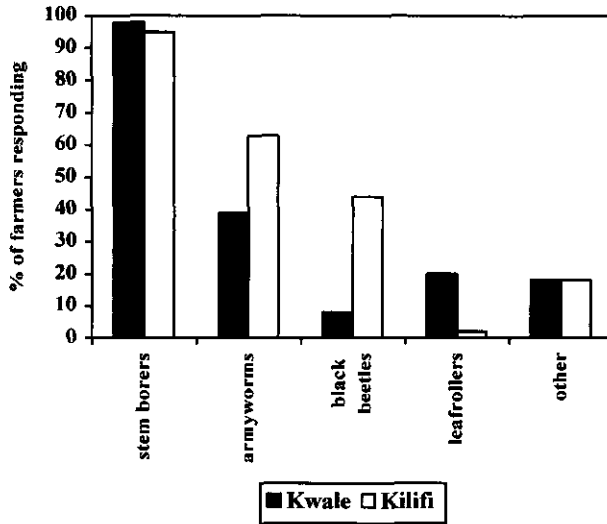
Figure 2.3. Insect pests of maize mentioned by farmers in Kwale and Kilifi Districts as being important. Black beetles = possibly chafer grubs or *Heteronychus* sp.
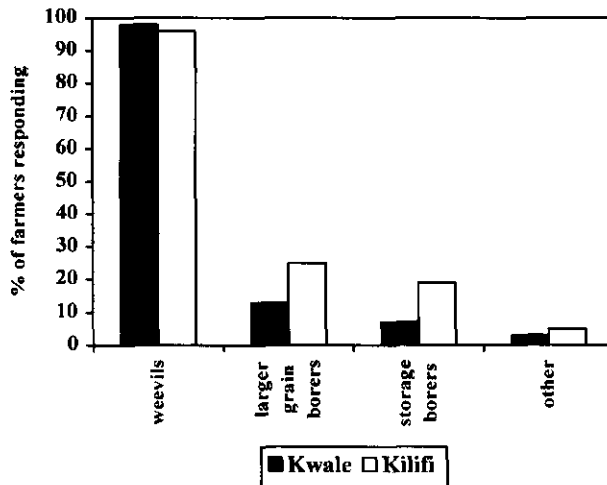
Figure 2.4. Insect pests in maize storage mentioned by farmers in Kwale and Kilifi Districts as being important.

Table 2.2. Percent of farmers reporting knowledge and utilisation of various management tactics for cereal stem borers in Kwale and Kilifi Districts.

Control method	Percent awareness		Percent utilization	
	Kwale	Kilifi	Kwale	Kilifi
Chemical control	93	96	41	19
Cultural control:				
Early planting	3	7	3	3
Resistant varieties	2	3	2	0
Proper weeding/rotation	3	1	3	0
Burn around field	0	2	0	0
Removing infested plants	11	2	3	2
Other	4	0	0	0
Neem	7	2	3	1
Bacillus thuringiensis	3	3	0	0
Natural enemies	1	1	-	-
Traditional methods:				
Sand or soil	0	1	0	0
Ash	13	9	4	3
Witchcraft	0	2	0	1
Tobacco leaves	0	7	0	2
Tree/seeds*	1	17	0	4
Do not know any method	4	3	-	-
Do not use any method	-	-	41	64

- = not applicable.
*Farmers reported that the following trees and shrubs could be used to control stemborers:
seeds: Mbarika (species unknown)
leaves: *Croton pseudopulchellus* Pax (Euphorbiaceae), *Tephrosia vogelli* Hook.f. (Papilionaceae),
       'Utudi' (possibly *Euphorbia tirucalli* L. (Euphorbiaceae)), 'Mbonobono' (possibly
       Harungana madagascariensis Poir. (Guttiferae) or *Trema orientalis* (L.) Bl. (Ulmaceae)).
Only *T. vogelli* and 'Mbonobono' were reported to be used for stemborer control.

Cultural control methods are often the most relevant and economic methods of pest control available to subsistence farmers (Van den Berg *et al.*, 1998). At the coast, only few farmers were aware of the stem borer-reducing effect of practices such as choice of cultivar, crop sanitation and early planting. Recently, researchers and farmers worked together in selecting promising and agronomically acceptable resistant maize cultivars (ISERIPM, 1997). Two suitable cultivars were handed over to the organisation responsible for certification, but the cultivars have not been released up to now (S. Sithanantham, personal communication). Crop sanitation recommendations such as burning of stems are not likely to be adopted because farmers left maize stems in the field purposely after harvest to increase soil fertility. An alternative to burning is placing stalks horizontally after harvest, thus exposing

them to the sun and heat (Gebre-Amlak, 1988; Päts, 1996). Stalks could also be turned into compost (ISERIPM, 1997). Both methods effectively reduce stem borer populations, require a low input of labour and money, and the crop residues can still be used to improve soil fertility. Early planting can be an effective measure to escape serious borer attack (Warui and Kuria, 1983), but this method has little potential in our study area. Farmers seldom risked planting before the onset of the rains because of the unreliability of rains. Lack of labour also means that early planting cannot be done over a wide area, and isolated early plantings may even be more severely attacked than later plantings (van den Berg *et al.*, 1998). Other cultural control methods such as tillage, crop rotation, the use of trap crops, water management and increased planting density are reportedly effective in reducing stem borer populations, but most of these recommendations are not practical or not feasible for subsistence farmers (van de Berg *et al.*, 1998).

Natural enemies

Approximately 50% of farmers were aware of the existence of 'good insects', with bees, ants and spiders being the most frequently mentioned beneficials. A total of 17 insect groups, which included ants, spiders, termites, praying mantids, grasshoppers, millipedes, black beetles and others (Table 2.3), had been observed eating stem borers. Of the potential predators displayed in glass vials, only *Orius* sp. (Hemiptera: Anthocoridae) had not been seen by farmers. This is not surprising, since *Orius* spp. are very small (approximately 1 mm) (van den Berg, 1993). More than 80% of farmers recognised ants (*Camponotus* sp.), earwigs (*Diaperasticus erythrocephala* Olivier) and spiders (Thomisidae), while a majority had also seen coccinellids (*Cheilomenes propinqua propinqua* (Mulsant)) and staphylinids (*Paederus sabaeus* Erichson) in their fields. The perception of the role of these insects in the agro-ecosystem varied considerably. Most farmers were not aware of the ecological role of the insects displayed to them, i.e. they did not consider them to be beneficial or

harmful. Approximately 20% of farmers considered spiders and ants to be 'good' insects. Both groups were appreciated for their predatory behaviour, and ants were also said to frighten wild pigs. Spiders and ants were also regarded as harmful by some farmers. Spiders were thought to fold maize leaves, while ants were said to eat mature maize cobs or to sting people. Earwigs, coccinellids, cockroaches and staphylinids were generally regarded as 'bad' insects. Their beneficial impact (Chapter 6) was either not recognised, or possibly considered to be less important than their damage. Farmers associated earwigs, coccinellids and staphylinids with crop injury such as feeding on cobs and folding of leaves. However, it is unlikely that these groups cause such symptoms (J. Marshall, R. Booth, personal communications) and farmers may have confused their presence with symptoms caused by other insects. The predatory coccinellid shown to the farmers, *C. propinqua propinqua*, for example, may have been confused with plant-feeding coccinellids of the subfamily Epilachninae. Cocoons of the parasitoids *Cotesia sesamiae*, indigenous to the study area, and the introduced *C. flavipes* had been observed by 33% of farmers in maize cobs or stems, but none of the farmers knew what these were.

Table 2.3. Predators of stem borers, as observed by farmers from two Districts at the southern Kenyan coast.

Insect	% respondents in		
	Kwale (N=60)	Kilifi (N=47)	Average (N=107)
Safari ant	9	23	16
Other ants	18	13	16
Spider	2	0	1
Praying mantids	1	1	1
Termites	2	0	1
Grasshoppers	1	1	1
Millipede	0	1	1
Black beetles	0	2	1
Unidentified	6	9	7

How to improve stem borer control?

Our study indicated a gap in farmers' knowledge on stem borers, stem borer control methods and natural enemies. There is a need to create awareness on the biology and ecology of pests and the role of beneficial insects in the farmers' fields. It is also important to explore new pest control strategies since only few effective, low input and acceptable control methods are available. Both could be done through the Farmers Field School (FFS)-approach. In this approach, farmers 'analyse' biology and agro-ecology of pests in group sessions held weekly during the growing season and learn and improve pest management by discussing and experimenting (van Huis and Meerman, 1997). By letting the farmers learn, experiment and generate their own technology, new IPM options that are acceptable to farmers in the target area will be developed. The FFS approach is highly successful in irrigated rice in Asia (Kenmore, 1997), but the concept is fairly new to sub-Saharan Africa. In Kenya, the FFS-approach has been applied in vegetable and coffee growing, where it had significant impacts with respect to the use of integrated pest and crop management practices and the concepts that underlie them. Farmers made their crop management decision differently as a result of the FFSs by, for example, assessing crop health and natural enemy activity before using insecticides (Loevinsohn *et al.*, 1998). It is not clear whether the same positive response can be obtained with a subsistence crop such as maize, as was suggested by observations from Zanzibar (van Huis and Meerman, 1997). A second potential problem is that the FFS-approach should be supported by the whole agricultural system (farmers, local research stations, extension services, the Ministry of Agriculture and the Government) in order for it to have a long-term success. At present, the national extension service is weak due to lack of means. It may take a long time before the extension service will reach its full potential and the FFS-approach can be successfully implemented.

Chapter 3

NATURAL ENEMIES OF CEREAL STEM BORERS IN EAST AFRICA: A REVIEW

ABSTRACT

The noctuids *Busseola fusca* and *Sesamia calamistis* and the pyralids *Chilo partellus*, *Chilo orichalcociliellus* and *Eldana saccharina* are the predominant stem borers of maize in East Africa. They are attacked by a wide range of egg, larval and pupal parasitoids, but information on predators, nematodes and microbial pathogens is less extensive. The most abundant and widespread parasitoids in the East African region are the egg parasitoids *Telenomus* spp. and *Trichogramma* spp., the larval parasitoids *Cotesia sesamiae* and *Sturmiopsis parasitica* and the pupal parasitoids *Pediobius furvus* and *Dentichasmias busseolae*. Predators, such as ants, spiders and earwigs can cause high mortality of eggs and young larvae in some areas. Nematodes and microbial pathogens have been reported to infect all life stages, but their impact is low under natural conditions. The abundance of natural enemies can vary considerably between locations and seasons. In general, indigenous natural enemies are not able to keep stem borer populations below economic injury levels. This paper summarises what is currently known of the natural enemies of cereal stem borers in East Africa.

INTRODUCTION

Maize (*Zea mays* Linnaeus) is a major food crop for millions of people in eastern Africa (Warui and Kuria, 1983; Minja, 1990). It is primarily grown by small-scale farmers, and the average yield is only 1750 kg/ha (FAO, 1999). A major constraint to an increased production is herbivory by insects. Lepidopteran stem borers are generally considered to be the most damaging insect pests (Nye, 1960; Youdeowei, 1989). If infestation occurs at a young plant stage, the growing point may be destroyed, resulting in deadheart and no yield will be obtained. If plants are attacked at a more mature stage, the damage is less devastating. However, losses can still be 20 to 60% of the potential yield (Warui and Kuria, 1983; Youdeowei, 1989).

In East Africa, injurious stem borer species include the indigenous *Chilo orichalcociliellus* (Strand) and *Eldana saccharina* Walker (Lepidoptera: Pyralidea), and the noctuids *Busseola fusca* (Fuller) and *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) (Ingram, 1958; Nye, 1960; Mohyuddin and Greathead, 1970; Seshu Reddy, 1983; Minja, 1990). The exotic species
Chilo partellus Swinhoe (Lepidoptera: Pyralidae), which reached Africa around 1930 (Tams, 1932), has become the dominant and most economically important stem borer in many areas (Mohyuddin and Greathead, 1970; Harris, 1990; Overholt *et al.*, 1994). *C. partellus* reached Africa around 1930 (Tams, 1932), and has since become the most important stem borer at low-to-mid elevations in East Africa (Seshu Reddy, 1983). There is evidence that it is becoming increasingly important at higher elevations as well (Kfir, 1997a).

Methods currently used to manage stem borers include chemical control, early planting and intercropping with non-cereals (Minja, 1990). Chemical control is usually recommended by national agricultural extension services, and research has shown that it can indeed be effective (Mathez, 1972; Warui and Kuria, 1983). The relatively short time larvae are exposed (i.e. before they enter the stem) makes it necessary to apply

pesticides on a regular basis. This time-consuming and expensive technology may not be feasible for the majority of small-scale farmers. Cultural control methods such as intercropping with non-cereals and early planting have been practised for centuries by farmers (Litsinger and Moody, 1976; Minja, 1990). Recent studies have shown that the impact of these methods is limited (Oloo, 1989; Skovgård and Päts, 1996). Host plant resistance is promising, but agronomically acceptable maize varieties are not yet available. Botanical pesticides, such as neem (*Azadirachta indica* A. Juss) and the commercially produced bacteria *Bacillus thuringiensis* Berliner have potential to control stem borers (Brownbridge, 1991; ICIPE, 1995), but these methods are costly and not widely used (Mihm, 1994). In East Africa, two biological control attempts have been made to increase mortality of *C. partellus*. In the first, nine parasitoid species were imported from India and released in Kenya, Uganda and Tanzania from 1968 to 1972. None of the parasitoids became established (CIBC, 1968-1972). In the second biological control attempt, the exotic larval parasitoid *Cotesia flavipes* was released at the Kenyan coast. The parasitoid became established and has now been recovered from the coast (Overholt *et al.*, 1994), southern western Kenya and western Tanzania (Omwega *et al.*, 1995, 1997). Parasitism by *C. flavipes* has been rising steadily and may eventually become an important factor in some areas (Overholt *et al.*, 1997). This paper summarises what is known of the mortality factors of cereal stem borers in East Africa, including potential biocontrol agents.

NATURAL MORTALITY

Natural mortality of stem borers in the field can be very high. Mathez (1972) estimated that only 5% of eggs produce moths which survive to die of old age, while a study in West Kenya showed that only a small portion of *Chilo* spp. eggs reached the adult stage (Oloo, 1989). Mortality was highest in the egg and early larval stages.

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Eggs

Observations from Uganda, western Kenya and the Kenyan coast suggest that generally only 10% of eggs survive to hatching (Mohyuddin and Greathead, 1970; Oloo, 1989). At the Kenyan coast, egg parasitism was an important mortality factor while predation was negligible (Mathez, 1972; Skovgård and Päts, 1996). In contrast, predation and disappearance were major mortality factors in western Kenya and Uganda whereas egg parasitism was not common in these areas (Mohyuddin and Greathead, 1970; Girling, 1978; Oloo, 1989; Oloo and Ogeda, 1990).

Larvae

Larval mortality can be very high under natural conditions. Oloo (1989) found that 90% of the larvae did not complete their development. Small larvae suffer heavily from cannibalism, predation and abiotic factors such as wind and rain, and mortality up to 100% has been recorded (Mohyuddin and Greathead, 1970; Mathez, 1972; Oloo, 1989). Late instar larvae feed inside the more protected environment of the stem, and their mortality is thought to be much lower than that of early instar larvae. Mathez (1972) found that 10 to15% of late instar larvae in maize stems at the coast was killed by parasitism and diseases. Late instar larvae may also get killed when they leave the stem in search of another host plant (Berger, 1992).

Pupae and adults

In western Kenya, mortality of pupae of *Chilo partellus* in sorghum reached 88%. Disappearance, possibly through predation by ants, was the most important mortality factor (Oloo, 1989). Mortality of adult stem borers has not been reported.

PARASITOIDS

Polaszek (1998) reviewed the parasitoids of lepidopteran cereal stem borers in Africa, as well as their taxonomic characteristics, distribution and host range. The parasitoid species attacking East Africa's most important stem borers are listed in Table 3.1. Some of the parasitoids in this table are incidental or of doubtful status and should therefore be considered with caution.

Table 3.1. Primary parasitoids of common cereal stem borers in East Africa.

Parasitoid	Host species	Host stage	Distribution	Reference
HYMENOPTERA				
Bethylidae				
* *Goniozus* sp.	C.sp.	L	Kenya	12
Goniozus garouae (Risbec) (as: *Parasierola* sp.)	C.sp., Es, Sc	L	Uganda	14
Goniozus indicus Ashmead	Co, Cp	L	Kenya	32
			Sub-Saharan Africa	26
Odontepyris transvaalensis (De Buyson)	?	L	Kenya	32
Braconidae				
Amicrocentrum curvinervis van Achterberg	Bf	?	Uganda	15
Amyosom nyanzaense (Quicke and Wharton)	Bf, Cp	L	Kenya, Uganda	17, 27
* *Apanteles* sp. (ater group)	Cp	L	Kenya	11,12
* *Apanteles* sp. nr *laevigatus* (Ratzenberg)	Co	L	Kenya	13
	Cp	L	East Africa	12
	Bf, Cp	L	Uganda	11
Bassus sp.	?	?	Kenya	32
Bassus sublevis (Granger)	Cp, Es	L	Kenya	27
Bracon sp.	Bf	L	Tanzania, Uganda	11
* *Bracon* (*Glabrobracon*) sp.	Co, Cp	L	Kenya, Tanzania, Uganda	12, 13, 16
Bracon chinensis Szépligeti (*Myosoma chinensis*)	Cp	L	Kenya	18
Bracon sesamiae Cameron	Bf, Cp, C.sp.,	L	Kenya	32
	Es	L	Tanzania, Uganda	27
Chelonus sp.	?	P	Kenya	13
Chelonus curvimaculatus Cameron	Co, Cp	E/L	Kenya	32
	Bf, Cp, Sc	E/L	Kenya, Tanzania, Uganda	11, 27
	?	L	East Africa	21

Table 3.1. Continued.

Parasitoid	Host species	Host stage	Distribution	Reference
Cotesia flavipes Cameron (*Apanteles flavipes*)	Cp	L	Kenya, Tanzania	25, 28, 29
Cotesia ruficrus (Haliday)	?	L	Kenya	32
(*Microgaster ruficrus*) (*Apanteles ruficrus*)	Sc	L	Ethiopia, Eritrea, Kenya, Somalia, Sudan, Uganda	27
Cotesia sesamiae Cameron	Co, Cp	L	Kenya	13, 16, 19, 32
(*Apanteles sesamiae*)	Bf, Cp, Es, Sc	L	East Africa, Sudan, Malawi	12
	Bf, Cp, Sc	L	Uganda	3
	?	L	Ethiopia, Eritrea	26
	Bf	L	Kenya, Uganda	2
	Bf, S.sp.	L	Kenya, Tanzania, Uganda	6
	Es	L	Tanzania	5
* *Dolichogenidae fuscivora* Walker	Bf, Cp	L	Kenya	32
	Bf	L	Ethiopia	24
Dolichogenidea polaszeki Walker	Bf, Cp, C.sp.	L	Kenya, Malawi	24
	Cp	L	Uganda	11
Euvipio rufa Szépligeti	Cp	L	Kenya	16, 20, 32
	Bf, Cp	L	East Africa	12
Glyptapanteles africanus (Cameron) (*Apanteles africanus*)	Cp	L	Kenya, Uganda	24, 32
Glyptapanteles maculitarsis (Cameron) (*Apanteles maculitarsis)*	Bf	?	Kenya, Uganda, Tanzania	24
Glyptomorpha spp.	Co, Cp	L	Kenya	10
Iphiaulax dubiotusus Shenefelt	Es	L	Tanzania	27
Macrocentrus sesamivorus Van Achterberg	Cp, Sc	L	Kenya	27, 32
Mesobracon? Sp.	S.sp.	L	Uganda	3
* *Meteorus* sp.	Bf	L	Kenya	11, 27
Microgaster laevigatus Ratzenberg	?	L	East Africa	21
Myosoma nyanzaensis Quicke and Wharton	Cp	L	Kenya	17, 32
	?	L	Kenya	21
Phanerotoma leucobasis Kriechbaumer	Bf	E/L	Kenya	27, 32
Rhaconotus sp.	Cp	L	Kenya	12
Rhaconotus scirpophagae Wilkinson	Cp	L	Kenya	13, 32
	Cp, C.sp.	L	Kenya, Tanzania	27
Stenobracon deesae (Cameron)	Cp	L	Sudan	9, 21
Stenobracon rufus (Szépligeti)	Bf, Co, Cp, C.sp., Es, Sc, S.sp.	L	Kenya, Tanzania, Uganda	11, 13, 27
Tropobracon sp.	?	L	Kenya	32
Chalcididae				
Antrhocephalus mitys Walker	Cp	P	Kenya	26, 30
* *Brachymeria* spp.	Co, C.sp.	P	Kenya	10, 12
	Bf, Cp, Es	P	Kenya	26

Table 3.1. Continued.

Parasitoid	Host species	Host stage	Distribution	Reference
* *Brachymeria dunbrodyensis* Cram	C.sp.	?	Kenya	10
Brachymeria kassalensis Kirby	Cp	?	Kenya	10
* *Brachymeria olethria* Waterston	Co	?	Kenya	10
	?	P	Kenya	32
Psilochalchis soudanensis (Steffan)	Bf, Cp, Es	P	Sudanic zone	12
(*Hyperchalcidia soudanensis*)	?	P	Uganda, Kenya	3, 16, 19, 32
(*Invreia soudanensis*)	?	P	East Africa	21
	Bf, Co, Cp, Es	P	Kenya, Uganda	26, 30
Eulophidae				
Pediobius sp.	?	?	Kenya	32
	Bf, Cp, S.sp.	P	Uganda	3
Pediobius furvus (Gahan)	Bf, Co, Cp, S.sp.	P	East Africa	12, 13, 16, 19,
(*Pleurotropis furvum* Gahan)	?	P	Sudan	21
	C.sp.	?	Kenya	10, 20, 32
* *Tetrastichomyia* sp. A	?	?	Uganda	26
* *Tetrastichus atriclavus* Waterston	Bf, S.sp.	P	Uganda	12
Tetrastichus sp.	?	P	Kenya	32
Eurytomidae				
* *Eurytoma* sp or spp.	Cp, Es	P	Uganda, Tanzania	12
E. oryzivora? Delvare	Cp	P	Kenya	32
	C.sp.	P	Tanzania	26
Ichneumonidae				
* *Charops* spp.	Bf, Cp	L	Uganda	11
	C.sp.	?	Kenya	10
Dentichasmias busseolae Heinrich	Cp, Co, B.sp.	P	East Africa	3, 7, 12
	?	?	Kenya	16, 18, 26, 32
* *Enicospilus* sp.	Bf, Sc	L	Tanzania, Uganda	12
Enicospilus sesamiae Delobel	Bf, Sc	L	Tanzania, Uganda	31
Ischnojoppa sp.	S.sp	L	Uganda	11
* *Ischnojoppa geniculata* Tosquinet	S.sp.	L	Uganda	12
* *Isotima* sp.	Bf, Cp	L/P	East Africa	12
Pristomerus sp.	C.sp.	?	Kenya	32
Procerochasmias nigromaculatus (Cameron)	Bf, Sc	P	East Africa	12
(*Procerochasmias glaucopterus* Morley)	?	?	Kenya	32
	Bf, Cp, Es, Sc	P	Kenya, Tanzania, Uganda	31
* *Syzeuctus* sp.	Cp	L	Kenya	13, 32
	Bf	L	Uganda	12
Syzeuctus ruberrimus Benoit	Co, Cp	L	Kenya	4, 31, 32
Syzeuctus tonganus (Kriechbaumer)	Co	L	Tanzania	31
Temelucha sp.	C.sp.	?	Kenya	32
Vadonina nimbipennis (Seyrig)	Bf, Co, Cp	?	Kenya	32
	?	?	Kenya, Tanzania, Uganda	13, 31
Xanthopimpla sp.	Cp	P	Kenya	32
Xanthopimpla citrina (Holmgren)	Bf, Cp, Sc	?	Tanzania, Uganda	31

Table 3.1. Continued.

Parasitoid	Host species	Host stage	Distribution	Reference
Xanthopimpla luteola Toiq	C.sp.	?	Kenya	10
Xanthopimpla stemmator (Thunberg)	?	?	Kenya	32
Pteromalidae				
Norbanus sp.	Cp	L	Kenya	32
Scelionidae				
* *Telenomus busseolae* (Gahan)	Bf	E	Kenya	16
	?	E	Kenya	13
	Bf	E	Uganda	12
	Sc	E	Uganda	22, 23
Telenomus sp.	Cp	E	Kenya	16
Telenomus applanatus Bin and Johnson	Es	E	Kenya	22, 32
T. nemesis Polaszek and Kimani	Co, C.sp.	E	Kenya	26, 32
T. thestor Nixon	?	E	Kenya, Uganda	26
Trichogrammatidae				
* *Lathromeris ovicida* (Risbec)	Bf	E	Uganda	12
Paracentrobia dimporpha (Kryger) (*Abbella dimorpha*)	Bf	E	Uganda	11, 30
* *Trichogramma* sp.	Cp	E	Uganda	20, 21
	Cp	E	Uganda	12
	Co, Cp	E	Kenya	13
	Sc	E	Kenya	13
	?	E	Kenya	18
	C.sp.	E	Kenya	32
Trichogrammatoidea sp.	?	E	Kenya	32
	?	E	Uganda	12
	Cp	E	Uganda	21
DIPTERA				
Chloropidae				
* *Scollophthalmus trapezoides* (Beck)	?	L	Kenya	13
* *Polyodaspis sp.? robusta* Lamp	Co, Cp	L	Kenya	13
* *Anatrichus erinaceus* Loew	?	?	Kenya	13
Muscidae				
* *Atherigona* sp.	C.sp.	L	Kenya	10, 11, 13
* *Atherigona* sp. (orientalis group)	Bf, Co, Cp	L	Kenya, Tanzania, Uganda	12
	?	L	East Africa	21
* *Phaonia* sp.	?	L	Kenya	13
Phoridae				
* *Diploneura* sp.	Bf	P	Uganda	3
* *Megaselia* sp.	Bf	P	Uganda	3
* *Plethysmochacta* sp.	?	?	Kenya	32

Table 3.1. Continued.

Parasitoid	Host species	Host stage	Distribution	Reference
Sarcophagidae				
Heteronychia benefactor Malloch (*Uroxanthisca benefactor*) (*Sarcophaga benefactor*)	Bf	L	Tanzania	6
* *Sarcophaga* spp.	Bf, Cp, S.sp.	L	Uganda, Kenya	12
			Kenya	21
Sarcophaga villa Curran (*Chaetophalla villa*)	Bf, Cp, S.sp.	L	Kenya, Tanzania, Uganda	11
Tachinidae				
Unidentified species	Bf	L	Kenya	12
* *Actia* sp.	?	L	Kenya	12
* *Actia sp.? comitata* Villeneuve	Bf, Cp, Es	L	Uganda	12
	Bf	L	Uganda	11
* *Actia sp.? hargreavesi* Curran	Cp	L	Uganda	12
* *Actia sp.? exsecta* Villeneuve	Bf, Cp, Es	L	Uganda	12
	Bf	L	Uganda	11
* *Drino imberbis* Wiedemann	Bf	L	Tanzania	12
(*Prosturmia imberbis*)	?	L	Uganda	8
* *Drino halli* Curran (*Paradrino halli*)	Bf	L	Tanzania	8, 12
* *Metagonistylum* sp.	S.sp.	?	Uganda	12
* *Nemoraea discoidalis* Villeneuve	Bf, S.sp.	L, L/P	East Africa	12
	Bf	P	Kenya, Uganda	11
	S.sp.	P	Uganda	11
* *Peribaea orbata* (Wiedemann)	Cp	L	Kenya	11, 12
* *Pseudoperichaeta laevis* Villeneuve	Cp	L	Uganda	11, 12
* *Siphona murina* Mesnil	Bf, Cp, Es, Sc	L	East Africa	12
	Bf	L	Kenya, Tanzania, Uganda	6
	Bf, Cp	L	Kenya, Tanzania, Uganda	11
Sturmiopsis parasitica (Curran)	Bf, E.sp., Cp, S.sp.	L, L/P	East Africa	12
	Co	L	East Africa	20, 21
	Co	L	Kenya	32
	C.sp.	?	Kenya	10
	Cp	P	East Africa, Sudanic zone	20

* incidental parasitoid or species of doubtful status; Bf = *Busseola fusca;* Co = *Chilo orichalcociellus;* Cp = *Chilo partellus;* Es = *Eldana saccharina;* Sc = *Sesamia calamistis;* B.sp. = *Busseola* species; C.sp. = *Chilo* species; E.sp = *Eldana* species; S.sp. = *Sesamia* species; ? = unknown; E = egg; L = larva; P = pupa.

1 = Gahan, 1928; 2= Wilkinson, 1932; 3= Ingram, 1958; 4= Benoit, 1959; 5= LePelly, 1959; 6= Nye, 1960; 7=Harris, 1962; 8= Robertson, 1965; 9= Mohamed and Venkametran, 1966; 10= La Croix, 1967; 11= Milner, 1967; 12= Mohyuddin and Greathead, 1970; 13= Mathez, 1972; 14= Girling, 1978; 15= van Achterberg, 1979; 16= Oloo, 1989; 17= Quicke and Wharton, 1989; 18= Seshu Reddy, 1989; 19= Minja, 1990; 20= Greathead, 1990; 21= Mohyuddin, 1990; 22= Polaszek and Kimani, 1990; 23= Polaszek *et al.*, 1993; 24= Walker, 1994; 25= Omwega *et al.*, 1995; 26= Polaszek, 1995; 27= van Achterberg and Polaszek, 1996; 28= Omwega *et al.*, 1997; 29= Overholt *et al.*, 1997; 30= Polaszek, 1998; 31= Zwart, 1998; 32= Overholt, unpublished.

Eggs

Egg parasitoids of stem borers in East Africa belong to the genera *Trichogramma*, *Trichogrammatoidea* and *Telenomus*. Egg parasitism fluctuates greatly between geographical locations and between seasons, presumably because of differences in climatic conditions (Mathez, 1972). At the Kenyan coast, Mathez (1972) recorded 92% parasitism for *Chilo* spp. eggs and 97% for *S. calamistis* eggs. In a more recent study, levels of parasitism ranged from 19 to 76% (Skovgård and Päts, 1996). Egg parasitism in western Kenya and Uganda seems to be equally variable, with parasitism ranging from less than 5% to over 50% (Mohyuddin and Greathead, 1970; Oloo, 1989; Oloo and Ogeda, 1990).

Larvae

The larval stages of stem borers are attacked by a great variety of parasitoids, but their impact is usually too low to influence stem borer populations (Mohyuddin and Greathead, 1970; Mathez, 1972; Oloo and Ogeda, 1990). In general, larval parasitism is less than 10% (Mathez, 1972; Girling, 1978; Oloo, 1989; Skovgård and Päts, 1996). *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae) and *Sturmiopsis parasitica* (Curran) (Diptera: Tachinidae) are the most widespread and abundant indigenous larval parasitoids in eastern Africa (Ingram, 1958; Milner, 1967; Mohyuddin and Greathead, 1970). *S. parasitica* is primarily found in the drier areas. High levels of parasitism have been reported from Zimbabwe and parts of Tanzania (Milner, 1967; Mohyuddin and Greathead, 1970), but it was not found in the coastal area of Kenya (Skovgård and Päts, 1996). *C. sesamiae* is more common in the wetter parts of Africa. Parasitism was 0 to 20% at the Kenyan coast and in Uganda (Milner, 1967; Skovgård and Päts, 1996). The exotic parasitoid *C. flavipes* is increasing its distribution and impact rapidly (Overholt *et al.*, 1994). At the coast, seasonal parasitism now ranges from 0 to 7%, while in western Kenya and Tanzania it is up to 63 % (Omwega *et al.*, 1997).

Pupae

Pediobius furvus Gahan (Hymenoptera: Eulophidae), *Dentichasmias busseolae* Heinrich (Hymenoptera: Ichneumonidae) and *Psilochalcis soudanensis* Steffan (Hymenoptera: Chalcididae) are widespread in East Àfrica. *P. furvus* was fairly common at some locations in Uganda and western Kenya (Ingram, 1958; Milner, 1967; Oloo, 1989), but its impact at the Kenyan coast was usually less than 10% (Mathez, 1972; Skovgård and Päts, 1996). *D. busseolae* was also a common parasitoid in West Kenya, and Mohyuddin and Greathead, 1970) suggested it might be able to play a significant role in the reduction of stem borer populations in certain areas. However, as with most parasitoids, the abundance of this species is quite variable. Its impact at the coast was negligible (Mathez, 1972; Skovgård and Päts, 1996), while parasitism in western Kenya reached up to 58% (Seshu Reddy, 1983). In Uganda, the parasitoid was also fairly common (Mohyuddin and Greathead, 1970).

PATHOGENS

Information on the impact of pathogens (fungi, bacteria, protozoa, viruses and nematodes) on stem borers is limited. A study in western Kenya suggested that their impact under field conditions is generally low (Odindo *et al.*, 1989). However, laboratory and screen-house experiments have shown that fungi, the bacteria *B. thuringiensis* and protozoa of the genus *Nosema* have high potential for controlling stem borers. The pathogens reported to infect stem borers in East Africa are listed in Table 3.2.

Table 3.2. Pathogens (bacteria, fungi, nematodes, protozoa and viruses) of cereal stem borers in East Africa.

Genus and species	Host species	Host stage	Distribution	Reference
BACTERIA				
Bacillus thuringiensis Berliner	?	L	Kenya	6
Monococcus sp.	?	L	Kenya	4
Streptococcus sp.	?	L	Kenya	4
FUNGI				
Genus not identified	?	L	Kenya	4
Aspergillus sp.	Cp	L	Kenya	4
Beauveria bassiana (Balsamo) Vuillemin	Cp	E+	Kenya	7
	Cp	SL+	Kenya	7, 10
	Cp	L	Kenya	11
	Bf	LL+	Kenya	10
Cordyceps sp.	Bf	?	?	1
Metarhizium sp.	?	L	Kenya	8
Metarhizium anisopliae var. *anisopliae*	Cp	E+	?	7
(Metschn.) Sorokin	Cp	SL+	?	7
Paecilomyces fumosoroseus (Wize)	Cp	E+	?	7
Brown and Smith	Cp	SL+	?	7
Rhizopus sp.	Cp	L	Kenya	4
NEMATODES				
Mermethidae				
Hexamermis sp.	Es, Bf, Cp	?	Kenya, Tanzania, Uganda	1, 2
Genus not identified	?	?	Kenya	4
Panagrolaimidae				
Panagrolaimus sp.	?	?	Kenya	3
Rhabditidae				
Genus not identified	?	?	Kenya	4
PROTOZOA				
Microsporidia	Bf, Cp, Es	L	Kenya	4
Gregarine	Cp	L	Kenya	4
Nosema sp.	Bf, Cp, Es	L	Kenya	5
Nosema marucae Odindo and Jura	?	L+	Kenya	9
VIRUSES				
Baculoviridae (granulosis virus)	Bf, Cp	L	Kenya	4
Polyhedral inclusion bodies	Bf, Co, Cp	L	Kenya	4

+ Fungus pathogenic against stem borers in laboratory experiments.
Bf= *Busseola fusca*; Co= *Chilo orichalcociliellus*; Cp= *Chilo partellus*; Es= *Eldana saccharina*; ? = unknown
E= eggs; YL= young larvae; LL= large larvae; L = larvae.
1= Milner, 1967; 2= Mohyuddin and Greathead, 1970; 3= Otieno, 1985; 4= Odindo *et al.*, 1989; 5= Odindo, 1990; 6= Brownbridge, 1991; 7= Maniania, 1991; 8= Nyambo and Mwangi, 1991; 9= Odindo *et al.*, 1991; 10 = Maniania, 1992; 11= Maniania, 1993.

Fungi

Fungi recovered from stem borer larvae and pupae include *Beauveria bassiana* (Balsamo) Vuillemin, *Cordyceps* sp., *Rhizopus* sp., *Fusarium* sp., *Metarhizium* sp. and *Aspergillus* sp. (Milner, 1967; Odindo *et al.*, 1989; Nyambo and Mwangi, 1991). Many of the fungi in these genera are saprophytic, and it is possible that they did not kill the stem borers but merely attacked when the host was already dead (N. Maniania, personal communication). Isolates of *Metarhizium anisopliae* var. *anisopliae* (Metschnikoff) Sorokin, *B. bassiana* and *Paecilomyces fumosoroseus* (Wize) Brown and Smith were collected from western Kenya and tested in the laboratory on *C. partellus*. Eggs and neonate larvae hatching from infested eggs were highly susceptible to all isolates of the three fungi, with mortality being over 80% (Maniania, 1991). However, when tested under field conditions, the same isolates only caused 12 to 30% egg mortality. In the field, *B. bassiana* strain B (= isolate ICIPE 35) was the most virulent strain on eggs (Maniania *et al.*, 1994), while isolates of both *B. bassiana* and *M. anisopliae* were most virulent on second instar *C. partellus* larvae. Fifth instar larvae of *B. fusca* were also susceptible to isolates of these two fungi. Thus, although the application of fungi appears not to cause high mortality of eggs under field conditions, its effect on larvae is considerable. Entomopathogenic fungi can be a useful addition to the current control methods of stem borers if applied when small larvae are exposed, but their cost and availability to farmers would have to be addressed.

Bacteria

Bacteria (*Bacillus* sp., *Monococcus* sp., *Diplococcus* sp. and *Streptococcus* sp.) were the most abundant micro-organisms in a survey in western Kenya, but their impact was relatively low (Odindo *et al.*, 1989). In another study, more than 150 strains of *B. thuringiensis* (*Bt*) were recovered from soil, stem borer frass and dead lepidopteran larvae. Several of these strains were highly effective against stem borers (Brownbridge,

1991). *B. thuringiensis* applied on eggs or maize leaves resulted in 100% mortality of neonate larvae, suggesting that ingestion of a small portion of egg shell or leaf is already lethal for early instar larvae. Large *B. fusca* larvae (5th instar) were also highly susceptible to several *B. thuringiensis* strains, with 80 to 100% mortality within 72 hours after ingestion of the bacteria (Brownbridge, 1989). Screenhouse and field trials confirmed that application of *Bt* significantly reduced stem borer populations. As a result, plant damage was lower and a considerable yield increase could be obtained (Brownbridge, 1991).

One of the problems that should be addressed before recommending the use of *Bt* for stem borer control is the low environmental persistence. The low persistence makes it necessary to forecast accurately the most vulnerable life stages of the borer (Brownbridge, 1991). Genetically engineered maize with the gene for producing *B. thuringiensis* may solve the problem and facilitate the cost-effective use by subsistence farmers (Gelernter, 1997). However, the potential for rapid development of resistance by insects to transgenic plants is a major concern, and resistance management tactics using *Bt* maize should therefore be used with this in mind (Whalon and Norris, 1997).

Protozoa

Protozoa of the genus *Nosema* (Microsporidia) have been recovered from field-collected stem borers in Kenya (Table 3.2) (Odindo, 1990). Unlike in the laboratory, where *Nosema* spp. cause big problems in cultures of lepidopteran larvae (Bordat *et al.*, 1984; Walters and Kfir, 1993), their impact in the field is negligible (Odindo *et al.*, 1989; Odindo, 1990). Screenhouse and field experiments showed that applying a spore suspension of *Nosema marucae* Odindo and Jura reduced the *C. partellus* population in sorghum significantly and increased the yield with 34 to 80% (Odindo, 1990; Odindo *et al.*, 1990). *N. marucae* was as effective as the insecticides carbofuran and trichlorophan (Odindo *et al.*, 1991). The effectiveness and non-toxicity to natural

enemies (Odindo *et al.*, 1990) makes *N. marucae* a potential component in the integrated pest management of cereal stem borers but more research is clearly needed.

Viruses

Information on viruses attacking stem borers is limited to a survey in Kenya, where granulosis virus and polyhedral inclusion bodies were isolated from various field-collected stem borer larvae (Table 3.2). The abundance of these viruses in the field was extremely low (Odindo *et al.*, 1989). In other parts of the world, granulosis viruses cause high natural mortality in stem borer larvae. In Réunion, for example, virus infection is common in *Chilo sacchariphagus* Bojer larvae (Fournier and Etienne, 1981), while high infection has also been reported from India (Mehta and David, 1980). This suggests that viruses may have potential for the control of stem borers in East Africa. However, their virulence and synchronisation with the host should be studied well. As with other microorganisms, a cost-effective mass rearing method should be developed and the availability to farmers should be addressed.

Nematodes

Reports on the impact of nematodes on stem borer populations vary considerably. A survey, primarily carried out in West Kenya, showed that mermithids and rhabditids accounted for less than 1% mortality among late instar larvae (Odindo *et al.*, 1989). Mathez (1972) and Overholt (personal communication) also reported a low impact at the Kenyan coast. In Tanzania however, mortality due to nematodes could be as high as 20 to 24% in the rainy season (Mohyuddin, 1968). Laboratory or field experiments examining the potential of nematodes have not been carried out in East Africa, but preliminary studies in South Africa suggested that nematodes could control *E. saccharina* to a certain extent. However, the use of nematodes was not economical (Spaull, 1990, 1992).

PREDATORS

Little information is available on the impact of predators on stem borer populations in eastern Africa. There seems to be a consensus that predators play an important (Mohyuddin and Greathead, 1970; Oloo, 1989; Oloo and Ogeda, 1990), but this presumption is mainly based on anecdotal observations. The currently known predators of stem borers in East Africa are listed in Table 3.3.

Eggs

Eggs are among the most vulnerable life stages of stem borers. Several authors (Mohyuddin and Greathead, 1970; Oloo, 1989) suggested that predation is an important mortality factor of eggs, because they attributed disappearance to predators. In western Kenya, disappearance of naturally occurring eggs was 93% (Oloo, 1989). A report from Uganda indicated that egg predation was equally high in this region. Four ant species, *Cardiocondyla badonei* (Arnold), *C. emeryi* (Forel), *Pheidole megacephala* Fabricius and *Tetramorium guineense* Fabricius (Hymenoptera: Formicidae), were observed preying on the eggs (Mohyuddin and Greathead, 1970). In western Kenya, egg predators included the earwigs *Diaperasticus erythrocephala* Olivier and *Forficula auricularia* Linnaeus (Dermaptera: Forficulidae), the coccinellids *Cheilomenes sulphurea* Olivier, *C. propinqus* Mulsant and an unidentified coccinellid (Coleoptera: Coccinellidae), *Chrysopa* sp. lacewings and the ants *Pheidole* sp. and *Camponotus* sp. (Hymenoptera: Formicidae) (Table 3.3). Various spiders were also observed preying on egg batches of *C. partellus* (Seshu Reddy, 1983; Oloo, 1989). Information on the abundance of predators is limited to a survey conducted in West Kenya. Earwigs were fairly abundant (average of 0.5 earwigs per plant), but ants, coccinellids, chrysopids and spiders were virtually absent (Dwumfour, 1990; Dwumfour *et al.*, 1991).

Table 3.3. Predators of cereal stem borers in East Africa.

Predator species	Host species	Host stage	Distribution	Reference
ARANEIDA				
Unidentified species	Cp	L	Kenya	3, 6, 10
COLEOPTERA				
Coccinellidae				
Cheilomenes sp.	?	?	Kenya	3
Cheilomenes sp.	Cp	E	Kenya	7
Cheilomenes sulphurea Olivier	Cp	E	Kenya	7
C. propinqus Mulsant	Cp	E	Kenya	7
DERMAPTERA				
Forficulidae				
Diaperasticus? erythrocephala Olivier	Cp	E/L	Kenya	3, 6, 10
	Cp	E/L	Ethiopia	4
Forficula auricularia Linnaeus	Cp	E/L	Kenya	7
HETEROPTERA				
Anthocoridae				
Orius sp.	?	E	Kenya	6
NEUROPTERA				
Chrysopidae				
Chrysopa ?sp.	?	E/L	Kenya	6
HYMENOPTERA				
Formicidae				
Camponotus sp.	Cp	E	Kenya	7
Camponotus rufoglaucus (Jerdon)	?	?	Kenya	3
C. sericeus (Fabricius)	Es	E	Uganda	2
*Carciocondyla schuckar*di Arnold (as: *C. badonei*)	Bf	E/L	Uganda	1
C. emeryi Forel	Bf	E/L	Uganda	1
Dorylus sp.	?	?	Kenya	6
Dorylus helvolus (Linnaeus)	Bf	L	Uganda	1
Pheidole sp.	Cp	E/L	Kenya	6, 10
Pheidole megacephala Fabricius	Cp or Bf	E/L	Uganda	1
Pheidole guineense Fabricius (as: *Tetramorium guineense*)	Bf	E/L	Uganda	1
T. bicarinatum Nylander	Es	E	Uganda	2

Bf = *Busseola fusca*; Cp = *Chilo partellus*; Es = *Eldana saccharina*; ? = unknown.

E = eggs; L = larvae.

1= Mohyuddin and Greathead, 1970; 2= Girling, 1978; 3= Seshu Reddy, 1983; 4= Gebre-Amlak, 1985; 5= Oloo, 1989; 6= Dwumfour, 1990; 7= Dwumfour *et al.*, 1991.

Larvae

Neonate larvae are vulnerable to predation, especially while migrating from the egg batch (often on the lower leaves of the plant) to the leaf whorl. In West Kenya and Uganda, disappearance of first instar larvae was approximately 90% (Mohyuddin and Greathead, 1970; Oloo and Ogeda, 1990). Ants are most frequently named as predators of small larvae (Mohyuddin and Greathead, 1970; Girling, 1978; Oloo, 1989; Dwumfour, 1990; Dwumfour *et*

al., 1991), and the high disappearance of small larvae in Uganda was fully attributed to the ant species *C. badonei*, *C. emeryi*, *P. megacephala* and *T. guineense* (Mohyuddin and Greathead, 1970). Spiders, lacewings and earwigs also prey on small larvae (Seshu Reddy, 1983; Dwumfour, 1990; Oloo and Ogeda, 1990). Predation of late instar larvae inside the stem has not been reported, but these larvae are often attacked by ants when dispersing from one plant to another (personal observation).

Pupae and adults

Mathez (1972) noticed that 'a few' pupae were eaten by ants, but thorough studies have not yet been conducted. It is, however, not likely that the impact of predators on pupae will be high. Predation of stem borer moths has not been observed.

CONCLUSION

Natural enemies are usually not sufficiently abundant to keep stem borer populations at low levels. The impact of fungi, bacteria, protozoa, viruses and nematodes is often mitigated by long dry periods between cropping seasons, and by lack of physical contact between stem borer larvae in a stem. The latter is also a serious constraint for the application of commercially produced microorganisms such as *B. thuringiensis*.

Furthermore, the costs and availability of commercial products may be a problem for subsistence farmers in Africa. Parasitoids and predators have been reported to cause high mortality in some regions, but their abundance is highly dependent on location and on season. Some parasitoids appear to be restricted to certain geographical areas, and thus, may be suitable candidates for redistribution within the continent.

The impact of parasitoids and predators could be enhanced by managing native habitats adjacent to maize fields. Wild grasses may play an important role in the conservation of parasitoids and predators. Stem borers migrate from maize to wild grasses when the crop dries up, and the presence of stem borers in wild grasses allows parasitoids to survive dry periods between cropping seasons. Wild grasses and other weeds may also provide shelter and alternative food for predators.

In many areas, mortality of the introduced stem borer *C. partellus* increased after the introduction of the exotic parasitoid *C. flavipes*. Other parasitoids from the native home of *C. partellus*, such as the tachinid *S. inferens*, might be considered for introduction into East Africa. Combination of the different approaches - classical biological control, conservation of indigenous natural enemies, application of commercially produced micro-organisms and redistribution of locally important natural enemies - may provide a suitable management strategy for the control of cereal stem borers in the region.

Chapter 4

ABUNDANCE AND MORTALITY OF *CHILO* SPP. EGGS IN MAIZE AND SORGHUM AT THE KENYAN COAST

ABSTRACT

The abundance and fate of *Chilo* spp. egg batches were studied on maize and sorghum. Infestation started at an early crop stage, and one to three oviposition peaks were apparent in most fields. Infestation levels varied between 0 and 10%, with peaks up to 28% of plants carrying egg batches. In 85 to 100% of cases, infested plants had only one egg batch. Infestation was higher on sorghum than maize, except for the first two to four weeks after plant emergence. Average egg batch sizes varied between 16 and 26 eggs, depending on site and season. Egg mortality ranged from 18 to 78%, with parasitism being the most important factor. Disappearance, predation and non-hatching were relatively unimportant, accounting each for less than 12% mortality.

INTRODUCTION

Cereal stem borers are a major constraint to production of maize (*Zea mays* Linnaeus) and sorghum (*Sorghum bicolor* (Linnaeus)) in East and southern Africa. Several species have been recorded, but the predominant and most economically important stem borer at elevations below 1500 m is the exotic *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae) (Mohyuddin and Greathead, 1970; Seshu Reddy, 1983; Overholt *et al.*, 1994). In the coastal area of Kenya, the indigenous species *Chilo orichalcociliellus* Strand (Lepidoptera: Pyralidae) and *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) are also found, but only in small numbers (Overholt *et al.*, 1994).

The development of stem borer generations can be continuous in areas where conditions are suitable for the growth of host plants throughout the year. At the Kenyan coast, however, the cycle is interrupted by a dry season (January to March), during which the stem borers enter diapause or migrate to wild host plants. Stem borers can cause great damage to the newly emerged by destroying the growing points of young plants. Sorghum partly compensates for such damage by tillering, but maize plants give no yield. If infestation occurs at a more mature plant stage, damage is less devastating.

Chilo spp. eggs are oviposited in batches of 18 to 41 in overlapping rows on the upper or under side of the leaf, or on the stem (Mathez, 1972; Alghali, 1985; Bate *et al.*, 1990; Päts and Ekbom, 1994). Egg batches are oviposited randomly in the field (Päts and Ekbom, 1994; Päts *et al.*, 1997). Eggs are highly exposed to biotic and abiotic mortality factors, with observations suggesting that only 10% of eggs survive to hatching. Parasitism was an important mortality factor at the Kenyan coast (Mathez, 1972). In Uganda and western Kenya, predation and disappearance, which is also largely attributed to predators, were the main mortality factors (Mohyuddin and Greathead, 1970; Oloo, 1989; Oloo and Ogeda, 1990).

The role of egg mortality on suppressing stem borer populations has been a point of discussion for many years. Myers (1929) and Box (1932) argued that increasing

mortality by the introduction of egg parasitoids is only useful if larval mortality is low, since mortality in larvae is positively density-dependent and a low mortality of eggs would be compensated for by a higher larval mortality. However, Tucker (1934a) and Pickles (1936) found egg parasitism and early larval mortality to be complimentary. Van Hamburg and Hassell (1984) reviewed the impact of augmentative releases of egg parasitoids on stem borer populations, and found that parasitism has most effect when initial egg densities are low.

In this study, infestation levels, seasonal abundance and location of egg batches within a plant were examined. Furthermore, egg mortality (by parasitism, predation, disappearance and non-hatching) was assessed in maize and sorghum fields during four consecutive growing seasons.

MATERIAL AND METHODS

Study sites

The study was conducted at two sites, Mtwapa and Kilifi (approximately 10 and 50 km north of Mombasa, respectively), at the southern coastal area of Kenya. Sampling was carried out during consecutive rainy seasons as indicated in Table 4.1. An experiment conducted at one site during one season is hereafter called 'trial'. There are 8 trials for maize and 7 for sorghum. In each trial, maize (cultivar 'Coast Composite') and sorghum (cultivar 'Serena') were sown adjacently. The fields were divided into 6 or 10 plots of 10x10 m, and each plot contained 15 rows and 34 plants per row. At planting, Di-Ammonium Phosphate was applied at a rate of 125 Kg/ha and a topdressing of Calcium Ammonium Nitrate (125 Kg/ha) was applied three weeks after plant emergence. Plants were thinned to one plant per hill after emergence. Weeding was done by hand and no pesticides were applied.

Chapter 4

Sampling

Sampling started one to four days after plant emergence and was conducted twice a week for most of the season. At the end of the growing season, the sampling frequency was reduced to once a week. Ten randomly selected plants per plot, as well as one or two consecutive plants on both sides in the same row, were inspected for *Chilo* spp. egg batches. Thirty or 50 plants per plot were examined on each sampling date (Table 4.1). Eggs of both *C. partellus* and *C. orichalcociliellus* were considered together, as eggs of these two species can not be readily distinguished. Non-hatched *Chilo* spp. egg batches were marked and their location (stem, under side of leaf, upper side of leaf) recorded. The number of eggs in each batch was counted using a hand lens (magnification 10x). Egg batches were monitored on a daily basis until the fate of all eggs in the batch (hatched, parasitized, predated, disappeared, non-hatched) was known. Since the causes of disappearance are not determined in this study, disappearance is regarded as a separate mortality factor and not included in predation. Eggs were considered to be 'predated' if at least part of the chorion was present, but the contents of the egg had vanished. 'Disappeared' indicated that both the contents and the chorion of the egg had vanished. Eggs were considered to be 'non-hatching' if the contents of the egg had not developed into the blackhead stage after 10 monitoring days, or if it had not hatched 3 days after the last egg hatched.

Table 4.1. Number of maize and sorghum plants sampled per plot and per field at two locations in the coastal area of Kenya during different growing seasons in 1992 and 1993.

Season[a]	Location	Planting Date	Number of plots per crop	Number of plants sampled per plot per crop
LR 1992	Mtwapa	20.04.92	6	50[b]
LR 1992	Kilifi	01.05.92	6	50[b]
LLR 1992	Mtwapa	20.06.92	6	50
SR 1992	Mtwapa	28.10.92	6	50
SR 1992	Kilifi	30.10.92	6	50
LR 1993	Mtwapa	09.04.93	10	30
LR 1993	Kilifi	16.04.93	10	30
SR 1993	Mtwapa[c]	21.10.93	10	30

n = number of samplings. [a] LR = long rains, LLR = late long rains, SR = short rains. [b] Towards the end of the season: 30 plants per plot. [c] maize only.

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Statistical analysis

Proportion of plants infested throughout the sampling period was computed for each plot at each site and during each planting of each crop. Egg mortality was calculated as the fraction of eggs dying due to a mortality factor and was also computed for each crop and for each trial. When mortality is being discussed, it refers to the apparent mortality i.e. the number dying in a stage in relation to the number that entered the stage.

A General Linear Model (SAS, 1988) was fitted to the combined data to examine the main and interaction effects of the various factors (location, season and crop). The data were transformed to the arcsine scale prior to analysis. Main effect means were separated using the Tukey's procedure.

RESULTS AND DISCUSSION

Abundance of egg batches

In most trials, infestation started early. One week after plant emergence (WAE), *Chilo* spp. eggs were already present in seven out of eight maize trials and in five out of seven sorghum trials. Infestation at such an early plant stage is likely to cause great damage. Larvae feeding in the leaf whorl may destroy the growing point of the young plants, which results in dead heart formation. Sorghum can partly compensate for this by stooling, but maize plants with dead hearts give no yield.

Between 0 and 10% of maize plants carried *Chilo* spp. egg batches on each sampling date, but peaks up to 28% were occasionally found (Figure 4.1). These infestation levels corresponded with 0 to 10 egg batches per 100 plants, and peaks up to 39 batches per 100 plants. The economic threshold level (ETL) set by Ekbom and Päts (1996) at 15% of plants with egg batches during the first 2 to 3 weeks after planting was only surpassed during the short rains of 1992. The applicability of ETL to small-scale farmers in East Africa may be questioned (van den Berg and Nur, 1998). The picture
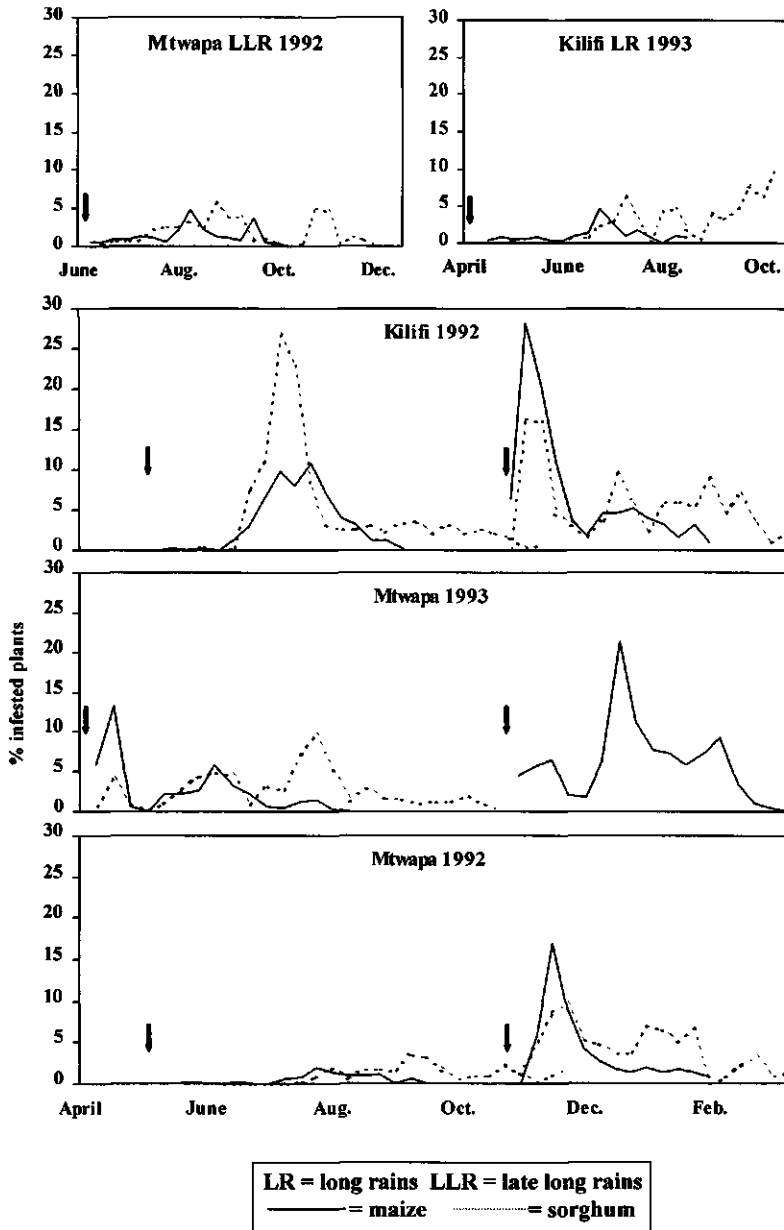
Figure 4.1. *Chilo* spp. egg infestation levels in Mtwapa and Kilifi. Arrows indicate time of sowing.

of infestation varied considerably between trials. In two trials, there was no clear oviposition peak. In three trials we found one peak and the in the remaining three trials two peaks could be distinguished. Peaks occurred later in the season (7 to 10 WAE) in five trials but in three trials they were found on young plants (2 to 3 WAE). The peaks were separated by 4 to 6 weeks, which corresponds approximately with the generation time of *C. partellus* (Ampofo, 1985). Other studies at the Kenyan coast also observed one to two oviposition peaks (Mathez, 1972; Warui and Kuria, 1983; Skovgård and Päts, 1996). Most plants (85 to 100%) carried only one egg batch but more batches (up to seven per plant) could occasionally be found when infestation levels were high. The majority of batches (95%) contained less than 40 eggs. Depending on site and season, average batch sizes varied between 16.4 and 24.0 eggs per batch. This is similar to egg batch sizes found by Päts *et al.* (1997).

On sorghum, infestation levels were comparable to those one maize: 0 to 10%, with peaks up to 27% of plants (Figure 4.1). These percentages correspond with 0 to 10 batches per 100 plants, and peaks of 36 batches per 100 plants. Zero to three oviposition peaks could be distinguished per season. Tillering ensured that young plants (shoots) were present at the end of the growing season and thereafter, which made a third peak possible. The main oviposition took place late in the growing season (8 to 9 WAE or 13 to 15 WAE) in four out of seven trials. In two trials, infestation was highest at the beginning of the season. Average batch sizes on sorghum were similar to that on maize and varied between 17.8 and 25.8 eggs per batch per trial. This concurs with studies in South Africa, where average batch sizes between 23 (Bate *et al.*, 1990) and 29 eggs were found for *C. partellus* on sorghum (van Hamburg, 1976).

Infestation was significantly higher on sorghum than on maize (during the period that both crops were present in the field) in five out of seven trials ($p<0.001$ for these trials). However, in the first four WAE, infestation was found to be higher on maize than on sorghum in four out of seven trials ($p<0.005$ for these trials). Infestation levels varied significantly between sites ($p<0.0001$) and between seasons ($p<0.0001$). They

were higher in Mtwapa than Kilifi, except during the long rainy season of 1993.

Location of egg batches

In the first two to three weeks after plant emergence, egg batches were almost exclusively found on the under side of leaves. In later plant stages, most batches were located either on the upper or on the under side of leaves, and a small number was found on the stem (Figure 4.2). The higher mortality of egg batches oviposited on solar-exposed leaf areas (Chapter 8) may be one of the reasons why female moths oviposit their batches on the under side of leaves on young plants. On older plants, top leaves will shade the lower leaves and egg batches on the upper side of leaves will be better protected from solar radiation than on young plants. Previous reports on the locations of egg batches have been contradictory. Mathez (1972) found most eggs on the upper surface on maize, and Päts and Ekbom (1994) most on the under side. On sorghum, Alghali (1985) and Bate *et al.* (1990) found most eggs on the under side, while van Hamburg (1976) found most on the upper side. Our results indicate that egg batch location varies considerably between plant stages, between seasons and between fields, which may explain the contradictions in earlier studies.

Egg mortality

Egg mortality was highly variable. On maize, average egg mortality was 19% to 78%, depending on site and season. On sorghum, an average of 18% to 69% of eggs died per season (Figure 4.3). Differences between maize and sorghum were not consistent: in four trials, mortality was significantly higher on maize than on sorghum ($p < 0.01$), and in three trials it was lower ($p < 0.001$).

Parasitism was the most important mortality factor of *Chilo* spp. eggs. The parasitoids were most likely *Trichogramma bournieri* Pintureau and Babault (Hymenoptera: Trichogrammatidae), although this species may be a synonym to a widespread species, which is currently under investigation (A. Polaszek, personal

Figure 4.2. Location of *Chilo* spp. egg batches on maize and sorghum plants.
1=Mtwapa, LR 1992; 2=Kilifi, LR 1992; 3=Mtwapa, LLR 1992; 4=Mtwapa, SR 1992; 5=Kilifi, SR 1992; 6=Mtwapa, LR 1993; 7=Kilifi, LR 1993; 8=Mtwapa, SR 1993.
LR=long rains. LLR=late long rains. SR=short rains.

communication). On maize, 6 to 59% of eggs were parasitized, and on sorghum 8 to 47% (Figure 4.3). These figures may be underestimates, as parasitized eggs may have been eaten or disappeared before detection. Parasitism was usually low (less than 10%) during the first four WAE, but increased rapidly from around eight WAE and peaked at 65% around 13. During the short rains, parasitism was often already as high as 40 to 60% in the first two WAE, probably due to population build-up during the long rains

and the absence of a long dry spell between the two seasons. Levels of parasitism were highly variable between seasons and between sites, an observation also made by Mathez (1972) and Päts *et al.* (1997). Climatic conditions such as temperature and humidity, as well as microhabitat and alternative host plants may influence the abundance of egg parasitoids.

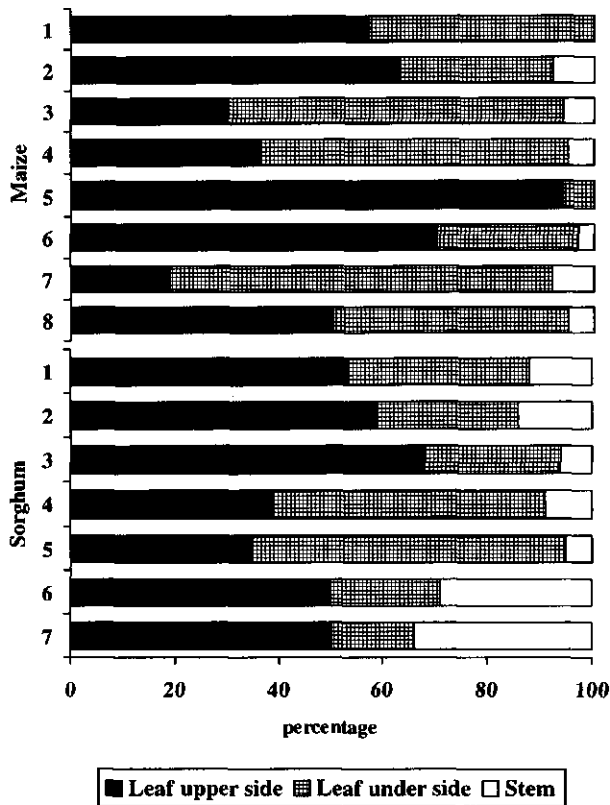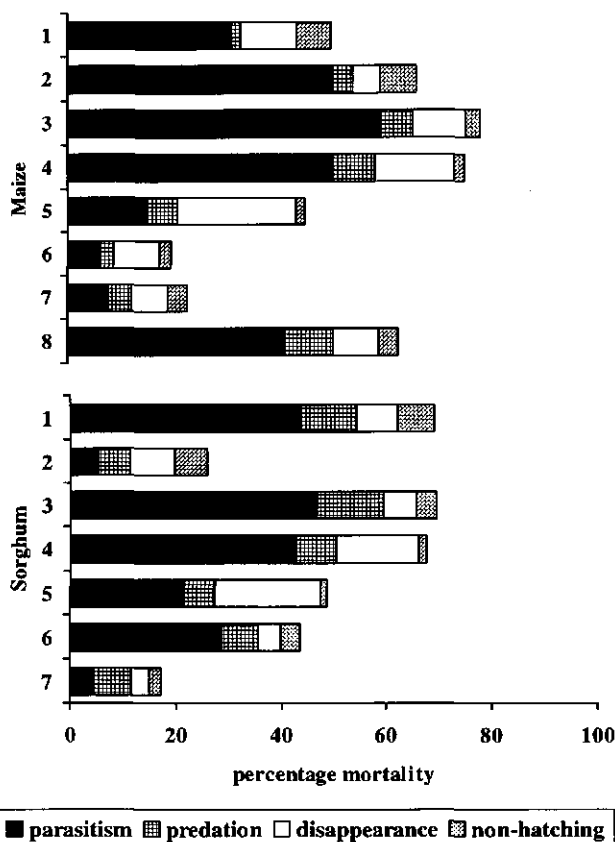

Figure 4.3. Causes of *Chilo* spp. egg mortality on maize and sorghum.
1=Mtwapa, LR 1992; 2=Kilifi, LR 1992; 3=Mtwapa, LLR 1992; 4=Mtwapa, SR 1992; 5=Kilifi, SR 1992; 6=Mtwapa, LR 1993; 7=Kilifi, LR 1993; 8=Mtwapa, SR 1993.
LR=long rains. LLR=late long rains. SR=short rains.

Disappearance of *Chilo* spp. eggs varied between 5 and 10%, except during the short rains of 1992 in Kilifi when it was 22% on maize and 19% on sorghum. Disappearance may have been overestimated as a mortality factor because disappeared eggs may already have died from other mortality factors such as parasitism or non-hatching. Disappearance in our study was low compared to other studies in Kenya and Uganda. Ogol *et al.* (1998) found 44% disappearance of *Chilo* spp. eggs on maize at Mtwapa in 1994 and 1995. In West Kenya and Uganda, egg disappearance was even as high as 90% (Mohyuddin and Greathead, 1970; Girling, 1978; Oloo, 1989). Disappearance is often attributed to predators (Girling, 1978; Leslie, 1988; Ogol *et al.*, 1998). In Chapter 8 of this thesis, it is shown that abiotic factors such as solar radiation and wind also play an important role in the disappearance of egg batches.

Predation was a relatively unimportant mortality factor, ranging from 2 to 8% on maize, and 6 to 12% on sorghum. As was the case with disappearance, predation may have been overestimated in our study. At the coast, predation seems to be less important than in West Kenya and Uganda, where ants, earwigs, coccinellids, chrysopids and spiders were thought to be responsible for over 90% egg disappearance (Mohyuddin and Greathead, 1970; Girling, 1978; Oloo, 1989; Dwumfour *et al.*, 1991). Egg predators found at the coast include ants, spiders, earwigs, coccinellids, lacewing nymphs, cockroaches, rove beetles, anthocorids and katydids. Ants were the only predators present at fairly high densities (up to 7.4 ants per plant), and earwigs were locally abundant, but other major egg predators were not (Chapter 5). Ants and earwigs were not effectively preying on eggs on plants (Chapter 6), which may explain the low occurrence of predation.

Non-hatching was a mortality factor of minor importance, with 2 to 7% of eggs not hatching on maize and 1 to 6% on sorghum. Non-hatching may be due to egg infertility, unfavorable climatic conditions or attack by sucking predators, although these were seldom found in our fields (Chapter 5). Ofomata *et al.* (2000) reported that 26 to 30% of *C. partellus* eggs did not hatch at a temperature of 25°C and a relative

humidity of 75 to 96%. With monthly averages of 24 to 28°C and 60 to 80% R.H., climatic conditions at the Kenyan coast are likely to negatively affect the ability of *Chilo* spp. eggs to hatch. A study presented in Chapter 8 revealed that solar radiation can also cause non-hatching.

CONCLUSIONS

Stem borers are especially damaging to young maize and sorghum plants. Our study, carried out at the Kenyan coast, showed that although eggs can be found within days after plant emergence, their numbers are often low. The economic threshold level of 15% infested plants during the first 2 to 3 WAE was only surpassed on three out of 15 occasions (twice on maize and once on sorghum). Parasitism was the most important mortality factor of eggs at the coast on both maize and sorghum. Egg parasitoids are generally recognized to be important regulating factors of pest species, since the pest is killed before it damages the crop. However, the impact of egg mortality on stem borer populations is also often disputed, as mortality in small larvae is positively density-dependent (van Hamburg and Hassell, 1984; Berger, 1992). The potential impact of egg mortality on stem borer populations will depend on the strength of the density dependence mortality of small larvae. If this is weak, then egg mortality may be important. Considering the questionable importance of egg mortality and the conflicting results of *Trichogramma* spp. releases (Box, 1932; Tucker, 1934b, 1935; Hassan, 1981), it may not be appropriate to focus stem borer management efforts on increasing mortality of eggs (van Hamburg and Hassel, 1984). A combination of the different control strategies currently in use - classical biological control with the larval parasitoid *Cotesia flavipes* Cameron (Hymenoptera: Braconidae), application of commercially produced micro-organisms and botanical pesticides, and cultural control methods - may provide a better management strategy for the sustainable control of cereal stem borers in East Africa.

Chapter 5

INCIDENCE OF *CHILO* SPP. STEM BORERS AND THEIR NATURAL ENEMIES IN COASTAL KENYA

ABSTRACT

Stem borer and natural enemy populations were studied during two growing seasons in five farmers' maize fields at the Kenyan coast. *Chilo partellus* and *C. orichalcociliellus* were the predominant stem borer species, while *Sesamia calamistis* was occasionally found. Stem borer numbers varied greatly between sites and seasons. A total of 13 parasitoid species were collected: two from eggs, nine from larvae and two from pupae. Egg parasitism ranged from 38 to 75%, but parasitism of larvae and pupae was less than 5%. The most common potential predator groups in the study area were ants, spiders and earwigs. Ants and spiders were represented by a rich variety of species at all sites, while of earwig two species were found. Predator populations were numerically dominated by ants. Ants were present throughout the growing season, with average seasonal densities of up to 7.4 ants per plant being recorded. Spiders were also found on all plant stages but only at low densities (0.3 per plant on average). Earwigs were locally abundant, when 0.9 earwigs per plant were found on average, but in other crops they were virtually absent. Ants are the only predator group expected to have some impact on stem borer populations and damage. Other groups are probably not sufficiently abundant or occur too late in the season.

INTRODUCTION

Cereal stem borers are a major constraint to maize production in East and southern Africa. The predominant stem borer species in lowland areas is *C. partellus* Swinhoe (Lepidoptera: Pyralidae) (Overholt *et al.*, 1994; Kfir, 1997b). *C. partellus* eggs are laid on the lower leaves or stems of maize plants and hatch after four to seven days. Young larvae initially feed in the leaf whorl and after two to three weeks start boring into the stem. Larvae feed inside the stem for two to three weeks before they pupate. During the growing season, the life cycle is completed in 25-50 days (Harris, 1990).

Insecticides are often recommended as an effective means to control stem borers (Van den Berg and Nur, 1998). Subsistence farmers, however, often cannot afford to buy insecticides or have no access to them (Saxena *et al.*, 1989; Chapter 2). Many other control options have been brought forward, such as crop sanitation, early planting or other cultural practices, host-plant resistance, biological or botanical control, but the effectiveness and acceptability to small-scale farmers is often questionable (van den Berg *et al.*, 1998). Thus, there is a need for low-input, effective and sustainable stem borer management strategy that may combine the use of several of the above mentioned control options. The utilisation and conservation of natural enemies could play an important role in this strategy. Bonhof *et al.* (1997) made an inventory of the natural enemies of *Chilo* spp. in East Africa and found 62 parasitoid, 15 predator and 18 pathogen species. Most studies concentrated on parasitoids, while not much is known about the other natural enemies and their impact on stem borer populations. Many authors presume that predators are important because of anecdotal observations where predators were seen taking away stem borer eggs and larvae, and because of the high disappearance of these stem borer life stages (Mohyuddin and Greathead, 1970; Kfir, 1988; Oloo, 1989; Oloo and Ogeda, 1990).

Information on natural enemies in maize-ecosystems in East and southern Africa is mainly limited to Kenya. Parasitism is highly variable between regions. Egg

parasitism by *Trichogramma* spp. and *Telenomus* spp. was high at the Kenyan coast (Mathez, 1972; Skovgård and Päts, 1996) but nearly absent in the western part of the country (Oloo, 1989; Oloo and Ogedah, 1990). Of the larval parasitoids, *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae) is most common (Mohyuddin and Greathead, 1970; Skovgård and Päts, 1996; Ogol *et al.*, 1998), although the introduced *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) is increasing in importance in many areas (W.A. Overholt, personal communication). Larval parasitism is generally less than 10% (Oloo, 1989; Skovgård and Päts, 1996; Ogol *et al.*, 1998). Pupal parasitism ranges from less than 10% to 58% (Oloo, 1990; Skovgård and Päts, 1996; Ogol *et al.*, 1998). Most common pupal parasitoids are *Dentichasmias busseolae* Heinrich (Hymenoptera: Ichneumonidae) and *Pediobius furvus* (Gahan) (Hymenoptera: Eulophidae) (Mathez, 1972; Oloo, 1989; Skovgård and Päts, 1996). Potential predators recorded from West Kenya include earwigs, coccinellids, spiders and ants (Seshu Reddy, 1983; Oloo, 1989). At the Kenyan coast, earwigs, ladybirds, lacewings and ants were present on maize foliage (van den Berg, 1993; Ogol *et al.*, 1998) while ants and wandering spiders were frequently found in pitfall traps (Skovgård and Päts, 1996). However, there is no information on the abundance of these predators or their interactions with stem borer populations.

In this Chapter, we present data on the abundance of predators, parasitoids, stem borers and alternative prey in five farmer's maize fields at the southern coastal area of Kenya. Relations between predators and prey in these fields are investigated and the potential impact of each predator group on stem borer populations is discussed.

MATERIAL AND METHODS

Study sites

The study was conducted at five sites along the southern Kenyan coast. Two rainy seasons can be distinguished in the study area: April to July (long rainy season, LR)

and October to November (short rainy season, SR). The total yearly rainfall is 1000 to 1200 mm, with an average temperature of 24 °C and a relatively humidity of 81% (Kenyan Agricultural Research Institute, Mtwapa, weather data 1992 to 1999).

At each of the five sites, a field of 25 x 25 m was sown with maize variety Coast Composite. Sowing was done the traditional way: three to four seeds were put in a planting hole. The planting holes were dug without row arrangement and were placed approximately one meter apart. Thinning of maize plants was not practised. The fertiliser Di Ammonium Phosphate (125 Kg/ha) was used at sowing time. Plants were top-dressed with Calcium Ammonium Nitrate (125 Kg/ha) to ensure healthy plant growth. Pesticides were not applied.

Sampling

Each site was sampled during two seasons (Table 5.1). In this Chapter, the term 'trial' will be used for the maize grown at one site during one season. Sampling five sites each 2 seasons gives 10 trials. Sampling started one to two weeks after plant emergence (WAE), and was conducted by collecting insects by hand, pitfall trapping and yellow sticky traps. Hand collection was always carried out in the early morning (7 to 11 h) under dry weather conditions. Twenty-five randomly selected plants were inspected for stem borers and potential predators by

1. checking briefly all plant parts without touching the plant for any fast-moving insects;
2. checking thoroughly all plant parts for other arthropods;
3. dissecting the plants for the presence of stem borer larvae and pupae.

All insects were captured for further identification. Stem borer eggs, larvae and pupae were reared in the laboratory for parasitoid emergence. Ratios of natural enemy to stem borer density were calculated for eggs, small larvae, medium-sized and large larvae and pupae separately. Per field, five pitfall traps filled with soapy water and some formaldehyde were placed in a cross design. The pitfalls were

emptied twice a week. The yellow sticky traps were hung in the tops of maize plants just before hand collection of insects and were inspected immediately after the hand collection had finished.

Based on studies described in Chapter 6, lacewings, bush-crickets, staphylinids, earwigs and spiders were classified as potential predators of eggs and small larvae. Ants were considered to be predators of all stem borer life stages.

Table 5.1. Sampling characteristics of the maize crops sampled at the five study sites.

Site	Study season[a]	Number of sampling dates	Number of plants
Kikambala	SR 1995	12	275
	LR 1996	14	350
Bomani	SR 1995	12	275
	LR 1996	14	350
Patanani	SR 1995	6	150
	LR 1996	9	225
Kandorazi	LR 1996	15	350
	LR 1997	18	450
Podo	SR 1996	7	348
	LR 1997	18	450

[a] SR = short rainy season; LR = long rainy season

Statistical analysis

For each trial, average stem borer and predator numbers were calculated over three consecutive periods, representing the vegetative, the reproductive (tasseling and silking) and the mature growth stage (Oloo, 1989). Also, the seasonal averages and averages per sampling date were calculated. Data were transformed (logarithmic transformation) before analysis but back-transformed means and standard errors of the means are given in the text and tables. Data were analysed using General Linear Model procedure of SAS (SAS, 1988). Data used were

1. Average number of predators and prey on each sampling date, or
2. Average numbers of predators lagged by one week (e.g. prey numbers of week 2 related to predator numbers of week 1).

RESULTS

Stem borer species

The stem borer population at the Kenyan coast is a complex of three species: *Chilo partellus*, *Chilo orichalcociliellus* Strand (Lepidoptera: Pyralidae) and *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae). All three species were found in our studies, with either *C. partellus* or *C. orichalcociliellus* being most abundant. At Patanani and Bodo, *C. partellus* was most commonly found and at Kandorani *C. orichalcociliellus*. At Kikambala and Bomani, *C. partellus* was the most abundant species in SR95, but in LR96 it was *C. orichalcociliellus*. *S. calamistis* generally accounted for less than 10% of all larvae. Only during the SR95 was *S. calamistis* abundant, accounting for 38% of larvae at Kikambala and 22% at Bomani. *S. calamistis* is not used in further analyses due to the low numbers encountered and the different life cycle to that of the *Chilo* species.

Stem borer abundance

Stem borer abundance varied considerably between sites and seasons. Populations were highest at Patanani during LR96, when 75% of plants were infested with *Chilo* spp. larvae and on average 5.72 larvae per plant were found. Infestation was lowest in Bomani during SR95 with larvae found in 16% of the sampled plants; the seasonal average was 0.38 larvae per plant. *Chilo* spp. egg batches were present throughout the growing season. An oviposition peak, usually at five to six WAE, could be distinguished in six trials. Average densities varied between crops and were 0.01 to 0.37 per plant (Table 5.2). Small larvae (L1-L2) were found in average seasonal densities of 0.15 to 0.94 per plant and were most abundant in the reproductive and mature plant stages. The number of medium-sized (L3-L4) and large (L5-L6) larvae ranged from 0.31 to 4.61 per plant, with a maximum of 41 in one plant. They first appeared in the field at three WAE, and were most abundant in the reproductive and mature plant stages (approximately seven to 10 WAE). The first pupae were

recovered at three WAE. On average, their densities were relatively low: 0.04 to 0.82 per plant.

Table 5.2. Percentage of maize plants infested by different stages of stem borers, and average number of each stage per plant, in different seasons and at the five sampling sites at the Kenyan coast.

Site	Season	Number of plants	Eggs		Small larvae	
			% infested	number $\bar{x}$ (se)	% infested	number $\bar{x}$ (se)
Kikambala	SR95	275	14.9	0.15 (0.05)	19.3	0.45 (0.08)
Kikambala	LR96	350	1.4	0.01 (0.02)	5.7	0.15 (0.05)
Bomani	SR95	275	6.5	0.07 (0.04)	12.0	0.31 (0.08)
Bomani	LR96	350	9.7	0.13 (0.03)	12.3	0.27 (0.05)
Patanani	SR95	150	5.3	0.06 (0.04)	16.0	0.51 (0.10)
Patanani	LR96	225	8.9	0.11 (0.04)	30.7	0.94 (0.10)
Kandorani	LR96	350	21.1	0.31 (0.04)	17.1	0.44 (0.06)
Kandorani	LR97	450	5.1	0.06 (0.02)	8.9	0.22 (0.05)
Bodo	SR96	348	6.6	0.08 (0.03)	12.9	0.49 (0.08)
Bodo	LR97	450	8.0	0.37 (0.03)	12.9	0.35 (0.06)
Average			8.8	0.14 (0.01)	14.8	0.41 (0.02)

Site	Season	Medium- and large larvae		Pupae	
		% infested	number $\bar{x}$ (se)	% infested	number $\bar{x}$ (se)
Kikambala	SR95	18.5	0.36 (0.06)	2.9	0.05 (0.02)
Kikambala	LR96	20.0	0.44 (0.06)	6.3	0.10 (0.04)
Bomani	SR95	16.4	0.31 (0.06)	4.4	0.05 (0.03)
Bomani	LR96	28.0	0.90 (0.08)	8.9	0.08 (0.03)
Patanani	SR95	32.0	0.70 (0.10)	4.0	0.04 (0.04)
Patanani	LR96	66.2	4.61 (0.16)	40.4	0.82 (0.08)
Kandorani	LR96	39.1	1.35 (0.09)	7.7	0.09 (0.03)
Kandorani	LR97	44.2	1.15 (0.07)	12.0	0.12 (0.07)
Bodo	SR96	35.9	1.04 (0.08)	18.1	0.14 (0.03)
Bodo	LR97	51.3	1.21 (0.07)	23.3	0.18 (0.04)
Average		35.2	1.21 (0.03)	12.8	0.17 (0.01)

Stem borer mortality

Mortality of eggs ranged from 38 to 75% between trials. Parasitism was the most important mortality factor at the time of sampling, with 33 to 64% of egg batches being black due to parasitism. Parasitism was low during the early crop stages but was often 100% towards the end of the growing season. Zero to 19% of batches were preyed upon by chewing predators. Predation by sucking predators was only found once. Parasitism of small larvae did not occur, but between 1 and 7% of small larvae were recovered dead in each trial. Parasitism of medium-sized and large larvae ranged from 0.2 to 3% of all larvae per trial, and 1 to 32% were recovered dead. The number of dead larvae was relatively high in SR95: 20 to 32% of all larvae of the three sites sampled. In LR96, the percentage of dead larvae at these same sites ranged from 4 to 11. Parasitism accounted for 0 to 4% mortality of pupae, while another 0 to 14% of pupae was recovered dead due to unknown reasons.

Abundance of stem borer natural enemies

Parasitoids

Twelve species of hymenopteran parasitoids and one unidentified dipteran parasitoid were reared from the field-collected stem borers: two from eggs, nine from larvae and two from pupae (Table 5.3). Egg parasitoids belonged to the genera *Telenomus* and *Trichogramma*. *Chelonus curvimaculatus* was an egg-larval parasitoid. Medium-sized and large larvae were parasitized by five parasitoid species, of which *Goniozus indicus* and *Cotesia sesamiae* were the most common. Pupae were parasitized by *Eurytoma braconidae* and *Dentichasmias busseolae*. *Trichogramma* sp. were the most abundant egg parasitoids, accounting for 89% of all egg parasitism. The larval parasitoid *G. indicus* was recovered 16 times (in all trials combined) and *C. sesamiae* 10 times (Table 5.3). The other larval parasitoids were found less than 10 times. Pupal parasitoids were rare: *D. busseolae* was found five times and *E. braconidis* only once.

Table 5.3. List of parasitoids collected from farmers' maize fields during the short rainy season (SR) and long rainy season (LR) at the five sampling sites along the Kenyan coast.

Species	Number of parasitized hosts	Host stage[a]	Kikambala[b] SR95	Kikambala LR96	Bomani SR95	Bomani LR96	Patanani SR95	Patanani LR96	Kandorani LR96	Kandorani LR97	Bodo SR96	LR97
HYMENOPTERA												
<u>Bethylidae</u>												
Goniozus indicus Ashmead	16	L	ᶜ	-	-	-	-	+	-	+	-	+
<u>Braconidae</u>												
Chelonus curvimaculatus Cameron	3	E/L	-	-	-	-	-	+	-	-	-	+
Cotesia flavipes Cameron	5	L	-	+	-	+	-	+	-	-	-	-
Cotesia sesamiae Cameron	10	L	-	+	-	+	+	+	-	+	-	+
Envipio rufa Szépligeti	2	L	-	+	-	-	-	+	+	-	-	+
Myosoma sp.	1	L	-	+	-	-	-	-	-	-	-	-
Tropobracon antennatus (Granger)	1	L	-	-	-	-	-	-	+	-	-	-
<u>Eurytomidae</u>												
Eurytoma braconidis Ferrière	1	P	-	-	-	-	-	+	-	-	-	-
<u>Ichneumonidae</u>												
Dentichasmias busseolae Heinrich	5	P	-	-	-	-	-	+	+	+	-	-
Syzeuctus sp.	1	L	-	-	-	-	-	-	-	+	-	-
<u>Scelionidae</u>												
Telenomus sp.	18	E	-	-	-	+	-	+	-	-	-	-
<u>Trichogrammatidae</u>												
Trichogramma bournieri Pintureau and Babault	152	E	+	+	-	+	+	+	+	++	+	++
DIPTERA												
Unidentified species	1	L	-	-	-	-	-	-	-	+	-	-

ᵃ E = egg; L = larva; P = pupa.
ᵇ SR = short rainy season; LR = long rainy season; 95 = 1995; 96 = 1996; 97 = 1997.
ᶜ ++ = abundant; + = present; - = absent

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Predators

Ants, spiders and earwigs were the most common potential predator groups on the foliage of maize plants at the five study sites (Figure 5.1). Other predators included coccinellids, lacewings, bush-crickets and staphylinids (Table 5.4), but numbers were very small and these groups were, therefore, not included in further analysis. Pitfall trap catches showed that ants, spiders, carabids and staphylinids were the most abundant ground-dwelling potential predators, but the catches were too much damaged to make identification to family level possible. Only few flying potential predators, mainly coccinellids and anthocorids, were present on the yellow sticky traps. Predator populations varied considerably between sites, seasons and plant growth stages. Predators were most abundant at Kandorani (both seasons), Bomani (SR95) and Patanani (LR96). Populations were lowest at Bodo (both seasons) and at Patanani during SR95 (Figure 5.1). Predator abundance increased with time and was highest in the last weeks of the growing season, when plants were mature (Figure 5.1). The number of predators (earwigs, spiders, ants) per *Chilo* spp. egg batch ranged from 24 to 271, while the number of predators per small larva varied from 4 to 33 between trials. Excluding ants resulted in ratios of 2 to 59 for egg batches and 1 to 4 for small larvae. The number of ants per medium-sized and large larva ranged from 1 to 24, and the number per pupae between 7 and 289.

Predator populations were numerically dominated by ants. Ants were represented by a rich variety of species, of which the genera *Camponotus, Crematogaster, Pheidole* and *Lepisiota* dominated at our study sites (Table 5.4). The species composition was highly variable between sites and seasons. At Bomani, for example, *Lepisiota* sp. 1 was common during SR95 but only found twice in LR96. At the nearby site of Kikambala, *Lepisiota* sp. 1 was seldom encountered. Average seasonal abundance of ants varied from 1.6 per plant to 7.4 per plant, with maximums of up to 300 ants per plant (generally of one species). Ants were most abundant at Kandorani and at Bomani during SR95. Densities were relatively low at Patanani during SR95

and at Bodo during LR97 (Figure 5.1). Ants were found from the first sampling date onwards, but their numbers were low (less than 0.1 per plant) early in the season. Ant density increased rapidly from nine WAE onwards, when averages of over 10 ants per plant were common in many trials.
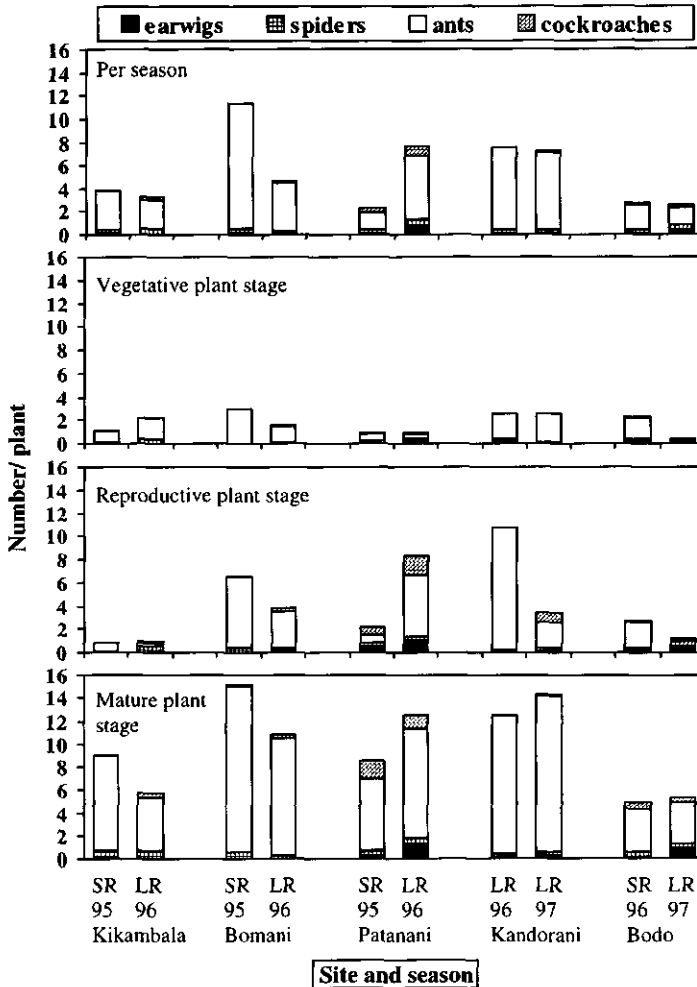

Figure 5.1. Average number of potential predators per maize plant, calculated per season and per plant growth stage, during the short rainy seasons (SR) and long rainy seasons (LR) of 1995 to 1997 at the five sampled sites along the Kenyan coast.

Table 5.4. List of known and probable predators collected from farmers' maize fields during the short rainy season (SR) and long rainy season (LR) at the five sampling sites along the Kenyan coast.

	Site and season									
	Kikambala		Bomani		Patanani		Kandorani		Bodo	
Species	SR95[a]	LR96	SR95	LR96	SR95	LR96	LR9	LR97	SR96	LR97
ARACHNIDA										
ARANEIDA										
Araneidae										
Unidentified (17 species)	–[b]	+	–	–	–	–	+	+	+	+
Clubionidae										
Cheiracanthium sp.	–	+	–	–	+	–	–	+	–	–
Unidentified (11 species)	–	–	–	+	–	+	+	+	+	+
Gnaphosidae										
Unidentified (8 species)	–	–	+	+	–	–	–	+	–	–
Hersilidae										
Unidentified (1 species)	+	–	–	–	–	–	–	–	–	–
Heteropodidae										
Unidentified (4 species)	–	–	–	–	–	+	+	+	–	–
Linyphiidae										
Unidentified (3 species)	+	+	–	–	–	+	–	–	–	–
Lycosidae										
Unidentified (15 species)	+	–	+	–	–	–	–	–	–	–
Oxyopidae										
Unidentified (5 species)	–	–	–	–	–	+	–	–	+	+
Philodromidae										
Tibellus spp.	–	+	–	+	–	–	–	–	–	–
Unidentified (2 species)	–	–	–	–	+	–	–	–	–	+

Table 5.4. Continued.

Species	Kikambala		Bomani		Patanani		Kandorani		Bodo	
	SR95[a]	LR96	SR95	LR96	SR95	LR96	LR9	LR97	SR96	LR97
Pholcidae										
Unidentified (1 species)	-	-	-	-	-	-	-	+	-	-
Salticidae										
Unidentified (22 species)	+	+	+	+	+	+	+	+	+	+
Solpugidae										
Unidentified (1 species)	-	-	+	-	-	-	-	-	-	-
Tetragnatidae										
Unidentified (4 species)	-	-	-	-	+	+	+	+	-	-
Theridiidae										
Chrostothes sp.	-	+	-	+	-	-	-	-	-	-
Unidentified (10 species)	+	+	+	-	+	+	+	-	-	-
Thomisidae										
Runcinia sp.	-	+	++	++	-	++	+	-	-	+
Unidentified (9 species)	-	+	+	+	+	+	-	+	-	+
INSECTA										
DICTYOPTERA										
Blattellidae										
Blatella sp.	+	+	+	++	++	++	+	+	+	++
COLEOPTERA										
Carabidae										
Cymindoidea deplanata Boheman	-	-	-	-	-	-	+	-	-	-
Cypholoba sp. nr. graphipteroides Guérin	+	+	-	-	-	-	+	-	-	-
Lebia sp.	-	-	-	-	-	-	+	+	-	-
Pheropsophus africanus Dejean	+	+	-	-	-	-	+	-	-	-

Table 5.4. Continued.

	Kikambala		Bomani		Patanani		Kandorani		Bodo	
					Site and season					
Species	SR95[a]	LR96	SR95	LR96	SR95	LR96	LR9	LR97	SR96	LR97
Carabidae										
Stenocallida fasciata Dejean	-	-	-	-	-	-	-	-	-	+
Stenocallidae ruficollis Fabricus	-	-	-	-	-	-	-	-	+	+
Tetragonoderus bilunatus Klug	+	-	-	-	-	-	-	-	-	-
Coccinellidae										
Cheilomenes propinqua propinqua (Mulsant)	+	+	-	-	-	-	+	+	-	+
Cheilomenes sulphurea sulphurea (Olivier)	-	-	+	-	-	-	+	-	-	-
Exochomus flavipes?	-	-	-	+	-	-	-	+	+	+
Rodolia sp.?	-	-	-	-	-	-	-	-	+	-
Staphylinidae										
Atheta sp.	-	-	-	-	-	-	-	-	-	+
Gabronthus mgogoricus Tottenham	-	+	-	+	-	-	+	+	-	+
Paederus sabaeus Erichson	-	+	-	+	-	-	+	+	-	+
Philonthus turbidus Erichson	-	+	-	+	-	-	-	-	-	-
DERMAPTERA										
Forficulidae										
Diaperasticus erythrocephala Olivier	+	+	+	+	+	++	+	+	+	++
Chelisochidae										
Chelisoches morio (Fabricius)	-	-	-	+	-	+	+	+	-	-
HYMENOPTERA										
Formicidae										
Camponotus sp. near *petersii* Emery	++	++	+	+	-	++	+	++	++	++
Camponotus acavapemensis Mayr	-	+	-	-	-	-	+	-	-	-
Camponotus cintellus Gerstaecker	-	-	-	+	-	-	+	-	-	-
Camponotus sp. 1	-	-	-	-	-	-	+	-	-	-
Camponotus sp. 2	-	-	-	-	-	+	+	-	-	-
Cardiocondyla shuckardi Forel	-	-	-	-	-	+	+	+	-	-
Crematogaster sp. or spp.	+	+	-	+	-	++	+	+	-	+
Crematogaster sp. 1	+	+	-	-	-	-	-	-	-	-

Table 5.4. Continued.

| | Kikambala | | Bomani | | Patanani | | Kandorani | | Bodo | |
Species	SR95[a]	LR96	SR95	LR96	SR95	LR96	LR9	LR97	SR96	LR97
Formicidae (continued)										
Crematogaster sp. 2	++	++	++	++	-	-	-	+	+	-
Dorylus nigricans Illiger	-	+	-	-	-	-	-	-	++	+
Lepisiota sp. 1	+	+	++	+	-	+	+	-	++	+
Lepisiota sp. 3	+	-	-	-	-	+	+	+	++	-
Lepisiota sp. 4	-	-	-	-	-	-	-	-	++	-
Merarnoplus magrettii Andre	-	+	+	-	-	-	-	-	-	-
Monomorium mictilis Forel	-	+	-	-	-	-	-	-	-	-
Monomorium osiridis Santschi	-	+	-	-	-	-	-	-	-	-
Monomorium pharaonis (Linnaeus)	-	+	-	+	-	++	-	-	-	-
Myrmicaria natalensis (F. Smith)	-	-	-	++	-	+	-	-	-	-
Pachycondyla sennaarensis (Mayr)	-	+	-	-	-	-	-	-	-	-
Pheidole sp.	-	-	-	-	+	+	+	++	-	-
Pheidole sp. 2	-	+	+	-	-	-	-	-	-	-
Pheidole sp. 4	+	-	+	-	++	++	++	-	-	+
Polyrhachis schistacea (Gerstaecker)	-	-	-	-	-	-	-	-	-	+
Platythyrea cribrinodis (Gerstaecker)	-	-	-	-	-	-	-	-	-	-
Tapionoma sp. 2	++	-	-	-	-	-	+	-	-	-
Technomyrmex sp. 1	-	-	-	-	+	+	-	-	-	-
Technomyrmex sp. 2	-	+	-	-	-	-	-	-	-	-
Technomyrmex sp. 3	-	-	-	-	-	-	-	+	-	-
Tetramorium nigrum Forel	-	-	+	+	-	-	+	-	-	-
NEUROPTERA										
Chrysopidae										
Chrysoperla congrua (Walker)	-	+	-	+	-	+	-	+	+	-
Oyochrysa sp.	-	-	-	-	-	-	-	+	-	-
HEMIPTERA										
Anthocoridae										
Lyctocorus sp.	+	+	-	+	-	-	-	-	-	-

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Table 5.4. Continued.

Species	Kikambala SR95[a]	Kikambala LR96	Bomani SR95	Bomani LR96	Patanani SR95	Patanani LR96	Kandorani LR9	Kandorani LR97	Bodo SR96	Bodo LR97
Lygaeidae										
Geocoris sp.	-	-	-	-	-	-	+	-	-	-
Geocoris sp. nr. lineola Ramb	-	-	-	-	-	-	-	-	+	-
Nabidae										
Nabis capsiformis (Germar)	-	+	-	+	-	-	-	+	-	+
Reduviidae										
Gardena sp. Dohrn	-	-	-	+	-	+	-	-	-	-
Haematochares ?obscuripennis Stål	-	-	-	+	-	-	-	-	-	-
Sphedanolestes sp.	+	-	-	-	-	-	-	-	-	-
ORTHOPTERA										
Gryllidae										
Arachnocephalus meruensis Sjostedt	-	-	-	-	-	+	-	-	-	-
Tartarogryllus sp.	+	-	-	+	-	-	-	-	-	-
Trigonidium sp.	-	-	-	+	-	+	+	+	-	-

[a] SR = short rainy season; LR = long rainy season; 95 = 1995; 96 = 1996; 97 = 1997.
[b] ++ = abundant; + = present; - = absent

Identifications were carried out by: P. J. van Helsdingen (National Museum of Natural History, Leiden, The Netherlands) for Araneida, T. van Gijzen (Arnhem, The Netherlands) for Carabidae, H. Fuersch (Germany) for Coccinellidae, A. Smetana (Canada) for Staphylinidae, H. Robertson (South African Museum, Cape Town, South Africa) for Formicidae, and Yde Jongema (Wageningen University, Wageningen, The Netherlands) for Blattaria, Carabidae, Dermaptera, Chrysopidae, Hemiptera and Orthoptera.

Spiders were widespread in maize fields along the coast and occurred throughout the season. Average densities seldom surpassed 0.3 to 0.5 spiders per plant (Figure 5.1) and maximum only one or two spiders per plant were found. Information on family composition of only the long rainy season of 1996 could be used, as material of other seasons was partly damaged. Identification up to genus level was not possible due to the present lack of knowledge of the taxonomy of African spiders and the large number of juveniles in the samples. In the long rains of 1996, 14 families were found at the five sites, the families Araneidae, Theridiidae, Salticidae and Clubionidae being the most common. Although a large number spider species or genera was found at the study sites, the numbers of each species were very low. The abundance of spiders increased in time and was approximately 0.2 per plant in the vegetative, 0.3 in the reproductive and 0.4 in the mature plant growth stage.

Two earwig species were found in our study fields: *Diaperasticus erythrocephala* and *Chelisoches morio*. The latter species was only collected five times and was therefore not included in the analysis. The earwig *D. erythrocephala* was most abundant in LR96 at Patanani (Figure 5.1), where maximums of seven adult earwigs or 40 nymphs per plant were occasionally found. At Kikambala and Bomani, earwigs were seldom found irrespective of the sampling season. Earwigs were first found at three WAE, but numbers were generally low early in the season.

Relations between predator and stem borer abundance

Analysis showed that numbers of egg batches and small larvae were not related to the number of ants, earwigs and spiders found on the same sampling date. When predator numbers of the previous sampling date were linked to prey numbers, earwigs were strongly related to small larvae ($p < 0.0001$). The intercept was negative (- 0.59), indicating that when earwig numbers were high at a sampling date, numbers of small larvae were low at the next sampling date. It is not possible to say whether the lower numbers of small larvae were indeed caused by earwigs. However,

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laboratory studies have shown that earwigs readily prey on *C. partellus* egg batches offered in Petri dishes and on plants (Chapter 6). The abundance of predators was not negatively linked to the number of stem boring medium-sized and large larvae and of pupae, neither on the same sampling date as when lagged.

DISCUSSION

Stem borer densities varied considerably between sites, even when in close proximity, and between seasons at the same site. At some sites, the first stem borer larvae were not found until 5 weeks after plant emergence, populations remaining low throughout the growing season. Initial stem borer density and mortality may have been responsible for the high variability in stem borer densities. The initial stem borer density per field may vary due to, for example, the presence of stems and stubble from the previous season or due to the presence of wild host plants near the maize field. Stem borers can survive the dry period in stems and stubble as diapausing larvae (Scheltes, 1978). They complete their development after the first rains and are able to infest the newly emerged maize crop. Another way stem borers overcome the dry period is by moving to wild habitats such as the grasses for *Sorghum arundinaceum* (Desv.) Stapf (Wild Sorghum), *Panicum maximum* Jacq. (Guinea grass) and *Pennisetum purpureum* Schumacher (Napier grass), that are common in the study area (Chapter 2). Wild sorghum is also known as *Sorghum bicolor* (L.) Moench subsp. *verticilliflorum* (Steud.) Piper (Grubben and Soetjipto Partohardjono, 1996). Until a few years ago, wild grasses were thought to act as a reservoir for stem borers and their presence was assumed to increase stem borer abundance (Bowden, 1976; Sampson and Kumar, 1986). However, recent studies have shown that rather than being a reservoir, most wild grass species act as trap plants for stem borers causing mortality of up to 100% (Khan *et al.*, 1997; Schulthess *et al.*, 1997).

Beside initial infestation density, stem borer populations are also determined by the mortality that occurs in the different life stages. At the five sites sampled for our study, parasitoids were an important mortality factor of stem borer eggs but not of the other life stages. The observed levels of parasitism on medium-sized and large larvae correspond with earlier findings in East Africa (Mathez, 1972; Girling, 1978; Oloo, 1989; Skovgård and Päts, 1996). The parasitoid *Cotesia flavipes* Cameron, which was released at the Kenyan coast in 1993 in a biological control program, was recovered infrequently from three of our crops. The abundance of this parasitoid in the coastal area has increased considerably from average parasitism of less than 1% in 1994 to 9.4% in 1998. In the long rainy season of 1999, the *C. partellus* density in Kilifi District (north of Mombasa, Kenyan coast) was reduced by 53% due to *C. flavipes* and reduction in Kwale District (south of Mombasa) was 33% (W.A. Overholt, personal communication). The impact of predators was difficult to estimate in the present study. Only few stem borer eggs, larvae or pupae were visibly preyed upon, but predators may have had an impact by causing disappearance. Disappearance was not estimated in this study, but earlier work showed that egg disappearance ranged from 5 to 22% (Chapter 4). The disappearance of young larvae can mainly be attributed to dispersal, and subsequent mortality due to desiccation, predation or inability to find a host plant (Litsinger *et al.*, 1991; Berger, 1992). Disappearance of late instar larvae is largely associated with dispersal and predator activity and that of pupae with predator activity only (Chapter 7).

Anecdotal observations and Petri dish studies indicated that coccinellids, earwigs, anthocorids, lacewings and ants were predators of stem borer eggs (Mohyuddin and Greathead, 1970; Oloo, 1989; Dwumfour, 1990; Dwumfour *et al.*, 1991). Spiders, earwigs, lacewings and ants were also observed preying on small larvae (Mohyuddin and Greathead, 1970; Oloo, 1989; Dwumfour, 1990; Dwumfour *et al.*, 1991). Ants, earwigs and spiders have a high predation capacity (Chapter 6) and are expected to be the most important predator groups due to their abundance in maize fields. Ants

and spiders colonise maize fields early in the season, so they may have an impact on stem borer populations when plants are in their most vulnerable stage. Ants being voracious predators of all stem borer life stages, and in view of their abundance and stable populations, may have an impact on stem borer mortality. Spiders, which feed almost exclusively on insects, would have potential as biological control agents, but little attention has been given to their role as pest regulators (Riechert and Lockley, 1984). Laboratory studies indicated that many spiders readily prey on small larvae offered in Petri dishes (Chapter 6), and that a *Tibellus* sp. (Araneida: Philodromidae) also consumed eggs. The earwig *D. erythrocephala*, reported from Ghana (Botchey and Kwapong, 1991), Ethiopia (Gebre-Amlak, 1985) and West Kenya (Seshu Reddy, 1983; Oloo, 1989), was also the most abundant earwig in this study. *D. erythrocephala* readily preys on *C. partellus* eggs and small larvae in the laboratory but has not been observed to feed on them in the field (Chapter 6). Earwigs are only locally abundant and peak numbers occur fairly late in the growing season, when stem borer eggs and young larvae are less common and the plants are no longer in their most vulnerable stage. Therefore, the potential of earwigs is thought to be less than that of ants and spiders.

Aphids (*Rhopalosiphum maidis* Fitch (Homoptera: Aphididae)) were common and present at the same time as eggs and small larvae in this study. The presence of alternative prey such as aphids may negatively influence predation of stem borers, especially when predators prefer the more abundant and more accessible aphids to the more hidden eggs and small larvae. We identified earwigs and coccinellids as predators of aphids in Petri dish studies in the laboratory (Chapter 6). Spiders are known to prey on aphids in many crops including apple orchards (e.g. Prokopy *et al.*, 1995; Wyss *et al.*, 1995), cereals (e.g. Provencher and Coderre, 1987; Toft, 1995, 1997) and sugar beet (Schroder *et al.*, 1999), but no records of spiders preying on maize aphids in Africa exist. Ants sometimes preyed on aphids, but more often did

they tend them for honeydew-production. By producing honeydew and providing a source of energy, aphids may attract ants and increase predation of stem borers.

CONCLUSIONS

In some trials, stem borer levels were low in our fields but on some occasions they reached damaging levels. Parasitoids were not common, except egg parasitoids that were especially common at Kandorani and Bodo. Parasitism had little impact on stem borer mortality in the sites and seasons studied. Predator communities were characterised by a rich variety of species, but predator numbers were generally low. Ants are the only predator group expected to have some impact on stem borer populations due to their occurrence early in the season, when maize plants are highly vulnerable to stem borer attack, their relative abundance, their acceptance of all stem borer life stages, and their activity on plants.

Chapter 6

PREDATORS OF MAIZE STEM BORERS IN KENYA: FIELD ACTIVITY, CONSUMPTION CAPACITY AND PREY PREFERENCE

ABSTRACT

The potential and actual role of the major predators of the maize stem borer *Chilo partellus* were studied at the Kenyan coast. Ants, earwigs and cockroaches were the most abundant predator groups. Direct observations identified flies of the family Chloropidae and three different ant species consuming *C. partellus* eggs in the field. Egg predation was low, with only 3% of batches being attacked during the observation period. The potential role of the most abundant and active predators of eggs, larvae and pupae was studied in Petri dishes and on plants in the laboratory. In Petri dishes, eighteen potential predator species consumed eggs and 15 consumed small larvae. Late instar larvae and pupae were sometimes attacked but only eaten by gryllids. Earwigs and cockroaches had a high acceptance and consumption rate of eggs and small larvae. When tested on plants, however, both groups rarely preyed on eggs while only earwigs ate small larvae. No conclusions regarding a preference of earwigs for small larvae or aphids, offered concurrently on plants, could be drawn. Based on the results of this study, it is expected that only ants and earwigs may have some impact on stem borer populations.

INTRODUCTION

Stem borers are major pests of maize in Africa (Youdeowei, 1989). *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae) is the predominant stem borer species in lowland areas (below 1500 m) of East and southern Africa (Sithole, 1989; Overholt *et al.*, 1994). Field studies show that mortality of stem borers can be high (e.g. Oloo, 1989; Skovgård and Päts, 1996; Ogol *et al.*, 1998), although often not sufficient to keep stem borer populations at levels below economic injury. Egg batches and small larvae are the most exposed life stages of the stem borer and are most vulnerable to mortality factors such as predation. Predation and parasitism are highly variable between sites and seasons. For example, at the Kenyan coast egg parasitism of more than 70% (seasonal averages) is not uncommon (Skovgård and Päts, 1996; Ogol *et al.*, 1998), but in the western part of the country egg parasitism is rare (Oloo, 1989; Ogol *et al.*, 1998). Parasitism of larvae and pupae is generally less than 20% (Mathez, 1972; Oloo, 1989; Skovgård and Päts, 1996; Ogol *et al.*, 1998). The effect of predation on stem borer eggs, larvae and pupae is not clear as visible signs of predation are rarely found. However, disappearance of these life stages is frequently as high as 90% (Mohyuddin and Greathead, 1970; Girling, 1978; Oloo and Ogeda 1990). Disappearance is generally thought to be a result of predation (e.g. Mohyuddin and Greathead, 1970; Oloo, 1989; Ogol *et al.*, 1998), but this assumption is mainly based on incidental field observations.

In 1995, an extensive study on the impact of local predators of maize stem borers was started in Kenya's Coast Province. The most abundant and widespread potential predator groups present in farmers' maize fields were ants, spiders, earwigs and cockroaches (Chapter 5). Exclusion cage studies demonstrated that predator populations could have a significant impact on disappearance of eggs and, in some cases, of pupae of *C. partellus* (Chapter 7). However, the identity and relative importance of the predator groups or species involved could, at that phase, not be determined.

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This paper reports on experiments carried out to identify the species preying on different developmental stages of stem borers, in particular highly exposed eggs and small larvae. Laboratory studies on predation of eggs and larvae were complemented by direct observations of predation of field-exposed stem borer eggs. The laboratory tests allowed comparison of many predator species with regards to their potential role, while the field observations estimated their actual role. The field experiments also yielded information on egg parasitism When the natural enemies responsible for a large part of stem borer mortality are known, conservation strategies can be developed to optimise the impact of these naturally occurring control agents.

MATERIAL AND METHODS

Site

All experiments were conducted at Muhaka Field Station (MFS) (04°19.48 S, 039°31.45 E) at the southern coastal area of Kenya. The area, located at 40 m altitude, receives approximately 1200 mm rainfall per year, divided over two rainy seasons. The first rainy season occurs from April until July (long rainy season) and the second from October to November (short rainy season). Soils in the study area are generally sandy, have a low structural stability and a low to very low fertility (Jaetzold and Schmidt, 1983).

Insects

All experiments were conducted with *C. partellus*, which was reared at MFS under ambient temperatures and light:dark conditions. Female moths, placed together with males in jars, oviposited on wax paper. First and second instar larvae were reared on maize leaves and late instar larvae on split maize stems. Pupae, collected and placed in jars, were incubated until the moths emerged.

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Adult potential predators and the aphid *Rhopalosiphum maidis* Fitch, a possible alternative prey, were collected from farmers' maize fields in the neighbourhood of MFS. All potential predators were individually placed in a Petri dish containing moist cotton wool and starved for 24 hours prior to the experiment.

Plants

The study field (30 x 40 m) was sown with the maize cultivar Coast composite. The fertiliser Di Ammonium Phosphate (D.A.P.) was applied after plant emergence at a rate of 125 Kg/ha to ensure plant growth and Calcium Ammonium Nitrate (125 Kg/ha) was applied at four WAE, if necessary. No pesticides were used in or near the field.

Experimental plants (cultivar Coast composite) were sown in pots in large field cages to prevent natural stem borer infestation. D.A.P. was applied after plant emergence and plants were watered whenever necessary. Plants were either taken out of the pot leaving the roots intact (gutter experiments) or left in the pot (direct observation, cage experiment).

Gutters

Three 3 to four week old maize plants, reared in large field cages, were placed in a gutter (120 x 17 x 14 cm) at 20, 60 and 100 cm distance. Before placement, the soil was removed from the roots and each plant cleared from possible insects. Water was put in the gutter up to a root-covering level to prevent insects from leaving or entering the plants via the stem. As an extra measure to prevent insects from leaving the plant via the stem, a ring of insect trap adhesive (Tanglefoot) was put around the base of the stem, just above the water level. In most cases, two of the plants in the gutter received a predator while the third plant had no predator on it (control).

Cages

The top and sides of the cages (60 x 60 x 48 cm) were made of very fine mesh (0.1 mm mesh width) while the bottom and door were made of wood. Each cage held one potted maize plant of three to four weeks old. Leaves of the plant were trimmed, if necessary, so that they would not touch the cage. A ring of insect trap adhesive was placed at the base of the stem of the plant as an extra measure to prevent insects from leaving the plant.

Direct field observations on predation

Day observations

Female *C. partellus* moths were allowed to oviposit overnight on three to four weeks old potted maize plants. The laid egg batches were marked with a felt-tip pen and the number of eggs in each batch was counted. Plants were then transferred to a maize field with plants of the same age and cultivar. Daytime observations took place in December 1998, towards the end of the cropping season of the short rains, and in an irrigated field during the off-season in February 1999. In December 1998, two plants were observed and in February 1999 four, from 6:30 to 18:30h (approximately dawn to dusk) for three consecutive days (Table 6.1). Each observer watched one plant from a distance of approximately 70 cm, in such a way that one row of maize was situated between the observer and the experimental plant. After every two hours of observation, there was a one hour break, so plants were watched for a total of 8 hours each day. At the start of each 2 hour-observation period, the number of eggs in each batch was counted. The time, duration and nature of visits by parasitoids and predators to experimental plants were recorded. When feeding was observed, the number of eggs consumed was counted after the predator left the batch. Individuals preying on egg batches were captured for identification after their meal. At the end of the three days observation, egg batches were collected and kept in the laboratory to determine their fate (parasitized, non-hatching or eclosed).

Table 6.1. Overview of methods of direct field observations to determine the fate of *C. partellus* egg batches on maize under natural conditions at the Kenyan coast.

Season	Date	PLANT			EGG BATCHES	
		Age (weeks)	number	stage	Number per plant (range)	Total observed
Short rainy season 1998	19-21 December	3	2	early veg.	2-4	6
	22-24 December	3	2	early veg.	2-6	8
Off-season 1999	2-4 February	4	4	early veg.	3-10	23
	9-11 February	5	4	early veg.	7-12	35
Long rainy season 1999	3 May	3	4	early veg.	6-12	32
	10 May	4	3	early veg.	2-5	10
	24 May	6	4	late veg.	2-6	15
	7 June	8	4	silking	1-14	35
	25 June	11	4	mature	2-10	29

Season	Date	OBSERVATION		
		Number of days	Period	Number of hours per day
Short rainy season 1998	19-21 December	3	06:30 – 18:30 h	8h
	22-24 December	3	06:30 – 18:30 h	8h
Off-season 1999	2-4 February	3	06:30 – 18:30 h	8h
	9-11 February	3	06:30 – 18:30 h	8h
Long rainy season 1999	3 May	1	18:30 – 18:30 h	11h 20min
	10 May	1	06:30 – 06:30 h	11h 20min
	24 May	1	06:30 – 06:30 h	11h 20min
	7 June	1	06:30 – 06:30 h	11h 20min
	25 June	1	06:30 – 06:30 h	11h 20min

veg. = vegetative

Day and night observations

In the long rainy season of 1999, observations on egg predation were made using a slightly different set-up. Four plants with *C. partellus* egg batches were observed for one whole day during different plant growth stages. Night observations were carried out using a flashlight covered with red plastic, in order not to disturb insects (de Kraker, 1996). Four times an hour, the flashlight was switched on for 5 minutes and off for 10 minutes, so egg batches were watched for 20 minutes per hour at night. After every two hours, a 30-minute break was taken so that the total observation time

was 11 hours and 20 minutes (Table 6.1). Information on predator abundance was obtained by recording the number of potential predators on the experimental plant and on the ground, in a circle of approximately 60 cm diameter around the plant.

Prey acceptance and consumption capacity

Petri dish studies

Potential predators, enclosed in a Petri dish, were offered either one batch of *C. partellus* eggs (range 5 to 157 eggs), 10 or 20 first instar larvae, five late instar larvae or three pupae. Egg batches, laid on wax paper, were zero to one day old. First instar larvae were one day old and offered on a piece of fresh maize leaf (6 cm²). Late instar larvae (approximately 17 days old) were put on a split piece of maize stem (3 cm) and allowed to eat for three hours. Pupae (one day old) were offered without maize plant parts. Prey acceptance and consumption capacity were recorded after 24 hours. The number of replicates for each predator species was highly variable and mainly depended on the availability of predators.

Predators with a high acceptance and consumption rate of eggs or small larvae (major predators) were also tested on aphids. *R. maidis* is a common and widespread aphid that occurs concurrently in the field with eggs and small larvae (Chapter 5). Aphids can often be found in high numbers, therefore their presence may reduce predation of stem borers and other prey. A total of 10 or 20 adult aphids were placed on a 6 cm² piece of maize leaf and offered to one predator in a Petri dish. Disappearance and death of prey were recorded after 24 hours.

Predation studies on plants

The Petri dish studies identified the earwig *Diaperasticus erythrocephala* Olivier and the cockroach *Blatella* sp. as major predators. The consumption of these two predators on eggs and small larvae was studied on maize plants. Three week old plants were transferred from field cages to the laboratory. For egg predation studies,

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the plants were placed in oviposition cages and mated female moths were allowed to lay eggs overnight. For studies with small larvae, three days old larvae were placed in the leaf whorl at densities of 10, 25, 50 or 100 larvae per plant. Earwigs were tested on plants in gutters, while cockroaches were tested on plants in cages to prevent them from flying away. Disappearance and death of eggs and larvae were recorded after 24 hours.

Prey preference

After the results of the predation studies on plants were known, the preference of *D. erythrocephala* for small larvae (two days old) relative to adult aphids was tested. Three week old maize plants were placed in the gutter set-up and infested with either 100 aphids and 0 *C. partellus* larvae, or 50 aphids and 50 larvae, or 0 aphids and 100 larvae. One earwig was placed on each plant, except for control plants, and the number of living and dead aphids and larvae was counted after 24 hours.

Statistical analysis

The fraction of disappearance was transformed by arcsine transformation prior to analysis. Differences in consumption of prey types and densities were analysed using General Linear Models, while means were separated using Student Newman Keuls test ($P<0.05$). Disappearance of prey on plants with and without a predator was compared using a t-test ($P<0.05$).

RESULTS

Direct field observations on predation

Ants, bush-crickets and ground beetles were observed on the ground surrounding the experimental plants in the study. Foliage-dwelling potential predator groups were ants, spiders, bush-crickets, coccinellids, earwigs, flies, ground bugs, cockroaches,

rove beetles and lacewings. Predator densities in the study field were very low. Ants (*Camponotus* sp. near *petersii* Emery, *Dorylus nigricans* Illiger, *Lepisiota* sp. and *Pheidole* sp.) were the most abundant predators both on the ground and on the plants. In the morning and afternoon hours, approximately 15 ants per m^2 were found on the ground surrounding the experimental plant compared to approximately two ants per m^2 at midday. Only few ants climbed into the plant and if they did, they usually stayed near the base of the stem and did not actively forage on the plant. Spiders, earwigs, bush-crickets and cockroaches occasionally visited the experimental plants. The other predator groups mentioned above were recorded only once or twice in the observation period.

Only six of the total of 193 (3%) egg batches were attacked by predators: four by ants and two by flies. *C.* sp. near *petersii*, *Lepisiota* sp. (twice) and an unknown ant removed whole egg batches close to the ground without leaving a trace. Two adults of the family Chloropidae (Diptera) preyed on eggs, both times early in the morning, between 7:30 and 8:30h. The flies sucked one or two eggs per batch. Pierced eggs turned black immediately after attack. Egg predation took place in February 1999 (four out of 58 egg batches) and during the long rainy season of 1999 (three out of 121 egg batches) but did not occur during the observations in December 1998.

A total of 10 egg batches (5%), all on the upper side of leaves, was blown off by the wind after the edges of the batch had curled away from the leaf. Thirteen egg batches (7%) disappeared due to unknown reasons, with seven of them disappeared during breaks at daytime and six during the breaks at night.

Eighty-two egg batches (42%) were visited by egg parasitoids. Of these batches, 46% turned black; 23% did not turn black, and of 31% it could not be determined whether they had been parasitized because the batches disappeared or were destroyed by ants in the laboratory. The egg parasitoids were most likely *Trichogramma bournieri* (Pintureau and Babault), although this species may be a synonym to a widespread species, which is currently under investigation (A. Polaszek, personal

communication). Parasitoids were active from approximately 6:30 until up to at least 20:00 h (i.e. after dark), but peak activity was between 9:00 and 12:30h. Despite the very different weather conditions encountered, egg parasitoids were found on all observation days.

Prey acceptance and consumption capacity

Ants, despite being the most abundant and active predators during the field observations, were not tested in the laboratory experiments. Ants are social insects that do no behave normally if taken out of their colony. When placed individually in a Petri dish with moist cotton wool, they appeared stressed and died quickly and offered *C. partellus* prey was not attacked.

Petri dish studies

The earwig *D. erythrocephala* and the cockroach *Blatella* sp. were the most voracious predators of *C. partellus* eggs (Table 6.2). Individuals of these predator species generally ate the whole egg batch, and consumed up to 112 eggs. Other egg predators include the coccinellids *Cheilomenes propinqua propinqua* (Mulsant) and *C. sulphurea sulphurea* (Olivier), the rove beetle *Paederus sabaeus* and nymphs of the lacewing *Chrysoperla* sp.. The spider *Tibellus* sp., the anthocorid *Lyctocorus* sp. and the gryllid *Trichonidium* sp. also preyed on eggs but were not included in Table 6.2 because the numbers tested were too small to give quantitative data. All, except for *Lyctocorus* sp., are chewing predators. Anthocorids of the genus *Orius*, important predators of eggs of many noctuid pests (van den Berg, 1993) did not prey on *C. partellus* eggs.

A total of 16 predators of small *C. partellus* larvae were identified. Beside the fairly abundant predators listed in Table 6.3, a few uncommon species were also found to prey on small larvae in Petri dishes: the spiders *Cheiracanthium* sp., *Chrosiothes* sp., *Runcinia* sp., two unidentified Clubionidae, two unidentified

Salticidae and one unidentified Thomisidae spider, the earwig *Echinosoma* sp. and the gryllid *Trichonidium* sp.. Consumption of larvae was highly variable and ranged from 1 to 20. Most larvae disappeared, and only few were found dead. In Petri dishes without a predator (control), no larvae disappeared and very few larvae were found dead.

Medium-sized larvae and pupae were preyed upon by the gryllids *Arachnocephalus meruensis* and *Tartarogryllus* sp. (n=10 for each predator-prey combination), but the cockroach *Blatella* sp., the rove beetle *P. sabaeus* and the earwig *D. erythrocephala* did not prey (n=20). Aphids were readily consumed by *Blatella* sp., *C. propinqua propinqua, P. sabaeus* and *D. erythrocephala* (Table 6.4). Adults of *D. erythrocephala* were most voracious, consuming on average 12 aphids per day, while most other predators consumed on average between 5 and 7 aphids per day.

Predation studies on plants

The prey acceptance and consumption capacity of 27 earwigs were tested on *C. partellus* eggs and small larvae offered on plants. Per plant, one to 16 egg batches were present. A total of 114 egg batches were offered. Two earwigs (7%) preyed on one egg batch each. The batches were situated on the under side of the second leaf, and at approximately 1 cm from the base of the leaf. None of the 36 egg batches on the 12 control plants (range 1 to 12 batches per plant) disappeared. Disappearance of small larvae was 47 to 51% on plants with earwigs and 19 to 33% on control plants (Figure 6.1a). Only few larvae were recovered dead. Disappearance was significantly higher on plants with earwigs than on control plants, except at infestation density of 10 larvae per plant. The disappearance of larvae did not differ between the four infestation densities (for plants with earwigs: p=0.21, for the control: p=0.39).

To cockroaches, a total of 71 egg batches was offered on plants (range 1 to 12 batches per plant), but none of the batches was preyed upon. From control plants (35

Table 6.2. Predators of *C. partellus* eggs in Petri dishes: species, prey acceptance and consumption capacity. Tested are adults, unless indicated otherwise.

Predator	N tested	% batches accepted	Eggs offered per batch mean number (SD)	If prey accepted: Eggs eaten mean number (SD)	mean %
DICTYOPTERA					
Blattellidae					
Blatella sp.	34	41	21.1 (9.4)	18.3 (7.1)	87
COLEOPTERA					
Coccinellidae					
Cheilomenes propinqua propinqua (Mulsant)	40	23	56.8 (23.4)	3.7 (2.2)	7
Cheilomenes sulphurea (Olivier)	38	8	65.6 (23.4)	2.3 (1.5)	3
Staphylinidae					
Paederus sabaeus Erichson	29	28	48.9 (18.1)	6.6 (2.8)	16
DERMAPTERA					
Forficulidae					
Diaperasticus erythrocephala Olivier	47	64	46.4 (24.0)	40.7 (23.1)	83
Diaperasticus erythrocephala Olivier (nymphs)	26	54	35.4 (14.6)	27.9 (14.6)	81
NEUROPTERA					
Chrysopidae					
Chrysoperla sp. (nymphs)	10	20	41.9 (29.0)	6.0 (2.8)	12

Table 6.3. Predators of first instar *C. partellus* larvae in Petri dishes: species, percentage of individuals eating and predation capacity. Tested individuals are adults, unless indicated otherwise.

Predator	N tested	% prey acceptance	Number offered	If prey accepted: Larvae eaten mean number (SD)	mean %
DICTYOPTERA					
Blattellidae					
Blatella sp.	34	82	10 or 20	8.3 (7.1)	46
Blatella sp. (nymphs)	14	64	20	7.0 (6.6)	35
COLEOPTERA					
Coccinellidae					
Cheilomenes propinqua propinqua (Mulsant)	19	79	10 or 20	5.4 (2.7)	46
Cheilomenes sulphurea sulphurea (Olivier)	13	92	10 or 20	10.1 (6.0)	73
Staphylinidae					
Paederus sabaeus Erichson	25	100	20	15.2 (5.3)	79
DERMAPTERA					
Forficulidae					
Diaperasticus erythrocephala Olivier	37	92	10 or 20	12.4 (5.5)	70
NEUROPTERA					
Chrysopidae					
Chrysoperla sp. (nymphs)	28	54	10	3.7 (2.8)	32

Table 6.4. Predators of aphids (*R. maidis*) in Petri dishes: species, percentage of individuals eating and predation capacity. Tested individuals are adults, unless indicated otherwise.

Predator	N tested	% prey acceptance	Number prey offered	If prey accepted: Aphids eaten mean number (SD)	mean %
DICTYOPTERA					
Blattellidae					
Blatella sp.	21	86	20	6.3 (4.2)	32
Blatella sp. (nymphs)	11	91	20	6.6 (6.2)	33
COLEOPTERA					
Coccinellidae					
Cheilomenes propinqua propinqua (Mulsant)	11	100	10 or 20	6.9 (2.8)	47
DERMAPTERA					
Forficulidae					
Diaperasticus erythrocephala Olivier	41	95	10 or 20	11.1 (4.6)	69

egg batches on 10 plants, range 1 to 7 batches per plant), no egg batches disappeared or were eaten. When cockroaches were offered small larvae, larval disappearance was 32 to 41% and a few larvae were recovered dead. On control plants, larval disappearance was equivalent to that on plants with a predator (Figure 6.1b). Differences between the four infestation densities were not found (p=0.22 for plants with cockroach, p=0.28 for control).
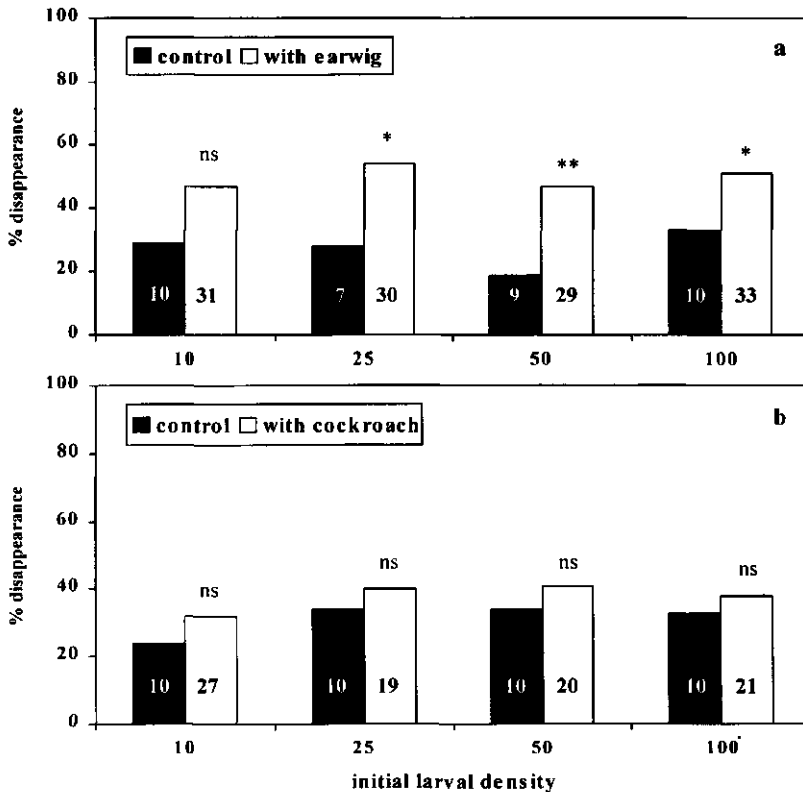
Figure 6.1. Percentage of disappeared small larvae on maize plants with and without an earwig (a) or cockroach (b) at different infestation levels. Number of replicates is indicated in the bars. ns= not significant; *=p<0.05; ** = p<0.01

Prey preference studies

Disappearance of aphids and *C. partellus* larvae was significantly higher on plants with an earwig than on plants without one (p=0.0002 to 0.04 for the different prey-density combinations) (Table 6.5). When both prey types were offered concurrently to earwigs, three times more aphids disappeared than small larvae (p=0.0001). However, a similar trend was found on control plants, where also significantly more aphids disappeared than small larvae (p=0.003).

Table 6.5. Aphids and first instar *C. partellus* larvae (*Cp* L1) disappearing from plants with an earwig and control plants at different aphid and L1 numbers.

Predator	N	Density		Number disappeared	
		Aphids	*Cp* L1	Aphids	*Cp* L1
D. erythrocephala	26	100	0	43	-
	29	50	50	30	10
	32	0	100	-	27
Control	11	100	0	27	-
	11	50	50	18	5
	10	0	100	-	15

DISCUSSION

Predators played only a minor role in the mortality and disappearance of *C. partellus* eggs in the present study. The low impact is most likely due to the small numbers of predators at the study site and the low predation activity of the predators present. Predator numbers were low, even during the off-season, when the experimental field was the only field with green cultivated plants in the area. Possibly, the sandy soil, which could reach a temperature of approximately 50°C at 12:00 h on sunny days, may have deterred diurnal crawling predators such as ants. The lack of food such as aphids or nectar and pollen may also have negatively influenced predator abundance in the field. Predators seldom actively searched on the experimental plants, especially on the young plants. On older plants, ants (mainly

Lepisiota sp.) were more active but they nearly always stayed close to the ground when climbing the plant. As a result, only egg batches situated low on the stem were encountered. A similar observation was made by Leslie (1988), who found that egg batches of the sugar cane borer *Eldana saccharina* Walker (Lepidoptera: Noctuidae) oviposited near the base of stalks were more severely attacked by ants than batches near the top of the plant.

The observations in this Chapter were limited to one field, and the question arises whether the findings can be generalised. Both the species composition and abundance of potential predators at MFS are generally lower than at other sites at the Kenyan coast (Chapter 5). Ants, for example, were found in average numbers of maximum 7.4 ants per plant at other sites, with densities of over 100 per plant not being uncommon. At MFS during the observations, the maximum number of ants concurrently on a plant was three, except for an invasion by the safari ant *D. nigricans*. Earwigs and cockroaches were also more common at other sites at the coast than at MFS. Although the higher number of predators does not necessarily lead to higher predation, it is possible that predation and disappearance of eggs at other sites is higher than in the present study. The reasons for the high variability in predator abundance are not clear, but differences in soil type, climatic conditions, field margin vegetation or agricultural practices may play a role.

Abiotic factors such as solar radiation and wind had a considerable impact on egg mortality in our study. Solar-exposed egg batches curled away from the leaf, after which the batches were blown off by the wind. Once on the ground, the blown-off egg batches were quickly taken away by ants. Although ants were the major predators observed preying on egg batches in the field, they were not tested in the laboratory because they could not be kept individually in Petri dishes. Information on the potential impact of ants on stem borer populations can best be obtained by field observations as described in this Chapter. Based on the results of our studies, it is expected that at the coast, ants do not play a large role in mortality of stem borer

eggs and small larvae. Eggs are likely to suffer higher mortality from parasitism (Chapter 4) while small larvae are most likely to disappear and die during dispersal. Ants may cause considerable mortality of late instar larvae. Late instar larvae often leave the original host plant and disperse via the ground (Berger, 1992), and ants take many of these larvae walking on the ground (Chapter 7). Earwigs and cockroaches are relatively common in maize fields at the coast and readily prey on *C. partellus* eggs and small larvae in Petri dishes. They were considered 'promising' predators, but when their consumption of eggs and small larvae was tested on plants, their impact was low. It is, therefore, expected that cockroaches do not have an impact on stem borer mortality in the field. Earwigs may have some effect, especially on small larvae.

The abundance and accessibility of alternative prey such as aphids, which are common in maize fields at the same time as small *C. partellus* larvae (Chapter 5), may influence the consumption of stem borer larvae. Most predators are polyphageous and accept many different arthropod prey, or even fungi, pollen, nectar and other plant resources. Earwigs such as *Forficula auricularia* L. and *Labidura riparia* (Pallas) accept armyworms, aphids, mites, Lepidopteran larvae and scale insects as prey (e.g. Mueller *et al.*, 1988; Kharboutli and Mack, 1993). Our data indicate that the common earwig in East Africa, *D. erythrocephala*, readily accepts aphids as prey, but it remained unclear whether earwigs had a preference for aphids or small *C. partellus* larvae. Disappearance of aphids was much higher than that of larvae on plants with an earwig, but a similar trend was found on control plants. Aphids may fall off the plant more easily when walking than stem borer larvae, and the presence of a predator or a high aphid density may act as a disturbance and increase aphid mobility (Vickerman and Sunderland, 1975).

Cockroaches are omnivorous (Borror, DeLong and Triplehorn, 1976). Only few records of cockroaches as predators of insect eggs or larvae exist (Leslie, 1982; Leslie, 1988; Carnegie, 1991). In South Africa, serological techniques identified

cockroaches as predators of stem borer eggs and larvae, but it was thought that they only consumed stem borers by exception, since cockroaches are normally not considered to be predacious (Leslie, 1988). This assumption was supported by results from the present study, where cockroaches only preyed on *C. partellus* eggs and small larvae in the confined area of the Petri dish but not on plants.

CONCLUSION

In conclusion, the studies presented in this paper have shown that the impact of predators on disappearance of *C. partellus* eggs and larvae at the Kenyan coast is small. Some of the more abundant predators showed potential after being tested in Petri dishes, but it emerged that their activity on plants in the laboratory and in the field was low. Although additional studies at other sites and in other seasons are necessary to be able to generalise our findings, our results suggest that efforts to conserve and increase predator populations, if successful, may not result in a significant reduction of the stem borer problem.

Chapter 7

NATURAL CONTROL OF *CHILO PARTELLUS* IN MAIZE: ASSESSMENT OF THE ROLE OF PREDATION

ABSTRACT

The impact of predators on mortality of the stem borer *Chilo partellus* was studied in maize fields in Kenya using exclusion cages or insect trap adhesive. Plants were infested with eggs, early instar larvae, late instar larvae and pupae. Recovery of these life stages from predator exclusion plants and control plants (accessible to predators) was compared. Disappearance of eggs from exclusion plants was 0 to 0.2% and from control plants 23 to 29%, indicating an impact of chewing predators on egg disappearance. Sucking predators did not play a role in mortality of eggs. Recovery of early instar larvae was low, but could not be attributed to predators. Recovery of late instar larvae ranged from 43 to 92% in control plants. The role of predators on disappearance of late instar larvae was ambiguous. Disappearance of pupae ranged from 13 to 44% and was significantly lower in exclusion plants in four out of six trials. Thus, predators appear to play a role in the disappearance of eggs and, in some trials, also of pupae, but have hardly an effect on larvae.

INTRODUCTION

The stem borer *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae) is a major pest in maize growing in East and southern Africa (Sithole, 1989; Overholt *et al.*, 1994; Kfir, 1997b).

Many small-scale farmers do not actively control stem borers (Chitere and Omolo, 1993; Grisley, 1997), despite the large number of offered control strategies. Many of these strategies are not practicable or available to subsistence farmers, while the effectiveness of some methods is questionable (van den Berg *et al.*, 1998). Indigenous natural enemies may play an important role in the reduction of stem borer populations in the fields of subsistence farmers. Understanding the role of natural enemies in suppressing stem borer populations is essential for developing sustainable management practices.

A life table study and anecdotal observations carried out in Kenya suggested that natural mortality of stem borers can be high (Mathez, 1972; Oloo, 1989). Parasitism of stem borer eggs, larvae and pupae appears to fluctuate widely from season to season, from area to area and from site to site. Egg parasitism was low in West Kenya (Mohyuddin and Greathead, 1970; Oloo, 1989), but ranged from 19 to 83% at the Kenyan coast (Skovgård and Päts, 1996; Ogol *et al.*, 1998). Larval parasitism was less than 10% at the coast (Skovgård and Päts, 1996; Ogol *et al.*, 1998) and less than 20% in West Kenya (Ogol *et al.*, 1998). Parasitism of pupae was 0 to 10% at the coast (Skovgård and Päts, 1996; Ogol *et al.*, 1998) but up to 58% in West Kenya (Oloo, 1989). Stem borer mortality due to pathogens appears to be negligible (Odindo *et al.*, 1989).

The role of predators on stem borer mortality has remained unclear until now. Very few preyed-on eggs, larvae or pupae are normally found, but if the widespread assumption that predators cause disappearance (Girling, 1978; Leslie, 1988; Oloo, 1989; Ogol *et al.*, 1998) is true, then their impact could be substantial. Disappearance was responsible for the highest generation mortality of stem borer eggs, larvae and

pupae in West Kenya (Oloo, 1989). Additional observations and small trials suggested that disappearance of eggs and young larvae could be as high as 90% (Mohyuddin and Greathead, 1970; Girling, 1978).

The predator guild of cereal stem borers in East Africa is extensive and has been reviewed by Bonhof *et al.* (1997). Ants (Hymenoptera: Formicidae) are the predominant predators in maize fields in the region (van den Berg, 1993). The beneficial role of ants in pest control has long been recognised and has been described for both annual (e.g. Risch, 1981; Perfecto, 1990, 1991) and perennial crops (e.g. Dejean *et al.*, 1997; James *et al.*, 1997). In East Africa, ants are represented by a rich variety of species, of which those belonging to the genera *Camponotus* and *Pheidole* appear to be most common. These genera have been reported from agricultural fields at the Kenyan coast (van den Berg, 1993), Kenya's Central Province (van den Berg, 1993), West Kenya (Oloo, 1989; van den Berg, 1993) and from Uganda (Mohyuddin and Greathead, 1970; Girling, 1978). Ants attack all life stages of the stem borer, and they are among the few predators preying on large larvae and pupae (Bonhof, 1998). Spiders, ladybirds and earwigs are also found on agricultural crops in East Africa (Oloo, 1989; Ogol *et al.*, 1998) but they appear to be less numerous and widespread than ants. Information on predators of stem borers has mostly been obtained through non-specific observations and hardly by quantitative studies.

In 1995, we started an extensive study on the abundance and impact of predators on maize stem borers at the Kenyan coast. The study confirmed that ants were the most widespread and numerous predators, with average seasonal densities per site ranging from 1.6 to 7.4 per plant. Spiders were present at densities of 0.1 to 0.5 per plant in each site. Earwigs and cockroaches were abundant at some sites and nearly absent at others. Coccinellids, chrysopids, bush-crickets and other predator groups were rarely found (Chapter 5). In this paper, we present the results of a study on the impact of predators on mortality of the stem borer *C. partellus* at the Kenyan coast.

MATERIAL AND METHODS

Study fields

Studies were conducted at the following sites at the southern coastal area of Kenya: Kwale Development Farm (KDF), ICIPE's Muhaka Field Station (MFS), Mazeras and Kaloleni (Table 7.1). KDF and MFS are situated 20 and 40 km South of Mombasa, respectively, while Mazeras and Kaloleni lie approximately 30 km West and 45 km north-west of Mombasa. The experiments were conducted during cropping seasons of the long rains (April-July) and short rains (October-November) of 1995 to 1998. In all fields, recommended agricultural practices were used. The maize variety Coast Composite was sown at a 30 x 75 cm line spacing and the fertiliser Di Ammonium Phosphate was applied (125 Kg/ha) at the same time. Plants were thinned to one plant per hole three weeks after plant emergence. After thinning, the crop was top-dressed with the fertiliser Calcium Ammonium Nitrate (125 Kg/ha) to ensure healthy plant growth. Manual weeding was done twice during the cropping season, and no pesticides were applied in or near the study field.

Cages

Experiments with eggs and small larvae were conducted in single-plant cages. The cages measured 0.4 x 0.4 x 0.2 m (L x W x H) and completely covered one maize plant. Locally available mosquito netting with a mesh width of 2 mm was used for the cages. This netting material was suitable for excluding most predators and parasitoids but could not prevent very small predators or *Trichogramma* spp. egg parasitoids entering the cage. Therefore, on plants in exclusion cages only, insect trap adhesive (Tanglefoot) was applied around the egg batches or at the base of the stem (experiments with small larvae) as an extra measure to exclude small predators and parasitoids. Leaves that touched the ground or netting were trimmed and arthropods were removed manually from all experimental plants and cages before the start of the tests. Bottom edges of exclusion cages were buried 10 cm deep into the soil while the

net of control cages was lifted 10 cm off the ground to allow predators access to the cage.

Table 7.1. Details of field studies on the impact of predators on *C. partellus* eggs, early instar larvae, late instar larvae and pupae, Coast Province, Kenya.

Stem borer stage	Trial	Site	Season	Number of plants		Days in field	Infestation density/plant	Predator population monitored?
				exclusion	control			
Eggs	1	MFS	LR 1998	26	30	4	average 53.2 eggs (range 3-256)	no
	2	MFS	SR 1998	30	30	4	average 28.7 eggs (range 1-109)	no
Early instar larvae	1	MFS	LR 1996	30	27	7	10 L1	yes
	2	KDF	LR 1996	40	40	7	10 L1	no
	3	KDF	LR 1996	24	35	7	10 L1	yes
	4	KDF	LR 1996	39	38	7	7 L2	yes
	5	MFS	LR 1997	35	41	7	7 L2	no
	6	MFS	LR 1997	19	15	7	7 L2	yes
Late instar Larvae	1	Kal	SR 1995	32	29	6	5 L4	no
	2	Kal	SR 1995	15	13	6	5 L4	yes
	3	KDF	SR 1996	24	23	6	5 L4	yes
	4	KDF	SR 1996	24	17	6	5 L4	no
	5	KDF	SR 1996	24	19	6	5 L4	no
	6	KDF	SR 1996	38	39	6	5 L4	no
Pupae	1	MFS	LR 1997	30	30	3	3 pupae	no
	2	MFS	LR 1997	30	30	3	3 pupae	no
	3	MFS	LR 1997	30	30	3	3 pupae	yes
	4	MFS	LR 1997	29	29	3	3 pupae	no
	5	MFS	LR 1998	35	35	3	3 pupae	yes
	6	MFS	LR 1998	26	27	3	3 pupae	yes

MFS = Muhaka Field Station   LR = long rainy season   L1 = first instar larvae
KDF = Kwale Development Farm   SR = short rainy season   L2 = second instar larvae
Kal = Kaloleni   L4 = fourth instar larvae

Methodology

Eggs

Experimental plants were sown in pots and placed in large cages to prevent natural infestation by stem borers. When two to three weeks old, they were brought from the field to the laboratory. Here, moths of *C. partellus*, hatched from field-collected pupae, were given the opportunity to oviposit on the plants overnight. Egg batches

were marked and the number of eggs in each batch was counted. The experimental plants were then brought to a 40 x 50 m field with maize plants of the same age, where they were randomly assigned to exclusion and control cages. Thirty plants were placed for each treatment (exclusion and control). After four days, the cages were removed, the plants were inspected for predators and then uprooted. The egg batches were collected and the fate of each egg in the batch was determined in the laboratory. Parasitized eggs were readily identified by their turning black in a few days time. White or brown eggs that failed to develop the characteristic orange-red transverse bars were considered non-viable. Predation by chewing predators was characterised by ragged edges of torn chorion. Eggs attacked by piercing-sucking predators had internal black areas or transparent areas beneath the chorion where the egg contents were removed. Moreover, the chorion of eggs fed on by sucking predators had usually collapsed.

Early instar larvae

Trials were conducted in a 40 x 50 m maize field, where single plant cages were placed over plants immediately after germination to prevent natural infestation of the plants. Each plant was randomly assigned to a treatment (exclusion or control). When the plants were three to four weeks old, they were infested with 10 first instar *C. partellus* larvae (trial 1 to 3) (Table 7.1). Forty cages were then opened by lifting the net while another 40 were closed again. Seven days after infestation, all experimental plants were dissected in the field and the number of larvae was counted. Before dissection, the plant and the band of insect trap adhesive (exclusion plants only) were inspected for predators and larvae.

Due to the low recovery in the first three trials, subsequent trials (4 to 6) were carried out using second instar larvae that are less likely to disperse than first instars (Berger, 1992). In trials 4 to 6, plants were infested with seven second instar larvae

(4 days old) (Table 7.1). The data collection procedure in trials 4 to 6 was similar to that in trial 1 to 3.

Late instar larvae

Forty to eighty plants, six to seven weeks old and without visible natural infestation, were selected in a 30 x 30 m maize field. The plants were randomly assigned to a treatment (exclusion or control) (Table 7.1). Just before artificial infestation, arthropods were removed from experimental plants and leaves of the experimental and neighbouring plants were trimmed in order not to touch each other or the ground. Predators were prevented from climbing exclusion plants using a band (approximately 3 cm wide) of insect trap adhesive at the base of the stem. Five small holes (5 to 6 mm diameter) were bored in the stem of each plant that was to be infested. After placing one large fourth instar *C. partellus* larva in it, the hole was loosely plugged with soft material from the maize stem. Six days after infestation, the experimental plants and the band of adhesive were inspected for predators and larvae. Plants were then dissected in the field and the number of dead and living larvae per plant was recorded.

Pupae

In each trial, 60 to 70 plants, seven to eight weeks old, were selected in a 30 x 30 m maize field and randomly assigned to a treatment (Table 7.1). Three small holes (5 to 6 mm diameter) were bored in the stem of each plant that was to be infested. After removing all insects from the plant foliage, zero to one day old *C. partellus* pupa was placed inside each hole. The hole was not plugged so it would roughly resemble the natural situation, where a larva makes an exit hole in the stem just before pupation to allow the emerging moth to leave the plant. Leaves of all experimental and neighbouring plants were trimmed and a 3 cm band of insect trap adhesive was carefully put at the base of the stem of exclusion plants only. The dissection

procedure was similar to that of late instar larvae but took place after three instead of six days.

Predators

To obtain information on the predator population in the study fields, 25 to 41 plants were visually inspected for arthropods, after which they were dissected to recover insects inside the stem. The abundance and species or family of all arthropods found on the plants were noted down. Information on ground-walking predators was obtained by counting the number and species of predator groups that passed an imaginary line between maize plants in a row and between rows.

Statistics

Plants with natural stem borer infestation and plants that had fallen down were excluded from analysis. Numbers of parasitized, disappeared, predated and non-viable eggs were compared between treatments using a G-test of independence. Differences between treatments in recovery of early instar larvae, late instar larvae and pupae were also tested with a G-test of independence.

RESULTS

Eggs

In the long rainy season, egg disappearance was 29% in cages accessible to predators (control) and 0% in exclusion cages. In the short cropping season, disappearance was 23% in control cages and 0.2% in exclusion cages (Figure 7.1). In both seasons, disappearance was significantly higher in control cages than in exclusion cages. A few eggs visibly preyed-upon by chewing predators were found in control cages. Eggs destroyed by sucking predators were observed in one egg batch only. Parasitism, most likely by *Trichogramma bournieri* Pintureau & Babault

(Hymenoptera: Trichogrammatidae) (A. Polaszek, personal communication), occurred only in the short rainy season and was higher in control cages (17%) than in exclusion cages (3%). The percentage of non-viable eggs was 17% higher in exclusion cages than in control cages in the long rainy season and 10% higher in the short rainy season.
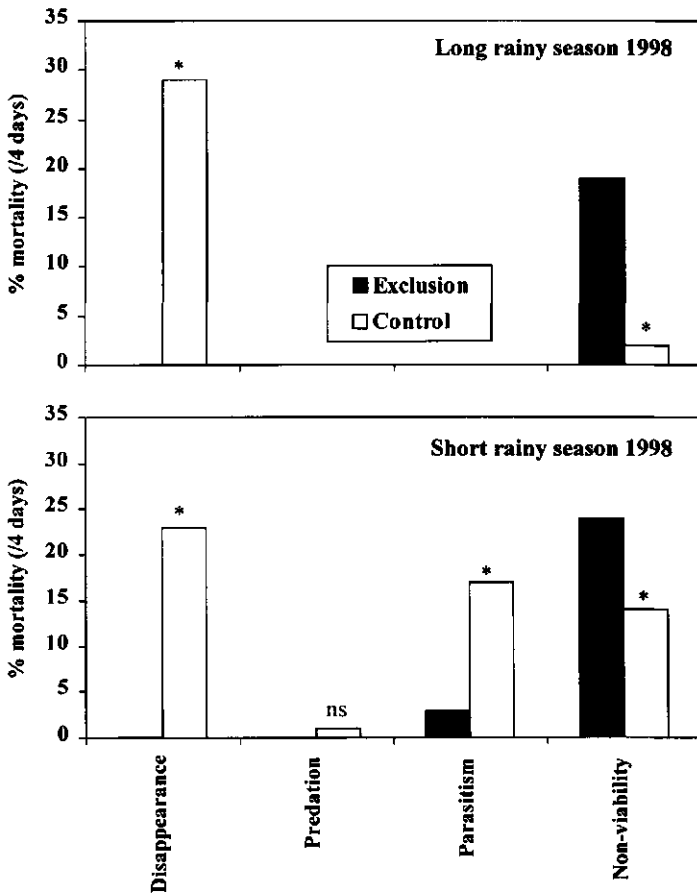
Figure 7.1. Mortality factors of *Chilo partellus* eggs in natural enemy exclusion and control cages. * indicates a significant difference (G-test of independence, p<0.05) between treatments, ns= not significant.

Early instar larvae

In the first three trials, when plants were infested with first instar larvae, the total recovery (living and dead) of larvae ranged between 20 and 50% (Figure 7.2a). Between 1 and 8% of larvae were recovered dead. Differences in recovery between treatments were not significant.

In trials 4 to 6, when plants were infested with second instar larvae, recovery ranged between 30 and 80% in both exclusion and open cages (Figure 7.2a), differences between treatments not being significant except in trial 4. In this trial, significantly more living and less dead larvae were recovered from plants in exclusion cages than from plants in open cages, but total recovery did not differ between the treatments.

Late instar larvae

Recovery of late instar larvae was 56 to 83% in plants where predators were excluded and 43 to 92% in plants accessible to crawling predators (Figure 7.2b). Significant differences between treatments were found in three cases. In trials 1 and 2, more larvae were found in exclusion plants than in those accessible to predators. In trial 3, however, exclusion plants contained fewer larvae than accessible plants. On average, 7 to 32% of larvae were recovered dead from exclusion plants and 7 to 17% from control plants. Differences in mortality were only found in trial 1, where more dead larvae were found in exclusion than in control plants.

Pupae

Recovery of pupae was 85 to 99% in predator exclusion plants and 56 to 87% in plants accessible to predators (Figure 7.2c). Significantly more pupae were recovered in exclusion plants than in control plants in four out of six trials. In both treatments, less than 10% of pupae were found dead in the stem, while preyed-on pupae were hardly found.
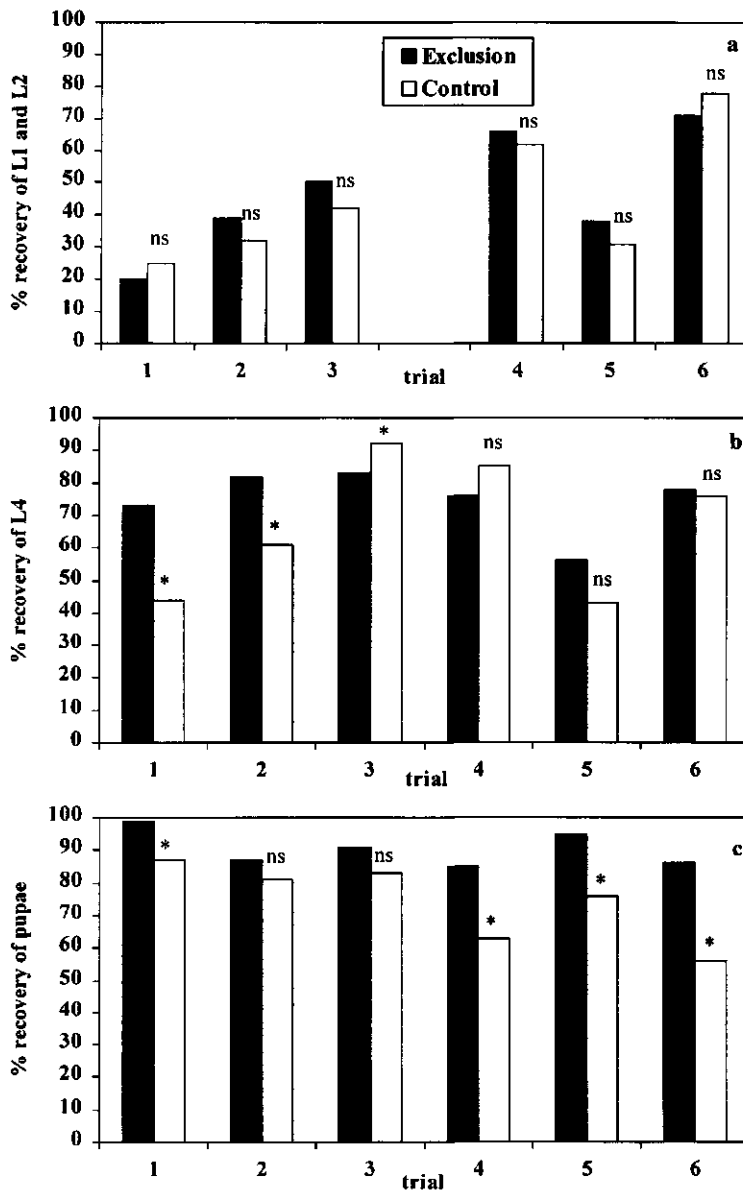
Figure 7.2. Recovery of first and second instar larvae (a), late instar larvae (b) or pupae (c) of *C. partellus* from predator exclusion and control cages in six trials (see Table 1). * indicates significant differences (t-test, p<0.05); ns = not significant

Predators

Ants, spiders and cockroaches were the most common potential predators of eggs and small larvae on maize foliage at the study sites, but their numbers were relatively low (Figure 7.3). Coccinellids, staphylinids and earwigs – also predators of eggs and small larvae - were occasionally found. At the time the trials with early instar larvae were conducted, the total predator population did not exceed 0.3 per plant. Ants are the only predators preying on late instar larvae and pupae of the stem borer. When the trials with these stem borer life stages were carried out, ants were found at densities between 0.2 and 8.2 per plant (Figure 7.4). Ants of the genus *Pheidole* were observed to feed on late instar larvae and pupae in the experiment. Ground walking predators included ants (*Pheidole* sp. and *Lepisiota* sp.) and small carabid beetles (*Lebia* species). Ants of the genus *Lepisiota* were especially numerous and active, with up to 50 crossings of the imaginary line per hour. However, these ants seldom climbed into the maize plants.
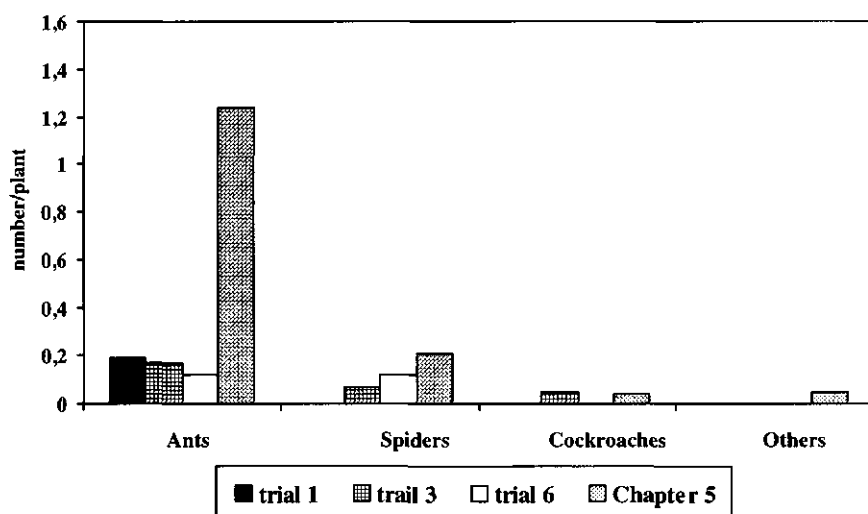
Figure 7.3. Predator guilds found on maize plants in the experimental field during trials with early instar larvae, and numbers of predators found at several sites along the Kenyan coast (as described in Chapter 5).
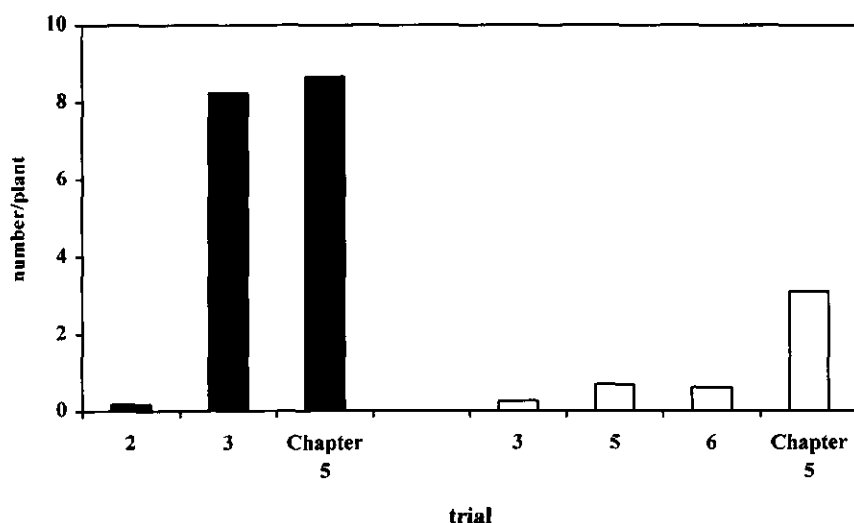
Figure 7.4. Number of ants found on maize plants in the experimental field during the trials with late instar larvae (black bars) and pupae (white bars), and numbers of ants found at several sites along the Kenyan coast (described in Chapter 5).

DISCUSSION

Excluding predators from maize plants had a significant impact on disappearance of *C. partellus* eggs. This disappearance is most likely caused by ants. Not only were they the most abundant potential predators, but they are also the only predator group that removes egg batches without leaving a trace (Chapter 6). Ants of the genus *Lepisiota* were observed peeling egg batches off the leaf and carrying them away in a study conducted at the same site. Under field conditions, solar radiation may also influence egg disappearance by causing dislodgement of egg batches (Chapter 8). The plants in experimental cages were probably more protected from physical factors than plants in the open field, and egg disappearance may therefore have been underestimated in the present study. Non-viability was considerably higher in our experiments than under natural conditions due to high temperatures that resulted in melting of the insect trap adhesive used around batches on exclusion plants. In the field, the percentage of eggs that fail to hatch is less than 7% (Chapter 4).

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Predators had little or no impact on the disappearance of early instar larvae. This finding contradicts with the common view that predators, and ants in particular, play an important role in the disappearance of small larvae (Mohyuddin and Greathead, 1970; Girling, 1978; Oloo and Ogeda, 1990). The impact of predators may have been limited due to their low numbers. Ants, despite being the most common predators, never exceeded averages of 0.2 per plant in our study, while average densities of 1.5 ants per plant are typical on young maize plants in the area (unpublished data).

Disappearance of small larvae must have been caused by factors other than predation. Rainfall, which can cause high disappearance (Chapter 8), did not occur during our experiments and therefore played no role. Cannibalism is negligible at densities of 10 or 20 early instar larvae (Chapter 8). Disappearance in our study was most probably a result of larvae falling onto the ground or against the net while spinning off the plant. Dispersal of *C. partellus* larvae is very high in the first larval stage (Berger, 1992). The small larvae (1 to 2 mm) have little chance of surviving as they are highly sensitive to desiccation, starvation and predation (Berger, 1992).

Disappearance of late instar larvae could seldom be put down to predators. The cryptic behaviour of large larvae and the low numbers or ants, which are the only predators known to attack large larvae inside the stem (Ajayi, 1985; Kfir, 1997b), are likely to have influenced this. The aggressive spitting and biting behaviour of large larvae may also deter predators (Takasu and Overholt, 1997). Cannibalism is expected to have been unimportant due to the low number of larvae and because the larvae had not yet tunnelled the stem in such a way that they encountered each other. As with early instar larvae, dispersal is expected to have caused a large part of the disappearance. Berger (1992) reported that many 5th or 6th instar *C. partellus* larvae leave the original host plant. Once outside the stem, the larvae are exposed to predators and abiotic factors. Unpublished data indicated that only 20% of large larvae (n=52) found a host plant again after they had left the original plant. The majority of larvae were attacked and carried away by ants (*Lepisiota* sp.) within a

few minutes after reaching the ground. On sunny days, when in the afternoon soil temperature reaches up to 50°C and ant activity was low, nearly all larvae on the ground died due to desiccation.

Predators frequently had a significant, though 'low, impact on disappearance of pupae inside the stem in four out of six trials. Pupae disappearing from exclusion plants may have been consumed by flying predators, although none were observed. Some pupae may also have fallen out of the holes if they were not placed sufficiently deep inside the stem. Once outside the stem, these pupae have little chance of surviving. We observed a small lizard eating a pupa on the ground, and other non-arthropod predators such as rodents or birds may also play a role in the disappearance of pupae outside the stem (Watmough and Kfir, 1995). Ants (*Lepisiota* sp.) frequently attacked *C. partellus* pupae on the ground but the attacks were not fatal (unpublished data). Under natural conditions, pupae cannot easily fall out of the plant because the exit hole chewed by the larva is covered with the epidermis of the plant. The absence of the epidermis in our study meant a higher exposure to mortality factors for the pupae, and disappearance may have been overestimated.

Possibilities to enhance predator impact

Increasing predator abundance, especially in the early crop stages, may have a considerable impact on stem borer populations and reduce the damage they cause. Predator numbers may be augmented in several ways. Intercropping, weed management and wild habitat management are frequently-studied strategies for enhancing natural enemy abundance or efficiency by increasing the agro-ecosystem diversity (e.g. Altieri, 1981; Andow, 1991). Intercropping maize with cowpea or the fodder tree *Leucaena leucocephala* had only limited potential of controlling stem borers in Kenya (Skovgård and Päts, 1996; Ogol *et al.*, 1998) and appeared not to augment predator numbers (Skovgård and Päts, 1996). The effect of weed

management has not been studied well, but Ogol *et al.* (1998) found little differences in parasitism and predation of stem borer eggs between weeded and unweeded plots. The third strategy, wild habitat management, appears to have potential and is currently the focus of a large project in Kenya. Wild habitats, which are an integral part of many small-scale farming systems in Africa, may contribute to pest-stable agroecosystems by enhancing natural enemy abundance (Altieri, 1991; Waage, 1991). Schulthess *et al.* (1997) found an inverse relationship between grass abundance and stem borer incidence in West Africa. They suggested that grasses either harbour natural enemies that prevent stem borers from reaching damaging levels on maize or that grasses act as trap plants. Khan *et al.* (1997) found that the fodder plants *Sorghum vulgare sudanense* (Sudan grass) and *Melinis minutiflora* (molasses grass) were highly attractive for natural enemies and increased the efficiency of parasitoids and predators in adjacent maize fields in Kenya (Khan *et al.*, 1997). The name for Sudan grass is synonym to *Sorghum xdrummondii* (Steud.) Millsp. and Chase ('t Mannetje and Jones, 1992).

CONCLUSION

The study presented in this paper shows that the impact of indigenous predators on stem borers at the Kenyan coast is generally low. A major reason for this small impact may be the relatively low abundance of predators, especially early in the season. Ants, being the most abundant of all predators in our study and preying on all stem borer life stages, appear to have most potential for augmentation of natural control. In order for predators, and especially ants, to play a role in reducing stem borer populations, their abundance should be enhanced. Habitat management strategies may have potential to do so, but more research is needed before recommendations can be made.

Chapter 8

THE IMPACT OF SOLAR RADIATION, RAINFALL AND CANNIBALISM ON DISAPPEARANCE OF MAIZE STEM BORERS IN KENYA

ABSTRACT

The effect of solar radiation, rainfall and cannibalism on the disappearance of eggs and larvae of the cereal stem borer *Chilo partellus* (Swinhoe) were studied. Disappearance and non-viability of egg batches was higher on plants exposed to solar radiation than on shaded plants. From plants exposed to rainfall, significantly fewer small larvae were recovered than from shielded plants. Cannibalism among larvae of the same size was not common except at high larval densities. Contrary to the common belief that disappearance is the result of predation, these studies showed that solar radiation and rainfall also play an important role in the disappearance of stem borer eggs and small larvae.

INTRODUCTION

The stem borer *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) is a major constraint to maize production in East and southern Africa (Sithole, 1989; Overholt *et al.*, 1994; Kfir, 1997b). Its eggs are laid on the upper and lower side of leaves or on the stem, and hatch after 4 to 8 days (Harris, 1990). Newly hatched larvae initially feed in the leaf whorl, where they can destroy the growing points if plants are attacked at an early stage. Larvae start tunnelling the stem when they reach the third larval instar (Overholt *et al.*, 1994). After the fifth or sixth instar, larvae pupate inside the damaged stems. During the growing season, *C. partellus* completes its life cycle in 25 to 50 days (Harris, 1990).

Stem borers can suffer high mortality under natural conditions. Mathez (1972) estimated that only 5% of eggs produce adults at the Kenyan coast, while partial life table studies in West Kenya showed that in maize, only 0.1% of eggs survived to become adults (Oloo, 1989). In Kenya and Uganda, mortality of *C. partellus* eggs ranged from 18 to 90% (Mohyuddin and Greathead, 1970; Oloo, 1989; Chapter 4), and mortality of larvae and pupae was often about 90% (e.g. Mohyuddin and Greathead, 1970; Girling, 1978; Oloo, 1989). In the above studies, mortality was almost entirely attributed to 'disappearance'. Predation is often considered to be responsible for disappearance and, therefore, seen as an important mortality factor of especially eggs and small larvae (e.g. Girling, 1978; Leslie, 1988; Oloo, 1989; Ogol *et al.*, 1998). However, in Chapter 7, it was shown that the above presumption is not always correct. Predators did play a role in the disappearance of *C. partellus* eggs and, in some trials, also of pupae, but their impact on early and late instar larvae, if any, was small and often ambiguous. Other factors beside predation must play a role in the disappearance of eggs and small larvae. Desiccation, rainfall and cannibalism have been reported to influence disappearance of Lepidopteran eggs and larvae. Larval disappearance may also be caused by dispersal and subsequent desiccation and predation (Litsinger *et al.*, 1991). Solar exposure caused desiccation of eggs of

Helicoverpa zea (Boddie) (Lepidoptera: Noctuidae), leading to dislodgement or non-viability (Nuessly *et al.*, 1991). Rainfall also dislodged eggs of this pest from the leaf surface of cotton (Nuessly and Sterling, 1994). van Huis (1981) observed that during rain showers in Nicaragua, maize whorls filled with water and overflowed, thereby washing away or drowning small *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) larvae feeding inside the whorl. Cannibalism is a widespread natural behaviour amongst larvae of many Lepidopteran species (e.g. Gould *et al.*, 1980; Breden and Chippendale, 1989; Chapman *et al.*, 1999), for example of the Southwestern Corn Borer *Diatraea grandiosella* (Dyar) and the European Corn Borer *Ostrinia nubilalis* (Hübner) (Lepidoptera: Crambidae) (Breden and Chippendale, 1989). Cannibalism has not been reported in African cereal stem borers, but the aggressive behaviour that large larvae of *C. partellus* and *Eldana saccharina* (Walker) (Lepidoptera: Pyralidae) often display among each other (Girling, 1978; Takasu and Overholt, 1997) gives a potential for cannibalistic behaviour. In this paper, we investigate the role of some factors other than predation, i.e. solar radiation, rainfall and cannibalism on the disappearance of *C. partellus* eggs and larvae at the Kenyan coast.

MATERIALS AND METHODS

Study site

All experiments were conducted at Muhaka Field Station (MFS) (04°19.48 S, 039°31.45 E), Kenyan coast, during the long rainy season of 1999. MFS is situated at 40 m altitude and receives 1200 mm rainfall a year, mainly from April to July (long rainy season) and from October to November (short rainy season). Mean average temperature is 24°C and the average relative humidity is 81% (weather data Kenyan Agricultural Research Institute 1992 to 1998).

The impact of solar radiation on disappearance and non-viability of eggs

Maize of the variety Coast Composite was sown in pots placed in large field cages to prevent natural stem borer infestation. Three to four weeks after plant emergence, the potted plants were brought to the laboratory, where mated female *C. partellus* moths were allowed to oviposit on them overnight. Batches oviposited on the upper side of the leaf were marked with a felt tip pen, and the number of eggs was counted. Insect trap adhesive (Tanglefoot) was put around the egg batch, 3 cm from the edge, to prevent walking predators from reaching the eggs. Batches oviposited on the lower side of the leaf and on the stem were not used for the experiment as they are less exposed to solar radiation. The plants were then returned to the maize field.

A total of eleven plants with 77 egg batches were placed under a white cotton cloth to avoid solar exposure (control plants) and 16 plants with 69 egg batches were not shaded (exposed plants). Temperature and relative humidity under the cloth and in the open were recorded three times a day (at 9:00h, 12:00h and 15:00 h). The number of hours of solar radiation was measured and weather conditions were recorded throughout the experiment. The egg batches were collected after four days (before hatching) and kept in the laboratory until the fate of each egg was known. Eggs had 'disappeared' when no trace of the egg batch could be found. 'Non-viable' eggs were white or brown eggs that failed to develop a brown centre (= the head capsule of the larva) (Mathez, 1972). Data were arcsine transformed before analysis and a t-test was used to compare between treatments.

The impact of rainfall on disappearance of small larvae

Maize plants (experimental and guard plants) of the cultivar Coast Composite were grown in pots in field cages to avoid natural stem borer infestation. At the peak of the long rainy season, the three to four weeks old experimental plants were placed in four groups of 15 plants each in an adjacent field between maize plants of the same age. Around each group, approximately 25 non-infested plants were planted as a guard row

and as a buffer against rain and strong wind. Plastic rain shields (2.5 x 3 metres) were placed over two of the groups (including the guard plants), while the remaining two groups were not shielded. All 60 experimental plants (30 exposed and 30 shielded plants) were infested with 20 first instar *C. partellus* larvae (0 to 1 day old) each. The experiment was conducted twice (trial 1 and 2). Experimental and guard plants were dissected and the number of dead and living larvae were counted after rainfall had occurred, which was after three days in trial 1 and after six days in trial 2. Data from guard plants were not included in the analysis but merely used to obtain information whether migration from experimental to guard plants had occurred. The amount and intensity of rainfall were estimated. Data were analysed with a t-test, performed on arcsine transformed fractions of dead or living larvae.

Cannibalism

The experiment was conducted with small *C. partellus* larvae (first instar, 1 day old), medium-sized larvae (third instar, approximately 15 days old), and large larvae (fifth or sixth instar, approximately 25 days old). All larvae were obtained from a laboratory rearing, where first and second instar larvae were fed on maize leaves and third and later instar larvae on pieces of maize stem. For the experiment, small larvae were placed in a Petri dish on a piece of maize leaf (28 cm²) in densities of 10, 25, 50 or 100 larvae. Under field conditions, densities of 10 and 25 small larvae per plant can easily be found, but densities of 50 or more small larvae per plant are less common (W.A. Overholt, personal communication). The medium-sized and large larvae were placed at densities of 5, 10, 20 or 40 larvae in a Petri dish with a split piece of maize stem (3 cm length). All Petri dishes were sealed with Parafilm. The fate of all larvae was recorded after four days. Data were arcsine transformed, after which they were analysed using General Linear Modelling. Mean separations were carried out by Student-Newman-Keuls test (SNK-test).

RESULTS

The impact of solar radiation on disappearance and non-viability of eggs

After four days in the field, disappearance of egg batches on plants exposed to solar radiation was four times as high as on control plants (Figure 8.1). Non-viability of egg batches was also significantly higher on exposed than on control plants. During the four days, on average 5.7 hours of sunshine were recorded per day and the total amount of rainfall was 3 mm. The average temperature was 21 to 30 °C and relative humidity 49 to 98% for the shaded plants, while temperature was 22 to 32°C and relative humidity 30 to 98% for plants in the open.

Impact of rainfall on disappearance of small larvae

During the first trial, rainfall was 30 mm, divided over 4 rain showers ranging in intensity from less than 0.1 mm/min to 0.4 mm/min. Most of the rain (24 mm) fell on the day of infestation and during the next day. Three days after infestation, significantly more small larvae had disappeared from exposed plants than from shielded plants (Figure 8.2). Some of the disappeared larvae were recovered in the guard rows: the exposed groups (3%) not being significantly different from the shielded groups (5%) (p=0.32). Between 2 and 4% of larvae were recovered dead in both treatments (p=0.20).

In the second trial, rain was absent during the first two days after infestation. During the following 4 days a total of 74.5 mm fell, divided over several showers varying from drizzle to heavy rain. When the plants were dissected six days after infestation, three times as many larvae had disappeared from exposed plants than from control plants (Figure 8.2). An average of 4 (exposed groups) and 5% (control groups) of the disappeared larvae were recovered from guard plants (p=0.55). Two to three percent of the larvae was recovered dead in plants of both treatments (p=0.42).
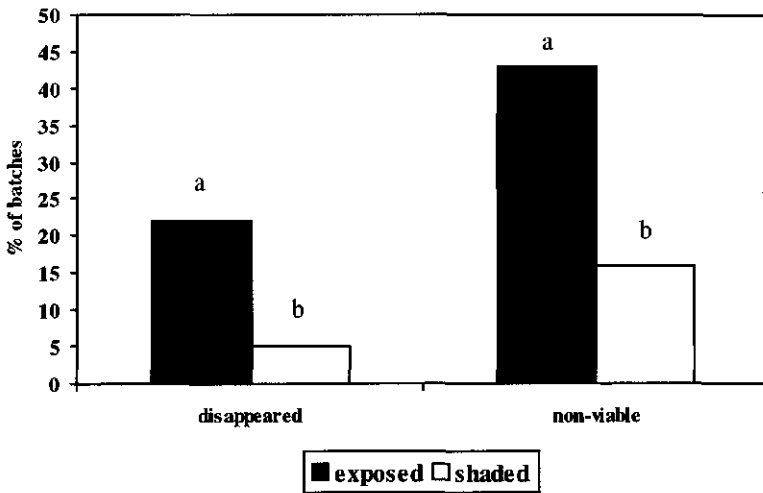
Figure 8.1. Percentage of disappeared and non-viable egg batches found on plants exposed to solar radiation and shaded plants (control). p= 0.003 for disappearance and p=0.002 for non-viability.
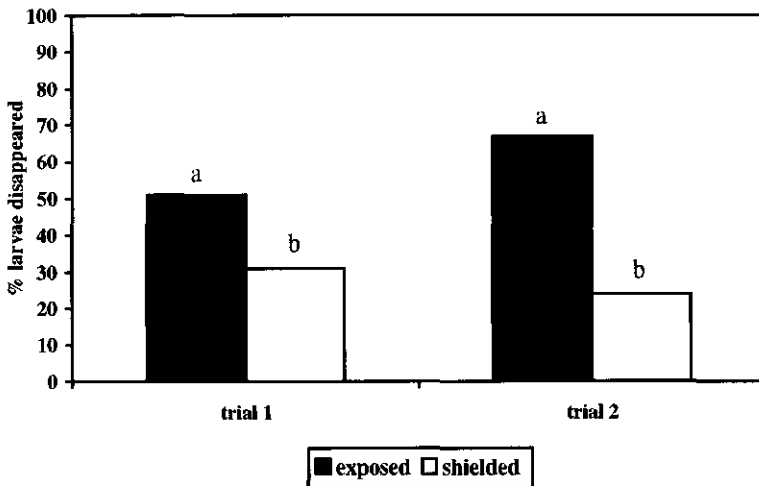

Figure 8.2. Percentage of small larvae that disappeared from plants exposed to natural rainfall and from shielded control plants (n=30 per treatment in both trials). For each trial, different letters indicate a significant difference between treatments (p= 0.02 in trial 1 and p=0.0001 in trial 2).

Chapter 9

GENERAL DISCUSSION

Maize is the main staple food for millions of people in eastern and southern Africa. In Kenya, yields obtained by small-scale farmers are less than 1500 kg/ha (Saxena *et al.*, 1989; Grisley, 1997). At the southern Kenyan coast, our study area, yields are similar (Chapter 2). Low soil fertility, drought or unreliable rainfall, and insect attack are the main factors reducing yields at the coast (Mathez, 1972; van Oosten, 1989; Waaijenberg, 1993; Chapter 2). Lepidopteran stem borers are the most damaging of the insect pests (Nye, 1960; Youdeowei, 1989), causing yield losses of 4 to 73% of the potential maize yield (for a review, see Seshu Reddy and Walker, 1990). Especially damaging is *Chilo partellus*, a species that was accidentally introduced into Africa in the 1930s and has now displaced indigenous stem borer species (Sithole, 1989; Overholt *et al.*, 1994).

SHOULD MAIZE BE GROWN IN THE COASTAL AREA OF KENYA?

Considering the low yields and the many problems associated with maize growing, one can question whether maize should be grown at all in the coastal area of Kenya. Maize was introduced into the area approximately 400 years ago, after which it gained popularity quickly. After a series of famines in the beginning of the 20th century, when farmers received maize to plant, the switch from sorghum and millets to maize was complete (Waaijenberg, 1993). Although sorghum is a more suitable crop for the poor, sandy soils and more adapted to the low, unreliable rainfall of the coastal area than maize (e.g. Mathez, 1972; Waaijenberg, 1993),

government efforts to reintroduce sorghum in the 1980s did not succeed. Maize also has some advantages over sorghum: it has a short growing cycle, is less vulnerable to pests (especially birds) and can be harvested, stored, transported and sold more easily than sorghum.

In addition to maize, cassava and cowpea are important crops at the Kenyan coast. Cassava is relatively drought resistant, has a good yield potential on poor soils, requires little labour and does not show a peak in labour demand, but it is less preferred less than maize and is also often infected with mosaic virus (Robertson, 1987). Cowpea is grown as intercrop or relay crop in maize. Yields are often low due to diseases and pests such as the legume pod borer *Maruca testulalis* Geyer (Lepidoptera: Pyralidae) (Okeyo-Owuor *et al.*, 1991) and the legume flower thrips *Megalurothrips sjostedti* (Trybom) (Thysanoptera: Thripidae) (Kyamanywa *et al.*, 1993). Although both cassava and cowpea are widely grown, maize remains the favourite food. As long as its supply in shops is (felt to be) unreliable and there is not better employment for (especially) women, farmers will continue to grow maize.

HOW CAN HIGHER MAIZE YIELDS BE OBTAINED?

As a result of the dramatic increase in population, maize yields are no longer sufficient to feed the people at the coast. Some of the problems in maize growing are beyond the farmers' control, but several measures could be taken to improve maize yields. Proper water and crop management techniques could assist the farmers to make better use of rainfall. Soil fertility could partly be increased by the application of fertiliser or manure. However, the economic benefits of fertilisation are often too low to make it worthwhile (Waaijenberg, 1993), and manure is not widely available at the coast due to the low number of cattle. Using nitrogen as a fertiliser may result in an increase in stem borer density (Chaudhary and Sharma, 1988; Kumar, 1994), but Mathez (1972) suggested that a higher stem borer density in healthy and strong

plants often results in lower damage than a lower borer density in weak and short plants. A crucial factor in the cultivation of maize is weeding; if the crop is weeded late, yields suffer or the crop may even fail (van Oosten, 1989; Waaijenberg, 1993). Weeding requires much more labour than most households can mobilise (van Oosten, 1989) and is therefore a major constraint. Weed growth in a young maize crop could be reduced considerably if the soil was partly covered, for example by intercropping the young maize crop with cowpea (ICIPE, 1994). However, cowpea is traditionally not sown as an intercrop until the maize is already in the tasseling phase (personal observation). The last adverse factor in maize growing is stem borers. The low rainfall, poor soil fertility and competition with weeds make maize plants short and weak, and therefore more vulnerable to stem borer attack and damage (Mathez, 1972).

HOW CAN STEM BORER CONTROL BE IMPROVED?

At this moment, only few suitable control methods are available to subsistence farmers. Host plant resistance, cultural control, botanical control and biological control appear to be the most promising and feasible ones for subsistence farmers (Seshu Reddy, 1998; van den Berg *et al.*, 1998).

Host plant resistance

Several maize lines with good levels of resistance or tolerance to stem borer attack have been developed in Kenya. Such cultivar as ICZ5, IC92M4 and IC92M5 were tested by a small group of subsistence farmers at the coast, which obtained 10 to 20% yield increase. Farmers liked the growing characteristics and the taste of the maize, and were interested in either purchasing or locally producing the seeds (ICIPE, 1994). The cultivars were handed over to the Kenyan Agricultural Research Institute (KARI) to undergo the usual national seed cultivar performance trials in 1995. So

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far, none of the above cultivars have been certified and it is not likely that they will ever be released by KARI (S. Sithanantham, personal communication).

Cultural control

Cultural control methods include many tactics, such as management of crop residues, intercropping, the use of trap crops and the management of wild host plants. Methods such as planting density, removal of infested plants, tillage, crop rotation, fertiliser use, choice of maize cultivar and water management have been studied but had little impact on stem borer populations or were not practicable for small-scale farmers.

Soil tillage

Soil tillage may result in mechanical damage of diapausing larvae or pupae by burying them with the residues so deep that moths cannot emerge, or it may bring them to the surface where they are exposed to natural enemies and adverse weather conditions. Tillage practices are viable options for stem borer control in commercial agricultural systems but less so in subsistence farming. Many farmers in rural areas do not have access to tractors or other machinery (personal observation) and soil tillage is usually done by hand and therefore shallow.

Crop rotation

The effect of crop rotation in stem borer management is questionable. Crop rotation is generally most effective against a pest that has a narrow host range and a limited range of dispersal (Wright, 1984). Moths of *C. partellus* have the capacity to disperse over long distances. Mated females are able to fly for more than nine hours nonstop and the maximum speed was 0.9 m/s in a flight mill during free flight (Päts and Wiktelius, 1989). Crop rotation will not prevent stem borer infestation because of the moth's ability to disperse over long distances (van den Berg *et al.*, 1998). It is

also debatable whether crop rotation is feasible and practical in the intercropping systems commonly found on small-scale farms.

Water management

Water management can influence stem borer populations through its effect on plant vigour and growth. Plants under drought stress appeared to suffer greater damage from *C. partellus* (van den Berg *et al.*, 1998) while high soil moisture content also increased stem borer incidences (Rivnay, 1967).

Crop residue management

Crop residues left in the field after harvest form a major source of borer infestation in the following season (Van den Berg *et al.*, 1998). The carry-over populations can be reduced by destruction of the crop residues, but this is not always feasible since farmers leave stems and stubble in the field purposely to increase soil fertility (Chapter 2). A more suitable method for subsistence farmers is placing the stems horizontally after harvest. Studies from the Kenyan coast and the Ethiopian highland indicated that temperature-induced mortality of larvae and pupae of *C. partellus* and *B. fusca* increased significantly when stems were placed horizontally and the post-harvest weather was dry and hot (Gebre-Amlak, 1988; Päts, 1996).

Intercropping

Intercropping maize with a non-host (often cowpea) reduces the incidence of stem borers (e.g. Omolo and Seshu Reddy, 1985; Omolo, 1986; Oloo and Ogeda, 1990; Skovgård and Päts, 1996). However, Skovgård and Päts (1996) considered the differences in stem borer numbers to be too small to have a marked effect on maize yields. They concluded that maize-cowpea intercropping as a sole method of stem borer control has only limited potential, but that it could be useful in combination with other control methods.

Management of wild host plants

The role of naturally occurring wild host plants in the survival of stem borer populations is unclear. Until a few years ago, wild hosts were seen as a pest reservoir and responsible for stem borer outbreaks on maize (Ingram, 1958; Bowden, 1976) and it was recommended to destroy them (Ingram, 1958; Nye, 1960; Seshu Reddy, 1983). However, Schulthess *et al.* (1997) discovered in the forest zones of Cameroon and Ivory Coast inverse relationships between grass abundance and stem borer incidence, contradicting the hypothesis of wild habitats being reservoirs for stem borers. The inverse relationship may be explained by grasses acting as trap plants and by grasses being sources of natural enemies, preventing stem borers from reaching damaging levels on maize (Schulthess *et al.*, 1997).

Several of the naturally occurring grasses attract oviposition of stem borers while only few stem borers are able to complete their life cycles on them. Ofomata *et al.* (2000) reported that mortality of the stem borers *C. partellus* and *C. orichalcociliellus* was much higher in napier grass (*Pennisetum purpureum* Schumacher (Gramineae)), guinea grass (*Panicum maximum* Jacq. (Gramineae)) and wild sorghum (*Sorghum arundinaceum* (Desv.) Stapf. (Graminae)) than in maize and sorghum. The name for wild sorghum is a synonym for *Sorghum bicolor* (L.) Moench subsp. *verticilliflorum* (Steud.) Piper (Grubben and Soetjipto Partohardjono, 1996). Stem thickness and plant nutrient levels, especially the relative amounts of nitrogen and silica, may provide an explanation for the difference in survival, as was demonstrated by Sétamou *et al.* (1993) for the stem borer *S. calamistis*. In recent years, studies have been conducted on the use of the forage grass *Sorghum vulgare* Pers. var *sudanense* (Gramineae) (Sudan grass) as a trap crop (Khan *et al.*, 1997). Sudan grass belongs to a complex of hybrids, and is a synonym to *Sorghum xdrummondii* (Steud.) Millsp. and Chase ('t Mannetje and Jones, 1992). Sudan grass attracted greater oviposition by stem borers than cultivated maize, resulting in a significant increase in maize yield. The grass could support survival of stem borers at

a similar rate to maize, so the proper management and timely harvest of Sudan grass is important (Khan *et al.*, 1997). Research is also carried out on a repellent crop, the forage grass *Melinis minutiflora* (molasses grass) which is a non-host for stem borers. Molasses grass repelled gravid stem borer females from ovipositing on maize, which resulted in a significant reduction in stem borer infestation in maize (Khan *et al.*, 1997). In areas where farmers own cattle, the use of trap and repellent crops has great potential because they do not only decrease stem borer infestation, but the grasses can also be used as fodder. However, this is not likely to happen in the southern coastal area of Kenya because keeping cattle is not common due to problems with diseases and pests such as the tsetse fly.

A second explanation for the inverse relationship between grass abundance and stem borer incidence is the presence of natural enemies. The proximity of patches of wild vegetation often positively influenced the colonisation, abundance and diversity of predators and parasites in crop fields in the U.S.A. and in Europe (e.g. Altieri and Schmidt, 1986; Dennis and Fry, 1992; Landis and Haas, 1992). Although not much is known about the situation in Africa, Khan *et al.* (1997) suggested that the presence of Sudan grass leads to increased natural enemy numbers, resulting in a higher reduction of stem borers.

Experiments not included in this thesis compared predator and stem borer populations during two seasons in a patch of wild grasses (mainly napier grass and wild sorghum) and in a bordering maize field at the coast. Ant, spider and earwig numbers were generally higher on wild grasses than on maize early in the growing season. Possibly, predators overcome the dry season in patches of wild grasses when no maize is present. Perennial grasses may also provide more food and shelter than young maize plants. When the maize crop was approximately 7 weeks old, the predator population in maize increased rapidly and surpassed that on wild grasses. After the cobs had been harvested and the maize plants had dried up, predator numbers decreased again on maize but did not increase on the wild grasses. A study

focussing on predation and parasitism of eggs, larvae and pupae of *C. partellus* showed that parasitism, death and disappearance of these life stages did not differ between maize plants placed either in a patch of wild grasses or in an adjacent maize field (unpublished data). Thus, neither studies found evidence for a positive influence of wild grasses on predator and parasitoid abundance in maize. The high mortality on many species of wild grasses is probably not caused by natural enemies but is more likely due to a difference in nutritional values of the grasses and maize.

Botanical control

Botanical pesticide extracts have been used traditionally by resource-limited farmers to protect their crops from pests. Neem (*Azadirachta indica* A. Juss (Meliaceae) is a tree whose leaves, bark and seeds are frequently used in the control of insects (ICRAF, 2000). Neem cake was equally effective as the insecticide Dipterex in reducing stem borer numbers, and a yield increase of 13% was obtained if neem cake was applied once and 36% when applied twice (ICIPE, 1995). The net gain in income (Kenyan shilling per hectare) of Dipterex is negative because of its high costs. Neem is often available on the farm or in the neighbourhood, so costs are minimal. Awareness programs and capacity building programmes have been developed and implemented in some regions of Kenya. Several projects have also distributed seeds and seedlings, and farmers are reportedly very interested in buying and using neem (ICIPE, 1995). *Tephrosia vogelii* Hook.f. (Fabaceae: Papilionoideae) is able to effectively reduce *C. partellus* damage (Mugoya and Chinsembu, 1995). It is occasionally used for stem borer control in Zambia (Mugoya and Chinsembu, 1995), Tanzania (Marandu *et al.*, 1987) and at the Kenyan coast (Chapter 2). Personal observations and the survey described in Chapter 2 indicate that only few farmers along the Kenyan coast are aware of the stem borer reducing effects of botanicals such as neem and *T. vogelii*. Consequently, botanicals were rarely used to control stem borers.

Biological control

A wide range of natural enemies of stem borer eggs, larvae and pupae has been identified (Chapter 3), but these indigenous natural enemies are not able to keep stem borer populations below economic injury levels (Oloo, 1989; Overholt *et al.*, 1994). In 1968, the first classical biological control project for stem borers was initiated in East Africa. Nine parasitoid species were released in Kenya, Uganda and Tanzania, but none of them established (CIBC, 1968-1972). In 1990, a second biological control project began in Kenya. The exotic larval parasitoid *Cotesia flavipes* was released in the southern coastal area of Kenya in 1993 (Overholt *et al.*, 1994). After establishment, it spread several hundred kilometres from the release sites and colonised new areas. Its suppressive impact on stem borer populations started in the 1997-1998 growing season in Kilifi District, the area north of Mombasa, when *C. partellus* density decreased by 53%. In the area south of Mombasa, the first results were seen in the 1999 growing season, when 33% less *C. partellus* larvae were found (W.A. Overholt, personal communication). In some areas, the impact of *C. flavipes* has remained low and research on the release potential of other parasitoids is therefore ongoing. The potential of the pupal parasitoid *Xanthopimpla stemmator* is currently being studied at the ICIPE. If the results of the laboratory studies are promising, releases may be carried out in the next year (W.A. Overholt, personal communication).

DISAPPEARANCE OF STEM BORERS: IMPORTANCE AND FACTORS INVOLVED

In many population dynamics studies of stem borers, 'disappearance' was found to be the major natural mortality factor and occurs at all life stages of the stem borer. It can be as high as 80 to 90% in all life stages of the stem borer (Mohyuddin and Greathead, 1970; Girling, 1978; Oloo, 1989). Disappearance is generally attributed

to predation, but this presumption is mostly based on anecdotal observations and only very few quantitative studies had been carried out before the research described in this thesis started.

Evaluation techniques used

Methods to evaluate the impact of natural enemies have been reviewed extensively (e.g. DeBach and Huffaker, 1971; Grant and Shepard, 1985; Luck et al., 1988; Bellows et al., 1992). Quantitative methods that provide an assessment of the impact of natural enemies include the use of exclusion cages or barriers, exclusion through the use of selective pesticides, host or prey enrichment, inclusion of hosts or prey and natural enemies, and observation of the fate of sessile prey. Evaluations in the laboratory (Grant and Shepard, 1985) and direct observations (Luck et al., 1988) may provide quantitative data on for example attack rates. For predators, mark-recapture methods such as serological tests and radio-active labelling can also be applied (Grant and Shepard, 1985; Luck et al., 1988; Bellows et al., 1992). No single technique is suitable for all situations but by using a combination of methods, the most reliable information may be obtained (Grant and Shepard, 1985). The choice of approaches largely depends on the objectives, equipment and technical support available to the researcher (Luck et al., 1988).

Given the working conditions in Kenya, I chose a combination of qualitative and quantitative methods that needed little capital and equipment but would provide a wide diversity of data and that could be used to crosscheck results. Qualitative data, such as the predators present, seasonal abundance and correlations were obtained by studying predator and prey populations in maize fields along the Kenyan coast (Chapters 5 and 6). The potential impact of those predators present was examined in the laboratory by means of feeding experiments (Chapter 6). Ants were not tested in the laboratory because they are social insects that do not behave normally if taken out of their colony. The consumption capacity of spiders was examined in Petri

dishes, other laboratory experiments could not be carried out due to the large number of spider species and the few individuals encountered per species. The role of predators on stem borers in the field was studied by determining the fate of egg batches on a daily basis (Chapter 4), by direct observation of predation events (Chapter 6) and by predator exclusion studies (Chapter 7). Based on the results from these studies, it was clear that predators only played a minor role in mortality of stem borers. Further studies focussing on different aspects of the principal predators or inclusion studies were therefore not conducted.

Impact of predators on disappearance

In this thesis, emphasis is given to the potential of predators to suppress stem borer populations in maize fields at the southern coastal area of Kenya. The results showed that predators played only a small role in the mortality of stem borers in the area. Very few egg batches, larvae and pupae were preyed upon (Chapters 4, 6 and 7). Predator exclusion studies also indicated that the high disappearance of small and large larvae could generally not be attributed to predation. However, predation was involved in the disappearance of egg batches and, in some trials, of pupae (Chapter 7). At the coast, disappearance of small larvae, large larvae and pupae ranged between 8 and 80%, and was 12 to 30% for egg batches (Chapters 4 and 7). The rate of disappearance in our studies was much lower than in studies conducted in West Kenya and Uganda. In these areas, Mohyuddin and Greathead (1970) and Oloo (1989) reported disappearance of all *C. partellus* life stages to be approximately 90%.

Impact of other factors on disappearance

During field observations, it was noticed that some egg batches curled away from the leaf and were blown off by the wind (Chapter 8). This type of disappearance occurred more frequently than disappearance by predation. Egg batches blown off

were mostly situated on the upper side of the leaf and thus exposed to solar radiation. In experiments it was not only shown that solar radiation played a role in dislodging egg batches, but non-viability was also significantly higher on solar-exposed plants than on shaded plants (Chapter 8). Rainfall did not dislodge egg batches since no egg batches disappeared after heavy rain (Chapter 8).

Disappearance of larvae was generally not caused by predation, so other factors must have played a role. Rainfall had a considerable impact on small larvae that are feeding inside the leaf whorl (Chapter 8), probably by drowning or washing the small larvae off the plant. Cannibalism may also have caused some larval disappearance. It occurred in all larval stages but only became significant at densities far exceeding natural larval densities and its impact is therefore thought to be low under field conditions. A factor that is expected to have had a larger role in larval disappearance is dispersal. Dispersal is essential for *C. partellus* since the number of eggs per batch is usually much larger than the number of larvae that a single plant can sustain (e.g. van Hamburg, 1980; Berger, 1989). Dispersal is especially high among newly hatched and both fifth and sixth instar larvae (Berger, 1992). Newly hatched larvae disperse by spinning off the plant using a silken thread (ballooning). They are then blown by the wind onto another plant. Ballooning allows the larvae to disperse quickly from one plant to another, but may also result in larvae falling onto the ground or onto a non-host plant. Many of these first-instar larvae will die through desiccation or predation (Litsinger *et al.*, 1991). Large larvae disperse to other plants by walking on the ground and some by walking over touching leaves. Observations showed that only 20% of fourth-instar larvae successfully reached a host-plant after having fallen onto the ground (Chapter 7) because most larvae were quickly taken by ants. On sunny days, when the soil temperature reached up to 50°C and ant activity was low, nearly all larvae walking on the ground died due to desiccation, thus 'disappearing' from the stem borer population.

EXPLANATION OF LOW IMPACT OF PREDATION

Four possible explanations can be found for the small impact of predators on stem borer mortality at the southern coastal area of Kenya:

1)   predator numbers are low on maize (Chapters 5 and 6);

2)   predators and stem borer prey do not occur at the same time (Chapter 5);

3)   predators appear not to search actively on maize plants (Chapter 6), and

4)   stem borers are not a preferred type of prey for predators (Chapter 6).

Low predator numbers

Of the predators encountered, only ants were found in considerable numbers (Chapter 5 and 6). Spiders were widespread but only present at average densities of 0.2 to 0.4 per plant. Earwigs were abundant in some fields, to an average of 0.9 per plant, but virtually absent in other fields. Other predators such as coccinellids, lacewings, praying mantids, bush-crickets, rove beetles and syrphid larvae were hardly found, and when encountered were often associated with aphid prey. Many of the above mentioned predator groups were also found by van den Berg (1993), who studied the natural enemies of *Helicoverpa armigera* in smallholder fields in West, Central and coastal Kenya. In his studies, ants and anthocorids were the only two common groups. Spiders were never abundant and earwigs were not included in the list (van den Berg *et al.*, 1993), but it is not clear whether they were never found or whether they were not mentioned because they were not preying on *H. armigera*. Anthocorids were encountered in our studies as well but only in small numbers. Furthermore, anthocorids were not preying on eggs, with the exception of one individual of a *Lyctocorus* species. Van den Berg (1993) found that both predator and pest populations were higher in western and central Kenya than at the coast. In West Kenya, average ant densities (*Pheidole* spp.) in sunflower and cotton fields were 0.8 to 3.5 per plant during the growing season, but in one off-season trial 12 to 38 (van den Berg *et al.*, 1995; van den Berg *et al.*, 1997). These numbers were

comparable to the numbers we found at the coast. Thus, although predator numbers appeared low, it seems to be fairly representative for the situation in many agricultural fields in Kenya.

Lack of temporal association

Stem borer eggs and small larvae are common in the first few weeks after plant emergence (Chapter 5), a time that the maize is also at the stage most vulnerable to stem borer attack. During that period, ants, spiders, earwigs and other predators of eggs and small larvae are not abundant. Predators often only become numerous later in the season, and they may have an impact on the second and third generation of stem borers. However, stem borer attack is not as destructive on plants in the generative or mature plant stage as it is on young plants.

Low searching activity of predators

Predators were seldom searching the maize plants for prey in our laboratory experiments and during the field observations (Chapter 6). Earwigs and cockroaches were voracious predators of *C. partellus* eggs and small larvae in Petri dishes (Chapter 6). Together with ants and spiders, they were also the most abundant potential predator groups in maize fields along the Kenyan coast (Chapter 5) and they were therefore considered to be promising predators. When prey was offered to earwigs and cockroaches on plants in the laboratory, earwigs consumed some egg batches and small larvae, but cockroaches did not. Cockroaches are omnivorous and generally not known to be predators, so their consumption of stem borers in Petri dishes was probably influenced by the experimental setup. During spot-checks carried out at daytime and at night, earwigs and cockroaches were never seen searching the plants for prey. Most of the time, the predators were found immobile in the leaf whorl or in a leaf sheath. In field observations (Chapter 6), cockroaches sometimes landed on experimental maize plants but they nearly always left

immediately. Earwigs were not found during the field observations. Spiders could stay on plants for several hours, but most of the time they remained motionless and did not search for prey. Ants (mainly *Lepisiota* sp.) were the only predators actively searching the plants. They seemed, however, to have difficulty climbing the maize stem and fell off frequently. As a result, ants nearly always stayed close to the ground and egg batches that were located higher up the plant were not encountered.

Preference for other prey

The impact of the predators on stem borers may be reduced by the presence of alternative prey such as aphids (*Rhopalosiphum maydis*). In our studies, earwigs, cockroaches and coccinellids preyed on aphids (Chapter 6). From literature, spiders (e.g. Provencher and Coderre, 1987; Kabissa *et al.*, 1996), carabids (Edwards *et al.*, 1979), lacewings (e.g. van den Berg, 1993; Kabissa *et al.*, 1996) and staphylinids (Edwards *et al.*, 1979) are also identified as predators of aphids in different crops. In maize fields at the southern Kenyan coast, aphids are present at the same time as eggs and small larvae of *Chilo* spp. (Chapter 5). The aphids are generally more numerous and more accessible than the stem borer eggs and larvae. Although no clear preference for aphids over larvae was detected for earwigs and cockroaches (Chapter 6), the presence of aphids is likely to influence predation on stem borer negatively.

CAN THE FINDINGS ON LOW PREDATION BE GENERALISED FOR OTHER AREAS IN KENYA?

Predator populations were highly variable between sites, even if these sites were situated a few kilometres apart. Populations also fluctuated widely between seasons at the same site. Therefore, extensive studies covering several sites and seasons are necessary before results can be generalised. The studies on the abundance of

predators (Chapter 5) covered two seasons for each of the five sites. Only some results, such as the low abundance of nearly all predator groups, were consistent over sites and seasons. Since predator populations already vary between sites, they are also likely to vary between larger geographical areas. Van den Berg (1993) showed that predator populations were considerably higher in West Kenya and in the Central Province than at the coast. Disappearance of eggs, larvae and pupae is much higher in West Kenya (Oloo, 1989) than at the coast (Chapters 4 and 7). Although no strong relation between predators and disappearance could be established in the coastal area, it is possible that the higher number of predators in western Kenya caused more disappearance.

RELATIVE IMPORTANCE OF MORTALITY

Several studies have shown that mortality may be high in all life stages of the stem borer (e.g. Mathez, 1972; Oloo, 1989; Skovgård and Päts, 1996; Ogol *et al.*, 1998, Chapters 4 and 7). The influence of this mortality on stem borer populations depends, among others, on whether density dependent mortality occurs and, if so, on the strength of this density dependent mortality. There is very limited strong evidence for the existence of density dependence acting on the early larval stages of stem borer populations (van Hamburg and Hassell, 1984). Van Hamburg (1980) suggested that mortality of early instar *C. partellus* larvae on sorghum increased, primarily due to dispersal, with increasing levels of infestation in glasshouse experiments. Berger (1992) also found more dispersal at higher infestation densities in very young (one day old) and in late instar larvae (third to fifth instar) *C. partellus* larvae in laboratory experiments. However, this density dependent response did not occur at intermediary life stages (i.e. first and second instar larvae). A density dependent response is likely to benefit the survival of *C. partellus* since usually far more eggs are oviposited than the maize plant can sustain (Berger, 1992). If

mortality of early instar larvae is indeed density dependent, then the impact of egg mortality on stem borer populations will be low unless egg mortality can reduce the larval populations below a treshold density where the density dependent mortality will no longer occur. To date, information on density dependent mortality of stem borer larvae is not sufficient to draw conclusions on the influence of mortality of especially eggs and small larvae on adult stem borer populations. Additional studies focussing on density dependent mortality under field conditions and on the strength of the density dependent mortality are needed.

CONCLUSION

The above shows that some effective, low input and acceptable control methods are available to small-scale farmers. In this thesis, it was shown that the majority of farmers were not aware of these control methods, and that the only method widely known was chemical control (Chapter 2). The farmers' awareness regarding stem borers and their control could be improved by for example the Farmer Field School (FFS)-approach. In this approach, farmers 'analyse' biology and agro-ecology of pests in group sessions held weekly during the growing season, learn and improve pest management by discussing and experimenting (van Huis and Meerman, 1997). By letting the farmers learn, experiment and generate their own technology, new IPM options that are acceptable to farmers in the target area will be developed. In Kenya, the FFS-approach was successful in high-value crops such as vegetables and coffee, but it is not clear whether the same results would be obtained with a subsistence crop such as maize. A prerequisite for the long-term success of the FFS is that the approach should be supported by the whole agricultural system: farmers, local research stations, extension services, the Ministry of Agriculture and the Government. At present, the national extension service is weak due to lack of means. It may take a long time before the extension service will reach its full potential and

the FFS approach can be successfully implemented at a large scale. Until then, classical biological control seems to be the most effective and feasible way to manage maize stem borers in Kenya.

SUMMARY

Damage caused by Lepidopteran stem borers is one of the most important constraints to maize production in East and Southern Africa. Of the stem borer complex, *Chilo partellus* Swinhoe is the most abundant species in lowland areas. Although control strategies exist, many are not effective or feasible for small-scale subsistence farmers to practice. Consequently, stem borers are rarely actively controlled. Although natural mortality of stem borers may be high, this not sufficient to keep densities at low levels. Disappearance is the major mortality factor in all life stages, often being as high as 80 to 90%. Disappearance is generally attributed to predation, although little quantitative information is available to support this assumption. In this thesis, the impact of predators on stem borer populations and their role in the disappearance of eggs, larvae and pupae was examined in the southern coastal area of Kenya.

In the first chapter, background information on maize cultivation and constraints to maize production in the coastal area of Kenya is presented. The biology and pest status of stem borers, as well as methods to control them, are also discussed.

Interviews held with small-scale farmers indicated that stem borers were considered a major constraint for maize production in the study area (Chapter 2). Despite this, farmers had limited knowledge of the life cycle of stem borers, on possible sources of infestation and on stem borer control practices. Chemical application was the only well-known control method and was regularly used by 30% of the respondents. Most farmers were not aware of the beneficial activity of predatory arthropods, although ants, spiders, praying mantids and 'crickets' were sometimes mentioned as predators of stem borers. There is a need to create awareness among farmers of the biology and ecology of pests and the role of beneficial insects in cultivation. Effective control methods should be developed

locally by farmers and researchers together, for example by using the 'Farmer Field School'-approach.

Information on the natural enemies of stem borers in East Africa is reviewed in Chapter 3. A large variety of natural enemies was identified with fifty-seven parasitoids, fifteen predators and fifteen pathogens being recorded. The review discovered that most emphasis was placed on the parasitoids of stem borers. Conversely, information on predators and pathogens is scarce.

Stem borer infestation starts at an early crop stage (Chapter 4). Infestation levels in our trials varied between 0 and 10%, with occasional peaks of up to 28%. Most plants carried only one egg batch with an average of 20 eggs. Egg mortality was highly variable between sites and seasons, and ranged from 18 to 78%. Parasitism was the most important mortality factor by far, accounting for 6 to 59% of the total mortality. Between 5 and 10% of eggs disappeared and 2 and 8% was visibly preyed upon. Between 2 and 7% of eggs failed to hatch.

Studies on the incidence of predator and stem borer populations at the Kenyan coast are described in Chapter 5. These indicated that *Chilo partellus* and *C. orichalcociliellus* were the predominant stem borer species although *Sesamia calamistis* was occasionally found. Thirteen parasitoid species were collected: two from eggs, nine from larvae and two from pupae. Egg parasitism was fairly high (38 to 75%) but parasitism of larvae and pupae was less than 5%. Ants, spiders and earwigs were the most common potential predators. Rarely encountered predators included coccinellids, lacewings, bush-crickets and rove beetles. Ants were the most abundant and widespread predators by far and were represented by a rich variety of species. Spiders were found at all sites and occurred throughout the growing season, but numbers were relatively low. Earwigs were fairly common at two sites but virtually absent at the other sites. Predator numbers were low in the beginning of the growing season, when maize is most vulnerable to stem borer attack. Their numbers

were generally not found to be related to the highly variable numbers of stem borer eggs and small larvae.

The important predators of stem borer eggs, larvae and pupae were identified through laboratory and field studies (Chapter 6). When prey was offered in Petri dishes, eighteen predator species consumed eggs and fifteen consumed small larvae. Late instar larvae and pupae were only taken by gryllids. Of the potential predators tested, earwigs and cockroaches had a high acceptance and consumption rate of both eggs and small larvae. The activity of cockroaches was unexpected, since they are normally not seen as predators of insects. When eggs and small larvae were offered on plants, earwigs consumed (a few) egg batches and small larvae, but cockroaches did not. An observation study showed that egg predation was low: only 3% of egg batches were attacked. Ants (three species) and adult flies of the family Chloropidae were seen to prey on eggs.

To evaluate the impact of predator populations on each stem borer life stage, a series of predator exclusion experiments were conducted (Chapter 7). Disappearance of eggs was 23 to 29% from plants accessible to predators (control plants) and zero to 0.2% from exclusion plants, thus showing that predators play an important role in egg disappearance. Few visibly preyed-upon or sucked eggs were encountered. Disappearance of small larvae was high but could not be attributed to predators. The impact of predators on disappearance of large larvae was small. In some trials, significantly more pupae were recovered from predator exclusion than from control plants. Thus, predators have an impact on the disappearance of eggs and, in some cases, of pupae, but have hardly any effect on larvae at the coast.

During field observations, egg batches were seen to disappear by curling away from the leaf and being blown off. To evaluate whether solar radiation played a role in this, disappearance of egg batches was compared between solar-exposed and shaded plants (Chapter 8). Disappearance was found to be four times higher on the

exposed plants than on the shaded plants after four days. Non-viability of eggs was also significantly higher on the exposed plants.

Predators did not influence the disappearance of small larvae and therefore other factors must have played a role. Rainfall can lead to high mortality of small larvae feeding in the leaf whorl, with 50% (first trial) and 65% (second trial) of larvae disappeared from plants exposed to rainfall (Chapter 8). From the shielded plants, 32 and 25% of larvae disappeared, respectively. Cannibalism also caused some disappearance among small and larger larvae, but this is not expected to be an important mortality factor under natural conditions. Most of the larval disappearance is thought to be caused by dispersal, and subsequent desiccation and predation.

The research described in this thesis leads to the conclusions that:
1. Predation plays a small role in the mortality of stem borers in plants, but may cause high losses among dispersing larvae;
2. Predator attack only partially explains the disappearance of stem borers;
3. Parasitoids cause high mortality in the egg stage but not in other life stages of stem borers;
4. Solar radiation and rainfall may cause considerable mortality of stem borer eggs and larvae.

SAMENVATTING

Stengelboorders (Lepidoptera) behoren tot de belangrijkste plaaginsecten in de maïsteelt in Oost- en zuidelijk Afrika. De meest voorkomende stengelboordersoort in het gebied, met name in lager gelegen delen, is *Chilo partellus* Swinhoe. In de loop der jaren zijn talloze methoden ter bestrijding van stengelboorders onderzocht, maar boeren maken slechts weinig gebruik van deze maatregelen. Niet alleen is de effectiviteit van de methoden vaak twijfelachtig, ook zijn veel benaderingen vaak niet haalbaar voor de kleinschalige boeren.

Stengelboorders worden in grote aantallen aangetroffen in maïsvelden, ondanks dat de natuurlijke mortaliteit vaak hoog is. Studies hebben aangetoond dat de grootste mortaliteit veroorzaakt wordt door verdwijning. In het westen van Kenia en in Oeganda verdween ongeveer 80 tot 90% van alle eieren, larven en poppen in het veld. Verdwijning wordt meestal toegeschreven aan predatie, maar deze aanname is slechts gebaseerd op toevallige waarnemingen en kleine experimenten. In dit proefschrift is de invloed van predatoren op de mortaliteit en verdwijning van stengelboorders onderzocht aan het zuidelijke deel van de Keniase kust.

In het eerste hoofdstuk wordt achtergrondinformatie bij het onderzoek in dit proefschrift gegeven. Naast een overzicht van de teeltmaatregelen en de grootste problemen in de maïsteelt in het studiegebied worden enige aspecten van stengelboorders (distributie, levenscyclus, bestrijdingsmethoden) besproken. Het hoofdstuk eindigt met een kort overzicht van het onderzoek dat in het proefschrift beschreven zal worden.

Boeren aan de Keniase kust beschouwden stengelboorders als het belangrijkste probleem in de maïsteelt (hoofdstuk 2). Desalniettemin was de kennis van stengelboorders gering. Vrijwel geen van de boeren was op de hoogte van de levenscyclus van de insecten, hun manier van overleven en van andere

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bestrijdingsmaatregelen dan chemische bestrijding. Chemische bestrijding werd regelmatig gebruikt door 30% van de ondervraagden. Andere methoden werden zelden toegepast. De meeste boeren waren zich niet bewust van de gunstige invloed van predatoren, hoewel mieren, spinnen, bidsprinkhanen en krekels soms genoemd werden als predatoren van stengelboorders. Boeren zouden meer inzicht moeten krijgen in de biologie en ecologie van plaaginsecten en hun natuurlijke vijanden, waardoor ze beter beslissingen kunnen nemen omtrent de bestrijding van plagen in hun velden. Effectieve bestrijdingsmethoden zouden door boeren en onderzoekers tezamen ontwikkeld moeten worden. Dit zou bijvoorbeeld gerealiseerd kunnen worden in 'Farmer Field Schools'.

Een overzicht van de natuurlijke vijanden van stengelboorders die gevonden zijn in Oost-Afrika is gegeven in hoofdstuk 3. Tot 1997 waren er 57 soorten parasitoïden, 15 soorten predatoren en 15 soorten pathogenen beschreven. De meeste informatie is te vinden over parasitoïden, over predatoren en pathogenen is relatief weinig bekend.

Veldexperimenten toonden aan dat stengelboorders reeds in een vroeg stadium in het gewas komen (hoofdstuk 4). Tijdens het groeiseizoen bevond zich op gemiddeld 0 tot 10% van de planten een eimassa, maar dit percentage kon stijgen naar 28%. Op de meeste planten werd slechts één eimassa gevonden die uit gemiddeld 20 eieren bestond. De eimortaliteit varieerde aanzienlijk tussen velden en seizoenen en lag tussen de 18 en 78%. Parasitisme was met 6 tot 59% veruit de belangrijkste mortaliteitsfactor. Vijf tot 10% van de eieren verdween en predatie lag tussen de 2 en 8%. Twee tot 7% van de eieren kwam niet uit door factoren anders dan parasitisme of predatie.

Studies naar de aanwezigheid van predatoren en stengelboorders gaven aan dat *Chilo partellus* en *Chilo orichalcociliellus* de meest voorkomende stengelboordersoorten waren (hoofdstuk 5). *Sesamia calamistis* werd slechts sporadisch gevonden in het studiegebied. Dertien soorten parasitoïden werden aangetroffen in de in het veld verzamelde stengelboorders: twee uit eieren, negen uit

larven en twee uit poppen. Eiparasitisme was redelijk hoog (38 tot 75%), maar parasitisme van larven en poppen was minder dan 5%. Mieren, spinnen en oorwormen waren de meest voorkomende potentiële predatoren. Lieveheersbeestjes, gaasvliegen, krekels en kortschildkevers werden af en toe aangetroffen. Mieren waren in grote aantallen aanwezig in elk maïsveld en werden gedurende het hele groeiseizoen gevonden. Hun aantallen waren echter laag aan het begin van het groeiseizoen, wanneer de maïsplanten het meest gevoelig zijn voor aantasting door stengelboorders. Hetzelfde gold voor spinnen, maar zij waren veel minder talrijk dan mieren. Oorwormen werden redelijk vaak aangetroffen in twee velden maar kwamen zelden voor in de andere velden. Predatoraantallen waren in het algemeen niet gerelateerd aan de aantallen eieren en kleine larven van stengelboorders.

De belangrijkste predatoren van eieren, larven en poppen van *C. partellus* werden geïdentificeerd met behulp van laboratorium- en veldproeven (hoofdstuk 6). Wanneer prooien werden aangeboden in petrischalen aten achttien predatorsoorten eieren en 15 aten kleine larven. De grootste aantallen werden gegeten door oorwormen en kakkerlakken. Grotere stengelboorderlarven en -poppen werden alleen door krekels gegeten. Oorwormen aten eimassa's en kleine larven wanneer deze aangeboden werden op planten, maar kakkerlakken deden dit niet en deze laatste groep heeft dan waarschijnlijk ook weinig invloed op predatie onder natuurlijke omstandigheden. Veldobservaties toonden aan dat slechts 3% van de eimassa's opgegeten werd. De predatoren waren mieren (3 soorten) en vliegen behorende tot de familie Chloropidae.

Een serie experimenten waarbij predatoren werden uitgesloten door middel van kooien of lijm werd uitgevoerd om de rol van predatorpopulaties op stengelboordereieren, -larven en -poppen te evalueren (hoofdstuk 7). Gemiddeld 23% (proef 1) en 29% (proef 2) van de eimassa's verdween van planten waar predatoren toegang tot hadden. Van planten waar predatoren niet bij konden verdwenen geen eieren. Zichtbaar aangevreten of leeggezogen eieren werden maar zelden

aangetroffen. Verdwijning van kleine larven was hoog, maar predatoren speelden hierin geen rol. De invloed van predatoren op verdwijning van oudere larven was klein en niet eenduidig, aangezien in twee proeven meer larven uit toegankelijke planten verdwenen en in één proef meer larven uit de controleplanten verdwenen. In een aantal proeven werden significant meer poppen aangetroffen in planten waar predatoren geen toegang toe hadden dan in controleplanten. De resultaten tonen aan dat predatoren een rol spelen in de verdwijning van eieren en, in sommige gevallen, van poppen, maar dat ze nauwelijks een effect hebben op larven.

In veldobservaties werd opgemerkt dat eimassa's opkrulden van het blad en weggeblazen werden. Om te evalueren of zonneschijn hierin een rol speelde werd verdwijning van eimassa's vergeleken op planten die in de zon stonden en die in de schaduw stonden (hoofdstuk 8). In de vier dagen dat de planten in het veld stonden verdwenen vier keer zoveel eimassa's van planten in de zon dan van planten in de schaduw. Op de planten in de zon kwamen ook significant minder eieren uit dan op planten in de schaduw.

Predatoren hadden geen invloed op de verdwijning van kleine larven en daarom moeten andere factoren een rol gespeeld hebben. Proeven toonden aan dat regen kan leiden tot grote mortaliteit van larven die in de bladschede zitten. In twee experimenten verdween 50 en 65% van de larven van planten die blootgesteld waren aan regenval (hoofdstuk 8). Van de overkapte planten verdween 32 en 25%. Kannibalisme was verantwoordelijk voor enige mate van verdwijning van kleine en grotere larven maar het is vermoedelijk geen belangrijke mortaliteitsfactor onder natuurlijke omstandigheden. Uit bovenstaande proeven kan afgeleid worden dat, in veel gevallen, verspreiding de belangrijkste oorzaak zal zijn van verdwijning van larven. Larven die zich verspreiden op zoek naar nieuw voedselplanten zijn bijzonder kwetsbaar en lopen een hoog risico om uit te drogen en om opgegeten te worden.

Het onderzoek dat in dit proefschrift beschreven is leidt tot de conclusies dat:

1. Predatoren weinig invloed hebben op de mortaliteit van stengelboorders op de plant, maar een hoge mortaliteit kunnen veroorzaken onder larven die zich verspreiden;

2. Predatie slechts een gedeelte van de verdwijning van stengelboorders verklaart;

3. Parasitisme hoog is in het eistadium maar niet in de andere levensstadia;

4. Abiotische factoren aanzienlijke mortaliteit van stengelboordereieren en larven kunnen veroorzaken.

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CURRICULUM VITAE

Maria Janetta (Marieke) Bonhof was born on 15 April 1969 in Oene (near Epe), the Netherlands. After concluding her secondary education at the Rijks Scholen Gemeenschap Epe in 1987, she started her studies at the National Horticultural College in Utrecht. During this 4-year education, she spent practical periods at Koppert Biological Systems and the Department of Phytopathology of Wageningen University. After graduating in 1991, she continued her education at Wageningen University. Here, she studied Crop Protection and specialised in Entomology. One of her research subjects included a 6-month research in Niger (West Africa) at the Département de Formation en Protection des Végétaux (DFPV), where the impact of predators on bruchid beetles in cowpea were investigated. She obtained her 'Ir' degree, equivalent to MSc, in 1994. After graduation, she was employed by the Directorate General for International Co-operation (DGIS) of the Dutch Ministry of Foreign Affairs. She was posted at the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya, where she worked at a small field station in the coastal area of Kenya. Her responsibilities included conducting research on biological control of the maize stem borer and the management and supervision of activities at the Field Station. Late 1999, she returned to the Netherlands to complete her Ph.D.-thesis. She is currently working as an entomologist at the 'Praktijkonderzoek voor Akkerbouw en Vollegrondsgroenteteelt' (Applied Research for Arable Farming and Field Production of Vegetables) in Lelystad, The Netherlands.