

**Towards an integrated crop management strategy  
for the African stalk borer, *Busseola fusca* (Fuller)  
(Lepidoptera: Noctuidae) in maize systems in  
Cameroon**

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## Abstract

This study attempts to produce baseline data on importance and geographic distribution of stem borers and identify key interactions among and between abiotic (soil nutrients) and biotic (different life stages of pests, beneficials, host plants, vegetation indices, intercrops) factors in the stemborer ecosystem in Cameroon, which is a prerequisite for the development of environmentally sound IPM-technologies. From 1993 to 1997, 297 farmers' maize fields in six benchmarks in the forest zone and three benchmarks in the mid-altitude were visited periodically. In the forest zone only, the benchmarks were grouped into three blocks representing gradients in human population density and, thus, in length of fallow period.

Five borer species were found on maize (*Busseola fusca*, *Eldana saccharina*, *Sesamia calamistis*, *Mussidia nigrivenella* and *Cryptophlebia leucotreta*) and four (*B. fusca*, *E. saccharina*, *S. calamistis*, *Poeonoma serrata*) on elephant grass, the most common wild host. Larvae and pupae per m<sup>2</sup> of *B. fusca* were three to nine times higher on *P. purpureum* than on maize, whereas for *E. saccharina* the situation was the reverse. It was concluded that *P. purpureum* is not a good trap plant because larval mortalities were too low.

Enumerative sampling procedures, based on Taylor's power law, were developed for the most common pest species in order to make estimation of pest densities as cost-efficient as possible without losing accuracy.

For any of the variables measured, there were no significant block effects in the forest zone; within field variability was highest and between field variation contributed more to total variability than location, emphasizing the insular character of forest fields. In the forest zone, *B. fusca* was the predominant species during the first and *E. saccharina* during the second season. In the mid-altitude, *B. fusca* was predominant during both seasons whereas *E. saccharina* was not found in any of the fields. In both zones, negative relations could be found between cob weight and stem or ear damage, with *B. fusca* the most damaging species. *B. fusca* numbers at harvest increased with egg infestation but was negatively related to egg parasitism or parasitoid sex ratio earlier in the season. Soil Mg had a negative effect on yield by increasing *B. fusca* densities whereas egg parasitism had a significant positive effect. Increasing density of cassava in the system had a negative effect on *B. fusca* densities, probably because of increased mortality of migrating first instar larvae.

Fifteen hymenopterous, two dipterous parasitoids and one fungal species were found. The scelionid egg parasitoids *Telenomus busseolae* and *T. isis* were the most common parasitoids and found in all locations in the forest zone. Most larval and pupal parasitoids belonged to the ingress-and-sting or planidial ingress guild. *Cotesia sesamiae*, the most common larval parasitoid of noctuid stem borers in eastern Africa was very scarce.

Recommendations are given for further research into habitat management (management of soil nutrients, trap plants and intercropping with non-hosts), biological control options ('redistribution' approach, microbial control using viruses) and on how to increase uniformity of field infestations for host plant resistance screening.

Keywords: Stemborers, Interactions, Maize

## Zusammenfassung

Die vorliegende Studie ist eine Aufnahme von Basisdaten ueber die Wichtigkeit und geographische Verteilung von Maiszuenslern und eine Erarbeitung von Schluesselinteraktionen innerhalb und zwischen abiotischen (Bodenaehrstoffe) und biotischen (Lebensstadien von Schaedlingen, natuerliche Feinde, Pflanzenwirte, Vegetationsbonitierungen und Mischkulturen) Faktoren in Maissystemen in Cameroon- die Basis fuer die Entwicklung von umweltfreundlichen integrierten Pflanzenschutztechnologien. Von 1993 bis 1997 wurden in 297 Maisfelder in sechs Doerfern (Benchmarks) im Regenwald und drei Doerfern in den Hoehenlagen periodisch Erhebungen gemacht; die Doerfer im Regenwald waren, entsprechend einem Populationsdichtegradienten oder Laenge der Brachenperiode, in drei Bloecken gruppiert,

Fuenf Maiszuenslerspezies wurden auf Mais (*Busseola fusca*, *Eldana saccharina*, *Sesamia calamistis*, *Mussidia nigrivenella* and *Cryptophlebia leucotreta*) und vier auf *Pennisetum purpureum* (*B. fusca*, *E. saccharina*, *S. calamistis*, *Poeonoma serrata*), dem wichtigsten wilden Wirt gefunden. Die Larven- und Pupendichten von *B. fusca* waren drei bis neun mal hoeher auf *P. pennisetum* als auf Mais; fuer *E. saccharina* war die Situation umgekehrt.

Fuer die wichtigsten Spezies wurden, basierend auf ‘Taylor’s Power Law’, enumerative Stichprobenplaene fuer eine moeglichts kosteneffiziente und akurate Schatzung von Schaedlingsdichten entwickelt.

Im Regenwald waren die Blockunterschiede fuer keine der erhobenen Variablen signifikant; der groesste Anteil an der Varianz machte die In-Feld Variabilitaet gefolgt von Zwischen-Feldvariabilitaet aus, was auf einen stark insularen Charakter der Felder im Regenwald hindeutet.

Im Regenwald war der wichtigste Schaedling waehrend der ersten Saison *B. fusca* und in der zweiten *E. saccharina*. In den Hoehenlagen war *B. fusca* immer die wichtigste Spezies, und *E. saccharina* wurden in keinen der Feldern gefunden. Kolbengewicht war in beiden Oekozonen negative mit sowohl Stengel- also auch Koernerschaden korreliert, mit *B. fusca* als den wichtigsten Schaedling. Dichten von *B. fusca* bei der Ernte waren negative korreliert mit Eiparasitismus oder ‘Sex ratio’ von Eiparasiten zu Beginn der Saison. Bodenmagnesium hatte eine positive Beziehung mit Schadelingsdichten und deshalb negativ mit Ertrag, waehrend - Eiparasitismus positive den Ertrag beeinflusste. *B. fusca*-Dichten nahmen mit zunehmender Bestandesdichte von Kassave im System ab, was auf eine erhoehte Mortalitaet von migrierenden jungen Larvenstadien auf diesem Nichtwirt hindeutet. Im Ganzen wurden fuenfzehn Schlupfwespen, zwei Tachinide und ein parasitischer Pilz gefunden. Die zwie Scelioniden Eiparasiten *Telenomus busseolae* und *T. isis* wurden waren die haeufigsten Spezies in allen Doerfern. Die meisten Parasiten gehoerten den ‘Ingress-and-Sting’ und ‘Planidial Ingress’ Gilden an. *Cotesia sesamiae*, der wichtigste Larvenparasit von Noctuiden Maiszuenslern im oestlichen Afrika war sehr selten.

Empfehlungen fuer ‘Habitat Management’ (Management von Bodennaehrstoffen, Fallenpflanzen und Mischkultur mit Nichtwirten) und Biologische Schaedlingsbekaempfungstechnologien (‘Redistribution’, BC mit Viren) und Methoden zur Erreichung von gleichmaessigen Feldinfestationen fuer das Bonitieren von resistentem Marerial wurden gegeben.

Schlagwörter: Stengelbohrer, Interaktionen, Mais

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**List of Abbreviations:**

TLU	Testing and Liaison Unit
CDC	Cameroon Development Corporation
NCRE	National Cereals Research and Extension project
CFA	Communauté Française d'Afrique
MAISCAM	Maïseries du Cameroun
SPC	Société de Provenderies du Cameroun
IRAD	Institut de la Recherche Agronomique pour le Developpment
MSV	Maize streak virus
IRAT	Institut de Recherches Agronomiques Tropical et des culture vivrières
USAID	United States Agency for International Development
IITA	International Institute of Tropical Agriculture
PHMD	Plant Health Management Division
RRPMC	Regional Research Project on Maize and Cassava
IFAD	International Fund for Agricultural Development
ICIPE	International Center of Insect Physiology and Ecology
IPM	Integrated Pest Management
CMS	Cameroon Maize Series
ANOVA	Analysis of Variance
SAS	Statistical Analysis System
GLM	General Linear Model
GLIM	Generalized Linear Model
PCA	Principal Component Analysis
CCA	Canonical Correlation Analysis
NARO	National Agricultural Research Organisation
SASEX	South African Sugar Experiment station
IRD	Institut de Recherche pour le Developpement
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo
NARES	National Agricultural Research Systems
HPR	Host plant resistance
CPV	Cytoplasmic polyhedrosis virus

## CHAPTER 1

### General introduction

#### **Origin, classification and ecology of *Z. mays***

The center of origin of maize is Mexico or Central America, with a possible secondary origin in South America (Martin et al., 1967; Wilkes, 1979; Pursglove, 1983).

*Z. mays* belongs to the botanical family of Poaceae (Gramineae) which is divided into the two sub-families, the Panicoideae and the Poideae. The sub-family Panicoideae has three tribes including Maydeae which contains maize (Pursglove, 1983).

Martin et al. (1967) and Pursglove (1983) describe the ecology of maize. The crop is grown from latitudes 50°N to 40°S and from sea level to 3300m. It is grown in regions with isotherms at tasseling of 21 - 30°C. Rainfall during the growing period should not fall below 200 mm and 450 - 600 mm are preferred, with periods of clear warm weather between the rain storms. Maize can be grown on a wide variety of soils, but performs best on well-drained well-aerated deep, warm loams and silt loams containing adequate organic matter and well supplied with available nutrients. The plant produces a large amount of biomass over a relatively short period; consequently it needs abundant supply of nitrogen. The plant is perhaps the most completely domesticated of all field crops. Its perpetuation for centuries has depended wholly upon the care of man (Martin et al., 1967).

### **The Geography of Cameroon**

#### *Location*

Cameroon is a large and ecologically diverse country located in the south of western/central Africa. Congo, Gabon and Equatorial Guinea border it to the south and Chad, the Republic of Central Africa to the northeast, Lake Chad to the north and Nigeria and the Atlantic ocean to the west. The country extends for 800 km between longitudes 9 and 16 degrees east and 1,300 km between latitudes 2 and 13 degrees north. The southern part of the country, which includes the South

(headquarters, Ebolowa), Centre (Yaoundé), East (Bertoua), Southwest (Buea) and Littoral (Douala) provinces is lowland humid forest (below 800 m above sea level except Mount Cameroon, which is 4100 m). The north western and central parts, the West (Bafoussam), Northwest (Bamenda) and Adamawa (Ngaoundéré) provinces are mid-altitude (800-1200 m) to highlands (above 1200 - over 3000 m). The northern part of the country, North (Garoua) and Far North (Maroua) provinces is lowland Sudano-sahelian savannah (below 600 m above sea level) (Figs. 1 and 4).

### *Climate*

#### *Temperatures*

Cameroon offers an almost complete range of inter-tropical climates. The varied relief and the proximity of the ocean also introduce gradations due to the effects of the mountains and the sea. The mean temperatures are high and vary little during the course of the year. They increase from south to north, decrease with altitude and vary between 20°C at Dschang at 1,400 meters above sea level and 28°C at Garoua in the north. There is little variation between day and night temperatures except in the north. The amount of sunshine varies in the same way. In the equatorial zone, it is lowered by the amount of rainfall, the relative humidity and cloud cover (Etia, 1973) (fig. 2).

#### *Rainfall*

Rainfall in the forest zone is between 3,000 to 4,500 mm per year. At the foot of Mount Cameroon and along the coast the rains are heaviest. There is precipitation almost throughout the year. The rest of the forest zone has two rainy and two dry seasons per year. The first rainy season is from March to mid-July and the second from mid-August to November, while the unreliable August break is from mid-July to mid-August. The second dry season is from mid-November to end of February. The forest zone is further divided into the humid and semi-humid forests. Two maize crops per year are planted during the rainy seasons. However, very often farmers around the big urban centres (Yaoundé and Douala) start planting when sporadic rains begin in January/February and continue till end of September, or plant in swampy lands during the dry season. These inland valleys

## Vegetation

### A) CONGO-GUINEAN REGION

#### 1. Nigero-Cameroon-Gabonian domain

- Mangroves
- Forest on littoral barriers
- Littoral forest
  - same, degraded
  - same, degraded by industrial crops
- Atlantic evergreen forest with *Caesalpiniaceae*
  - same, degraded
  - same, degraded by industrial crops
  - same, colonizing
- Seasonally flooded swampy forest
- Seasonally flooded marshy grassland
- Mount Cameroon elephant bush
- Raphia swamp

#### 2. Cameroono-Congolian domain

- Dja evergreen Cameroono-Congolian forest
  - same, degraded
- Upper Nyong swampy forest with *Sterculia*
- Raphia and Swampy forest
- Flooded forest with *Guibourtia*
- Aquatic prairie with *Echinochloa* and upper Nyong flooded prairie
- Seasonally flooded marshy grassland

### 3. Congo-Guinean domain of the semi-deciduous forest

- Semi-deciduous forest with *Sterculiaceae* and *Ulmaceae*
  - same, degraded
  - same, degraded by industrial crops
  - same, colonizing
- Grass-savanna with *Pennisetum* and *Imperata*
- Shrub-savanna with *Annona* and *Bridelia*
- Shrub-savanna with *Terminalia glaucescens*
- Zone of the Congo-Guinean seasonally flooded prairies

### 4. Afro-montane domain of the altitude evergreen forest

- Submontane forest
  - same, degraded
- Domesticated submontane landscape
- Montane forest
  - same, degraded
- (Subalpine prairie)

### B. SUDANO-ZAMBEZIAN REGION

#### 1. Sudanian domain

- Sudano-Guinean savanna with *Danielia* and *Lopha*
  - same, degraded
- Sudano-Guinean seasonally flooded prairie
- Ironstone outcrops zone
- Wood-savanna and medio-Sudanian open dry forest
- Sudano-Sahelian wood-savanna

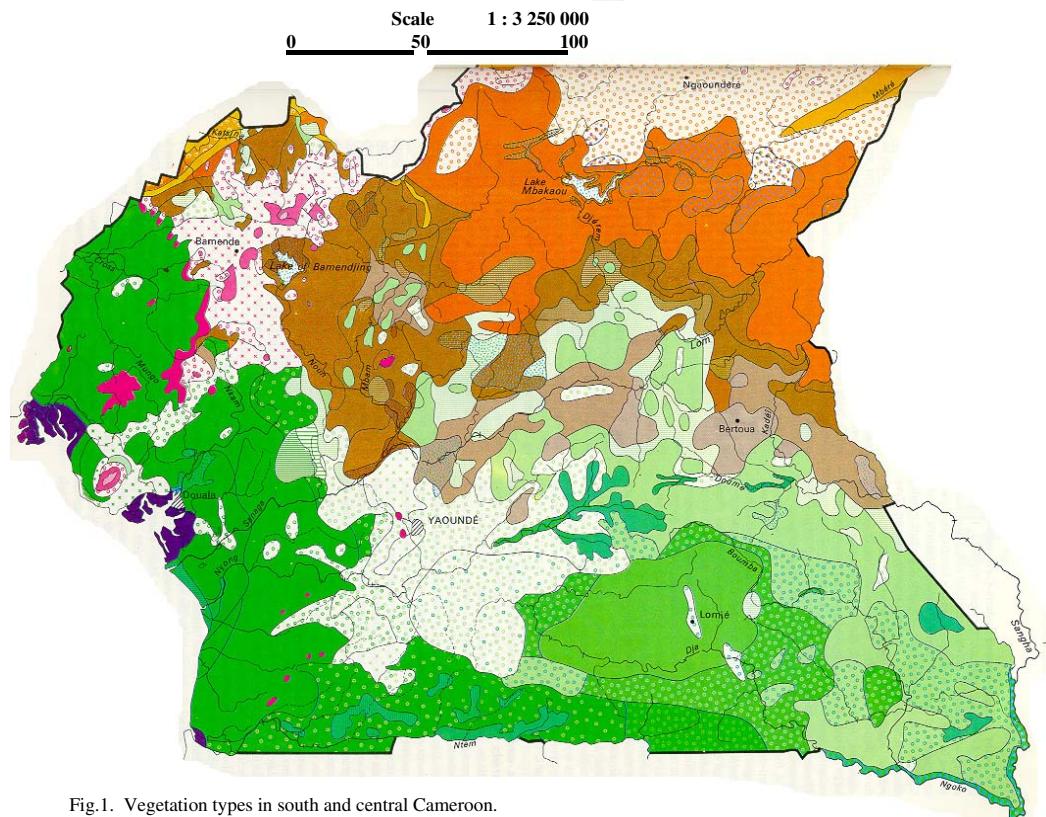


Fig.1. Vegetation types in south and central Cameroon.

Source: Laclavère and Loung (1973).

in the south of the country are becoming increasingly important for growing maize and other vegetables for fresh consumption during the dry season.

The mid-altitude and highlands have two seasons, a rainy season from mid-March to late October and a dry season from November to mid-March. Average annual rainfall range from 1,300 to 4,000 mm. Although two maize crops could be grown in a year, this is done only in a few mid-altitude locations. Usually in August before the crop planted in March/April is ready for dry harvest, the second crop is planted.

The Sudano-sahelian zone is divided into two rainfall belts: the Garoua - Maroua belt with 400 - 800 mm per year, and the Garoua - southeast Bone with 800 – 1,200 mm per year. There are two seasons in a year and the rainy season begins in May/June up till October (fig. 2).

### *Soils*

The soils of Cameroon are varied and this is linked to the parent rocks, topographical factors, their age and the bioclimatic environment in which they are formed. According to Gavaud and Muller (1973) eight main categories of soils are represented, with varying suitability for maize cultivation (fig. 3). The northern part of the country is not shown in the map because this work was carried out in the south only.

- Raw mineral soils containing traces of organic matter and a few centimeters of fragments of weathered rocks. They are found in the mountains of the Northwest and Mandara in the Far North provinces. Their limitation is due to the fact that they are very shallow and this is a physical constraint to maize cultivation because the maize plant has deep roots. However, if ridges are made there will be better rooting and more nutrients available.

- Lightly evolved soils developed on recent deposits. They may be hydromorphic on recent alluvial deposits, carbonated on older alluvial deposits, planosolic or halomorphic. Hydromorphic soils have an aeration problem because they are saturated with water and hence not suitable for maize cultivation during the rainy season. They are found along the coast and inland rivers.

- Vertisols. These are clayey, dark and affected by seasonal shrinking and swelling. Vertisols have poor physical properties but good chemical qualities and

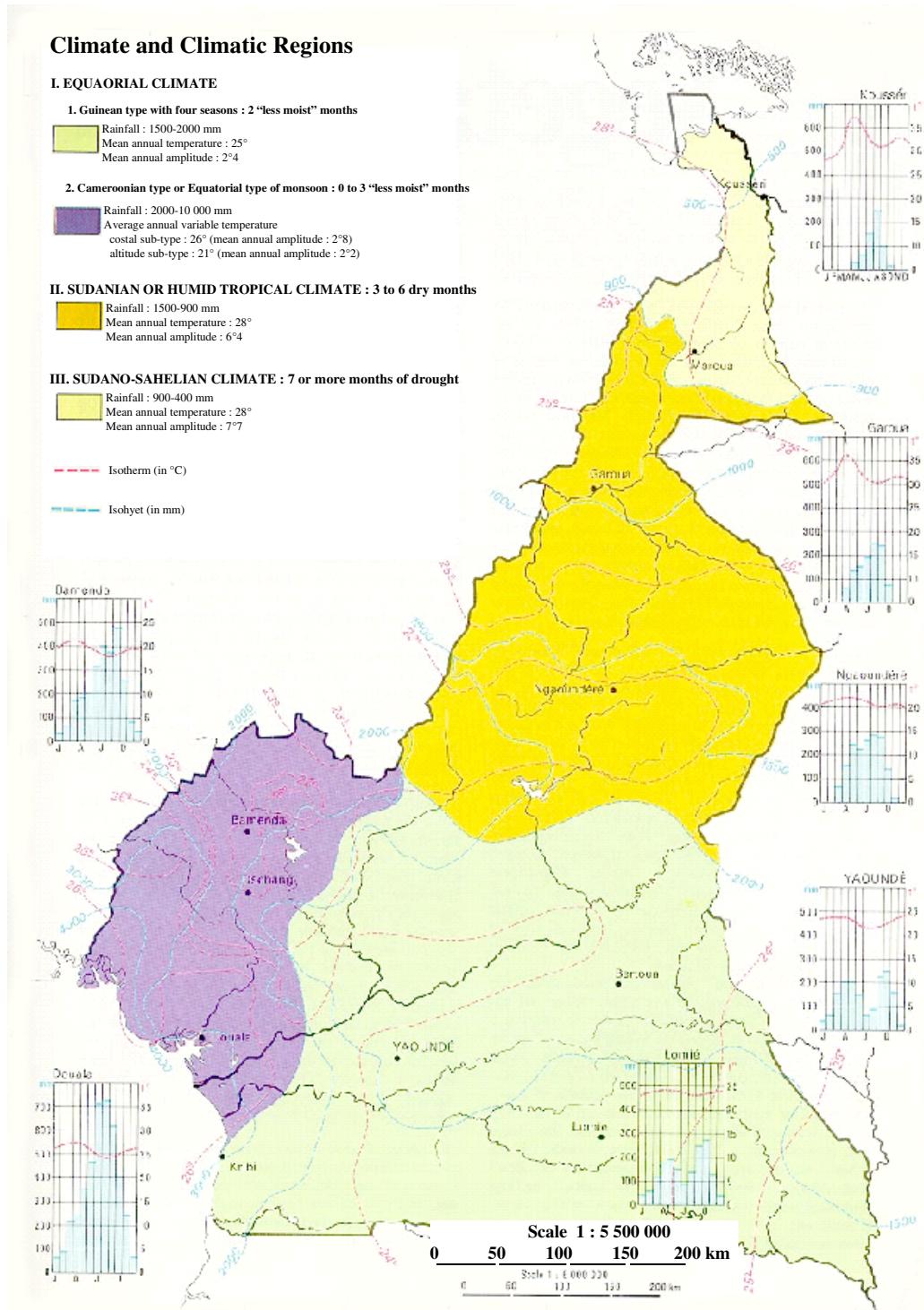


Fig. 2. Temperature and rainfall zones of Cameroon.

Source: Laclavère and Loung (1973).

## Soils

### Raw mineral and lightly evolved soils

- Regosolic and lithosolic soils, with ferruginous and leached facies, of mountains and hills, on crystalline rocks
- Lightly evolved alluvial soils, with carbonated facies of subaerial beaches and bars
- Lightly evolved soils of volcanic

### Vertisols

- Topomorphic and lithomorphic vertisols
- Pediplain topomorphic and lithomorphic vertisols

### Browned soils

- Tropical eutrophic brown soils

### Fersiallitic and ferruginous soils

- Slightly leached ferruginous soils of alluvial piedmonts
- Ferruginous soils with concretions and cuirasses

### Ferralsols

- Aliatic modal red soils
- Indurated aliatic soils
- Orthic modal red soils
- Indurated orthic soils
- Modified orthic soils
- Rejuvenated and impoverished orthic soils

### Ferralsols cont'd

- Strongly rejuvenated and impoverished (degraded) ..
- Topomorphic yellow soils
- Modified topomorphic yellow soils
- Bauxitic cuirasses

### Hydromorphic soils

- Soils with vertic gley ("yaérés")
- Humid soils with gley, with acid anmoor
- Mangrove soils on marine alluvium

### Associations

- Slightly leached ferruginous soils and phanerosolic leached soils on eolian sands
- Penevolved ferralsols, regosolic and lithosolic soils of steep slopes
- Modified ferrallitic red and yellow soils
- Penevolved depthless orthic ferrallitic soils, lithosolic and regosolic soils of the hills
- Orthic ferrallitic soils and undifferentiated hydromorphic soils
- Strongly rejuvenated ferrallitic soils and undifferentiated hydromorphic soils
- Yellow ferrallitic soils and undifferentiated hydromorphic soils
- Modified ferrallitic yellow soils and undifferentiated hydromorphic soils

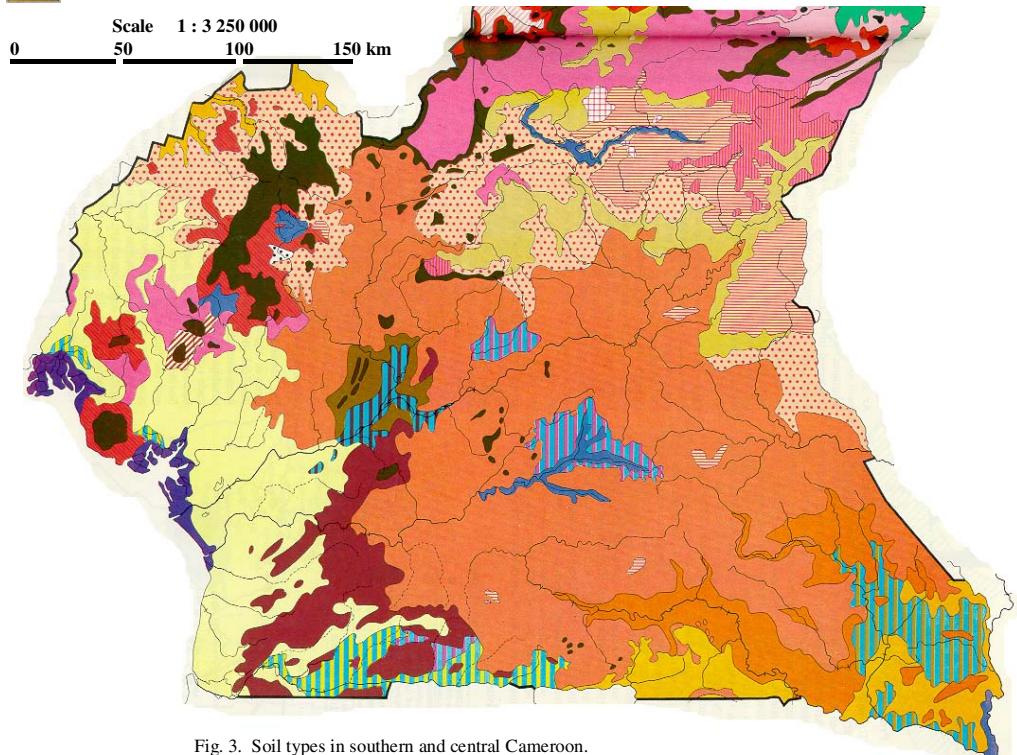


Fig. 3. Soil types in southern and central Cameroon.

Source: Laclavère and Loung (1973).

contain a lot of nutrients. During the rainy season, they cannot be used for cultivation because they are clayey. They are good for muskwari (dry season) sorghum cultivation. In the Far North province, maize is grown during the rainy season on lithomorphic vertisols along seasonal streams. These do not contain much clay but alluvium. Therefore, there is good aeration.

- Andosols and brown eutrophic soils are young soils with a homogenous profile, developed on the basic volcanic formations associated with raw and lightly evolved mineral soils. They are rich soils and are very good for maize cultivation, although they are subject to erosion. The only problem is phosphorus availability because this nutrient is retained by volcanic ash (allophans). Maize can therefore not be grown on a sustainable basis without having to supplement phosphorus. They are found around Foumban in the West province.

- Fersiallitic and ferruginous soils. Fersiallitic soils are intermediate in fertility between ferrallitic and vertisols. They are found around the Northwest and Adamawa provinces (high altitude areas). They are good for agriculture because hydrolysis of minerals is incomplete and they are relatively saturated with nutritive elements.

- Leached planosolic and solonetz soils with unsuitable physical and chemical characteristics.

- Ferrallitic soils covering almost two thirds of the country south of latitude 8 degrees. The vegetation cover is forest. These soils are poor in nutrients, acidic and fragile. Physically ferrallitic soils are deep and if well managed, maize yields are good.

- Associations of the various soil types described above found here and there (fig. 3).

### **Importance of maize in Cameroon**

The diversity of ecological conditions allow Cameroon to produce both food (cereals, root and tubers, musa, legumes etc.) and cash (cocoa, coffee, cotton, oilpalm, rubber etc.) crops. Climate wise, the entire territory with the exception of the Far North province where drought is a limiting factor falls within the suitable range for maize cultivation. However, poor soil management practices, erosion (abiotic factors), pests, diseases (both in field and storage) and weeds (biotic) as

well as socio-economic factors of labor, no access to credit facilities to purchase inputs, poor road infrastructure etc. affect maize production and yields (Mokwunye and Vlek, 1985; McHugh and Kikafunda-Twine, 1995). Resource poor farmers do about 80% of maize production in Cameroon and average yields are far below the world average of 3,700 kg/ha. Average maize yields range from 1,259kg/ha in the highlands to 1,973kg/ha in the mid-altitude (McHugh and Kikafunda-Twine, 1995).

Despite the production constraints, cereals constitute on the overall, major staples in Cameroon (Agricultural census, 1984). The main cereals grown are maize, rice, sorghum and millet, with maize being the most important and cultivated in varying amounts in all ten provinces of the country. About 70% of the country's maize are grown in the mid-altitudes and highlands of the West and Northwest provinces (Ayuk-Takem and Atayi, 1991).

**Table 1. Maize production in Cameroon by provinces, 1986**

Province	Land area (km <sup>2</sup> )	% of total area	Production in metric tons	% of total production
West	13,000	3.0	200,000	38.3
Northwest	17,320	3.7	160,000	26.5
Littoral	20,220	4.4	45,000	7.5
Southwest	24,910	5.3	10,000	1.7
Centre	68,942	14.8	50,000	8.2
South	47,190	10.1	10,000	1.7
East	108,900	23.4	30,000	5.0
Adamawa	61,992	13.3	40,000	6.7
North	67,793	14.6	46,000	7.7
Far North	34,260	7.4	10,000	1.7
Total	465,417	100.0	601,000	100.0

Source: Ayuk-Takem and Atayi (1991)

Maize is the staple food in these provinces and is consumed mainly dry in the form of "fufu". In the forest zone, maize is the third most important crop after groundnuts and cassava and is consumed mainly fresh, with little quantities stored as seeds (Testing and Liason Unit (TLU) Ekona, 1988; Enyong, 1990; Almy et al., 1990). However, in the high rainfall forest areas of Littoral and Southwest provinces, immigrants from the mid-altitude and highlands working in the Cameroon Development Corporation (CDC), the second largest employer after the Government, grow maize for dry consumption (TLU Ekona, 1988). In the forest/savannah transition zones of the Centre and East provinces, maize is the

staple and is consumed dry (Enyong, 1990). In the North and Adamawa provinces, maize “fufu” is gradually replacing sorghum and millet “fufu” (Yatahad, 1994).

Diagnostic socio-economic studies carried out by both the Nkolbisson and Ekona Testing and Liaison Units (TLU) which were farming system components of the National Cereals Research and Extension (NCRE) project (NCRE Annual Reports, 1988, 1989, 1990) showed that farmers around the big towns of Yaoundé and Douala are market oriented and with the fall in cocoa prices, maize has become an important source of cash. In the past before the drastic fall of cocoa and coffee prices and the devaluation of the franc CFA in 1994, maize was basically a subsistence crop in Cameroon. A study of the average farm earnings and contribution of different sources to the income of farmers in the Northwest province (NCRE, 1982) showed maize contributed only 4% although 90% of the farmers grew maize. Thus although maize was the most commonly grown crop, it was primarily a subsistence crop. At that time, very often, customary laws prohibited the sale of maize in village markets. Also, in the past, large industries that use maize as primary input such as Maïseries du Cameroun (MAISCAM), Brasseries du Cameroun, Société de Provenderies du Cameroun (SPC) imported maize from Zimbabwe and East Africa. However, with the devaluation of the CFA franc by 50% in January 1994 and the drought that affected Zimbabwe in the early 90s, the price of imported maize doubled instantly and these large buyers began turning to local sources to satisfy their needs (Akinwumi and Coulibaly, 1996). Consequently, a new trend in the production and utilization of maize in Cameroon is its increasing importance as a cash crop. Many farmers abandoned, reconverted or even slashed down their traditional cash crop fields and replaced with maize (Yatahad, 1994). Also, the new agricultural policy encourages farmers to diversify their crop production and maize cultivation is expanding very fast, especially in the forest zone (Akoa, 1994). Important outlets for maize are large urban centres, neighboring countries, wholesalers, retailers, maize processing companies etc. As such, in the northern provinces, the above sources bought 3,021 tons of maize from local stores in 1991, 1,704 tons in 1992 and 273. 434 tons from the northeast Benoué project in 1991 (Yatahad, 1994). Nevertheless, local

production has not met the country's needs. MAISCAM imported 15,000 tons of maize in 1991, 16,500 tons in 1992 and bought 800 tons from farmer groups within the northeast Benoue project in 1993. Some livestock feed companies imported 9,000 tons of maize in 1992 (Conté and Fusillier, 1993). The breweries still import important quantities of maize from east and south Africa. There is still potential to increase maize production and marketing in Cameroon, particularly in the vast areas of the Centre, South and East provinces. In the 90's many more large-scale farmers (more than 5 ha) started cultivating maize in these areas. The National Employment Fund, created to help solve rising unemployment together with the Institute of Agronomic Research for Development (IRAD) provided important quantities of seeds and other inputs as well as storage technology to some young farmers in these provinces. In Yaoundé, the price of maize grain in April moved from about 100 Frs. per kg in the late 1980s to 500 Frs./kg in 1998 (Directorate of Agriculture, personal comm.).

### **Biotic and abiotic problems affecting maize production and storage in Cameroon**

As stated earlier various constraints, poor soil management and erosion, pests, diseases and weeds, storage, maize varieties as well as socio-economic factors hamper optimal maize production in Cameroon. All these constraints are present to varying extent in the various ecological zones, although poor soil management cuts across zones (Mokwunye and Vlek, 1985). Maize is grown basically as an intercrop although the cropping system differ depending on climate, soil conditions, socio-economic, ethnological preferences, technological and managerial factors of the agricultural production process.

#### *Poor soil management*

In the forest zone, the prevailing farming and cropping system is based on slash and burn food crop production. Forest of varying fallow period is slashed, burned and the land tilled before planting it to groundnuts, cassava, maize, plantains, with various other vegetables. After maize, groundnuts and cassava are harvested, plantains are left in fallow while the forest regrows. In the mid-altitude and highlands there is land scarcity. Slash and burn is no more common nowadays.

Maize is interplanted with colocasia (taro) or groundnuts in the mid-altitude. In the highlands, it is intercropped with beans or Irish potatoes (McHugh and Kikafunda-Twine, 1995). After maize is harvested in August, the fields in both the mid-altitude and highlands are planted either to phaseolus beans or cowpeas. The same fields are again cultivated to maize in the following year.

In the Adamawa, North and Far North provinces, maize is often grown as a sole crop or intercropped with groundnuts, cowpeas or sorghum or in rotation with cotton and/or legume crops (mostly groundnuts and cowpeas) during the rainy season.

These soil management practices offset rapid decline in soil fertility to an extent as intercropping or rotation with legumes improves the nitrogen contents of the soil. However, as far as maize production is concerned, nitrogen deficiency (across the country) and phosphorus (in localized areas) were cited as major constraints to maize cultivation (NCRE, 1982, 1983, 1984, 1985, 1986, 1988, 1989, 1990; IRA, 1983; Ndjang, 1987).

In the lowland high rainfall forest region, the effect of fertilizer application on the yield of several maize varieties grown on representative soils (ultisols and oxisols or ferrallitic soils following French classification) showed a strong response to applied nitrogen and phosphorus in Ntui (forest/savannah transition zone). The magnitude of the response varied with the variety used. In the forest zone, phosphorus and potassium did not give consistent response in on-farm trials (NCRE, 1989, 1990). Sixty kg nitrogen per ha is profitable for maize production in both the forest and transition zones, whereas yield response to phosphorus might be profitable in the transition zone but not in the forest zone. The ultisols and oxisols of the forest zone also have acidity and aluminum toxicity problems. Soil fertility management systems for intensive and continuous maize production in Cameroon have therefore to take into account these soil constraints. Failure to do so will lead in most cases to a rapid loss in soil fertility and result in soil degradation and decreasing yields.

### *Pests*

Pests of maize in Cameroon consist of insects, rodents and birds. According to importance, insects are the most troublesome both in the field and in storage. The

most notorious insect field pests of maize in the country are stem and ear borers belonging to the order Lepidoptera such as *Busseola fusca* (Fuller) (Lep.: Noctuidae), the African sugarcane borer *Eldana saccharina* (Walker) (Lep.: Pyralidae), the pink stalk borer *Sesamia calamistis* (Hampson) (Lep.: Noctuidae), and the cob borers *Mussidia nigrivenella* (Ragonot) (Lep.: Pyralidae) and *Cryptophlebia leucotreta* (Meyrick) (Lep.: Tortricidae) (Awono, 1981; Billong, 1986; Aroga, 1987a; McHugh and Kikafunda-Twine, 1995; Cardwell et al., 1997; Schulthess et al., 1997a). *B. fusca* is the most widespread and abundant, followed by *E. saccharina* (Cardwell et al., 1997). Stem borer pests reduce maize yields by 0 - 59% across the country (Ndemah, 1991; Cardwell et al., 1997).

The next important group of pest insects that attack maize in the field are the leafhoppers belonging to the genus *Cicadulina* (Homoptera: Cicadellidae). Three species are reported to be found in farmers' fields; *C. mbila* (Naudé), *C. triangula* (China) and *C. arachidis* (China) (Aroga, 1987a). Leafhoppers are vectors of maize streak virus (MSV). Yield losses due to MSV vary greatly between ecological zones and years and can be as much as 100%. Fortunately most varieties are resistant against MSV.

Occasional leaf-feeding pests are the armyworm *Spodoptera exempta* (Walker) (Lep.: Noctuidae) various locusts and grasshoppers such as *Zonocerus variegatus* (Linnaeus) (Orth.: Acrididae), aphids such as *Rhopalosiphum maidis* (Fitch) (Homoptera: Aphididae) and *Schizaphis gramineum* (Rondani) (Hom.: Aphididae), spittlebugs *Poophilus* and *Locris* species (Homoptera) etc. These are minor pests on field maize.

In storage, the most common insect pests are *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae) and *S. oryzae* (Linnaeus) (Col.: Curculionidae). Other less common coleopteran pests are *Rhyzopertha dominica* (Fabricius) (Coleoptera: Bostrichidae), the flour beetles, *Tribolium* spp. (Coleoptera: Tenebrionidae), the angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lep.: Gelechiidae) and the Indian meal moth, *Plodia interpunctella* (Hübner) (Lep.: Pyralidae) (Baleguel, 1984; Beyo, 1988; Fongang, 1988; Foko, 1990; Asanga, 1993). The grain weevil *S. zeamais* and rice weevil *S. oryzae* can cause maize losses of up to 100% depending on the storage conditions.

Rodent pests that feed on maize especially in storage include *Rattus* spp. (Rodentia: Muridae) and the house mice *Mus* spp. (Rodentia: Muridae).

Birds can also become a problem both in the field and in storage, depending on the location and exposure of the grain. The most common bird pests are the gray headed sparrow *Passer griseus* (Passeriform: Ploceidae), the rock dove/feral pigeon, *Columba livia* and the village weavers *Ploceus cucullatus* (Muler) (Passeriform: Ploceidae) (Asanga, 1993).

### *Diseases*

Several diseases are associated with maize production, grain and seed storage in Cameroon. Foko (1987) has compiled an exhaustive list of the various pathogens (according to agro-ecologies) that affect maize. Important diseases found on field maize are the blights and rusts. These vary according to ecological zones, although there is some overlap as reported by Foko (1974) and Cardwell et al. (1997). Highland rust is caused by the pathogen *Puccinia sorghi* (Schweinitz) and lowland rust by *Puccinia polysora* (Underw.). Other foliar and stem diseases of some importance across the country include *Bipolaris maydis* (Misikado et Miyake) Shoeaken and *Physoderma maydis* (Miyabi), *Cercospora zea-maydis* (Tehon and Daniels), *Phaeosphaeria maydis* (Miyake) and streak virus (Cardwell et al., 1997). Foliar diseases cause yield losses that range from 6 - 17% in the different ecological zones and seasons (Cardwell et al., 1997). Smut, *Ustilago maydis* (DC) and head smut *Sporisorium reilianum* (Kühn) Langdon and Fullerton are also found in farmers' fields. Pathogens associated with maize in storage and seeds are *Aspergillus flavus* (Link), *A. niger* (van Tieghem) (Deuteromycetes: Moniliales), *Fusarium moniliforme* (Sheld) and *Penicillium* spp. among others (Mbiapo et al., 1979; Foko, 1987). These pathogens can produce mycotoxins such as aflatoxins and fumonisin, which render grain unfit for human and animal consumption.

### *Weeds*

There are several weed species that cause havoc and reduce maize yields but the predominant ones according to agro-ecologies are *Chromolaena odorata* (Linnaeus) (Asteraceae) in the forest zone, *Imperata cylindrica* var *africana*

(Anderss.) (Poaceae) in the mid-altitude and highland savannah and the parasitic *Striga* spp. in the lowland moist savannah of the northern provinces.

### **Possible solution to the problems**

#### *Background*

Although maize was introduced in Cameroon some 400 years ago during the 16th century, research on this crop did not start until Cameroon became independent in 1960 (Ayuk-Takem and Atayi, 1991). From 1960 to 1965, most of the research on maize was aimed at introducing and testing varieties from areas of the world considered to be similar with a view to the quick identification of varieties adapted to the diverse ecological areas of Cameroon. Applied research on maize started in 1965/66 when the former French Research Institute, IRAT (Institut de Recherches Agronomiques Tropical et des Culture Vivrières) introduced varieties from West and East Africa (including Madagascar), France and Israel and tested them at Dschang (1,400 m). Systematic breeding work on maize started in 1971 at Bambui (1,600 m) and Dschang.

The NCRE project was set up in 1979 with substantial financial support from USAID and technical expertise provided by the International Institute of Tropical Agriculture (IITA), Nigeria and Benin. One of its major objectives was the improvement and promotion of maize in Cameroon. Besides improved maize cultivars, chemical fertilizers and agroforestry techniques were widely tested and extended to farmers to address the problems of increasing soil erosion and declining fertility (NCRE, 1990). NCRE adopted a teamwork approach whereby varying disciplines were brought together as a team when tackling problems. Crop improvement was done through the combined efforts of breeders, agronomists, pathologists, physiologists, economists, extensionists etc. Such an effort required regular monitoring of activities on-station as well as on-farm. There was the Testing and Liaison Unit (TLU) with a largely extension and training function, whereby the fruits of research were brought appropriately to farmers while acquiring feedback from the farmers back to the researchers in order that researchers may better focus - in on the real issues and needs and thereby set their priorities accordingly so that farmers and consumers are getting

what they rightly want and deserve in terms of produce types and qualities. Lastly, NCRE co-operated with parastatal bodies and co-operatives in order to provide the desired crop varieties and technologies and introduce them into production more quickly and in substantial acreage.

Unfortunately as far as the crop protection disciplines of plant pathology and entomology are concerned, the maize improvement unit can be credited to have worked with plant pathologists only to incorporate resistance to the major pathogens affecting maize. Other than insecticide rates recommended to farmers to fight against maize stem borers and storage pests, NCRE did not achieve much in the domain of insect pest management. However, the Plant Health Management Division (PHMD) of IITA has been providing a lot of technical support to help build up management practices that are sustainable and environmentally safe towards solving maize stem borer problems in Cameroon. Through the Regional Research Project on Maize and Cassava (RRPMC) and the International Fund for Agricultural Development (IFAD) sponsored projects under the supervision of IITA in collaboration with the Institute of Agronomic Research for Development (IRAD), emphasis is being given to identifying the reasons for ecological imbalances leading to pest problems in cropping systems in order to find environmentally and economically sound means to keep pest populations from reaching damaging levels. The methodology adopted is the ecosystem analysis approach, which gives the same importance to all trophic levels, cultivated and wild host plants, the pests, their natural enemies, climate and soil without a pre-conceived idea about their role in the system. The main management strategies being elaborated or sought include biological control, host plant resistance and habitat management (Schulthess et al., 1997a).

#### *Host plant resistance*

Host plant resistance has traditionally controlled diseases on maize. Most maize germplasm in the country has resistance to the most prevalent diseases. Nevertheless extremely massive and damaging epidemics of pathogens can occur due to oversights in breeding techniques. Errors in breeding strategy such as developing a germplasm base that is too narrow, or developing, and releasing lines that have not been rigorously screened under controlled disease pressure,

cause boom and bust cycles and devastating epidemics. Opening of new ecological zones and cropping intensification can lead to destructive outbreaks of diseases particularly if the germplasm is susceptible (Cardwell, personal communication).

As for maize stem borers, in a first approach to reduce borer problems in Africa, IITA Ibadan, Nigeria placed emphasis on host plant resistance. Until now, only moderate resistance has been achieved. In Nigeria, like in most of West Africa, the species involved are *S. calamistis* and *E. saccharina*. In Cameroon, *B. fusca* and *E. saccharina* are important and breeding for resistance was being done without much input from entomologists. Efforts are now being made to develop methodologies that will enable uniform field infestations under natural conditions for host plant resistance purposes. Also, because of the low economic thresholds for maize stem borers (Usua, 1968) due to the plant's inability to tiller, reduction in the numbers of borers per plant has to be considerable. There is also an overlap of species and generations throughout the year as well as variation in seasonal abundance on the different plant parts. Thus a variety resistant to one borer species during one season, may still be vulnerable to another species found in the same area. Therefore an integrated approach combining various control options is most applicable to the stem borer pest problem.

#### *Biological control*

Maize is exotic to Africa but stem borers with the exception of *Chilo partellus* (Swinhoe) (Lep.: Pyralidae) are indigenous pests that probably evolved with native grasses mostly and in the case of *E. saccharina* with sedges (Atkinson, 1980; Schulthess et al., 1997a). Biological control against stem borers in Africa including the introduced pest *C. partellus* has been tried several times in the past without success on the continent (Mohyuddin and Greathead, 1970). Some control was achieved on the East African Island against *S. calamistis* and *C. partellus* (Appert et al., 1969). On continental Africa, however, *C. flavipes* did not get established until relatively recently, probably because no follow up was made to investigate the reasons for failed establishment. In the mid 90ties, new releases by the International Center of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya, led to the establishment of *C. sesamiae* in Kenya and northern Tanzania

(Omwega et al., 1997; Overholt et al., 1997). Both ICIPE and IITA/PHMD initiated biological control projects, which encompassed the new association approach, exchanging natural enemies' species and strains between African regions and biocidal control. These projects include detailed pre-release studies in the stem borer ecosystem, work on suitability of the borer species and follow up studies. The bulk of the investigations presented in this thesis are part of pre-release studies.

#### *Habitat management*

Wild hosts have long been regarded as a reservoir for stem borer outbreaks on maize. Research carried out by PHMD Benin however showed that most wild hosts of stem borers act as trap plants (Sekloka, 1996; Schulthess et al., 1997a; Cardwell et al., 1997). The same habitat management studies at PHMD also showed that soil and thus plant nitrogen enhances both stem borer development and plant tolerance to borer attacks (Sétamou et al., 1993, 1995). Silica had the opposite effect. Therefore with increasing acreage of maize, the best food source for borers (Shanower et al., 1993), use of fertilizer which increase their survival and fecundity and concomitant destruction of the natural habitat of borers, pest problems will very likely increase in an area.

#### *Chemical control*

This is the only pest control method currently used by large-scale farmers who can afford to buy insecticides. The most recommended insecticide by the Ministry of Agriculture is furadan (active ingredient carbofuran) at the rate of 10 kg active ingredient per ha. Very often, farmers use insecticides that are destined for cocoa and coffee plantations without knowledge of the appropriate doses and the health and environment hazards that these chemicals may cause. Also, as shown by Neuenschwander et al. (1986) insecticide sprays can cause new outbreaks of the cassava mealybug, *Phenacoccus manihoti* Mat. - Fer. by killing the exotic wasp *Apoanagyrus lopezi* (De Santis) (Hym.: Encyrtidae) which usually keeps the pest under perfect control. Consequently, insecticide sprays in a maize-cassava intercrop, which is the most common intercropping system used in the rainforest

zone, will always be to the detriment of the cassava crop. Also chemicals have to be applied repeatedly and this is not sustainable.

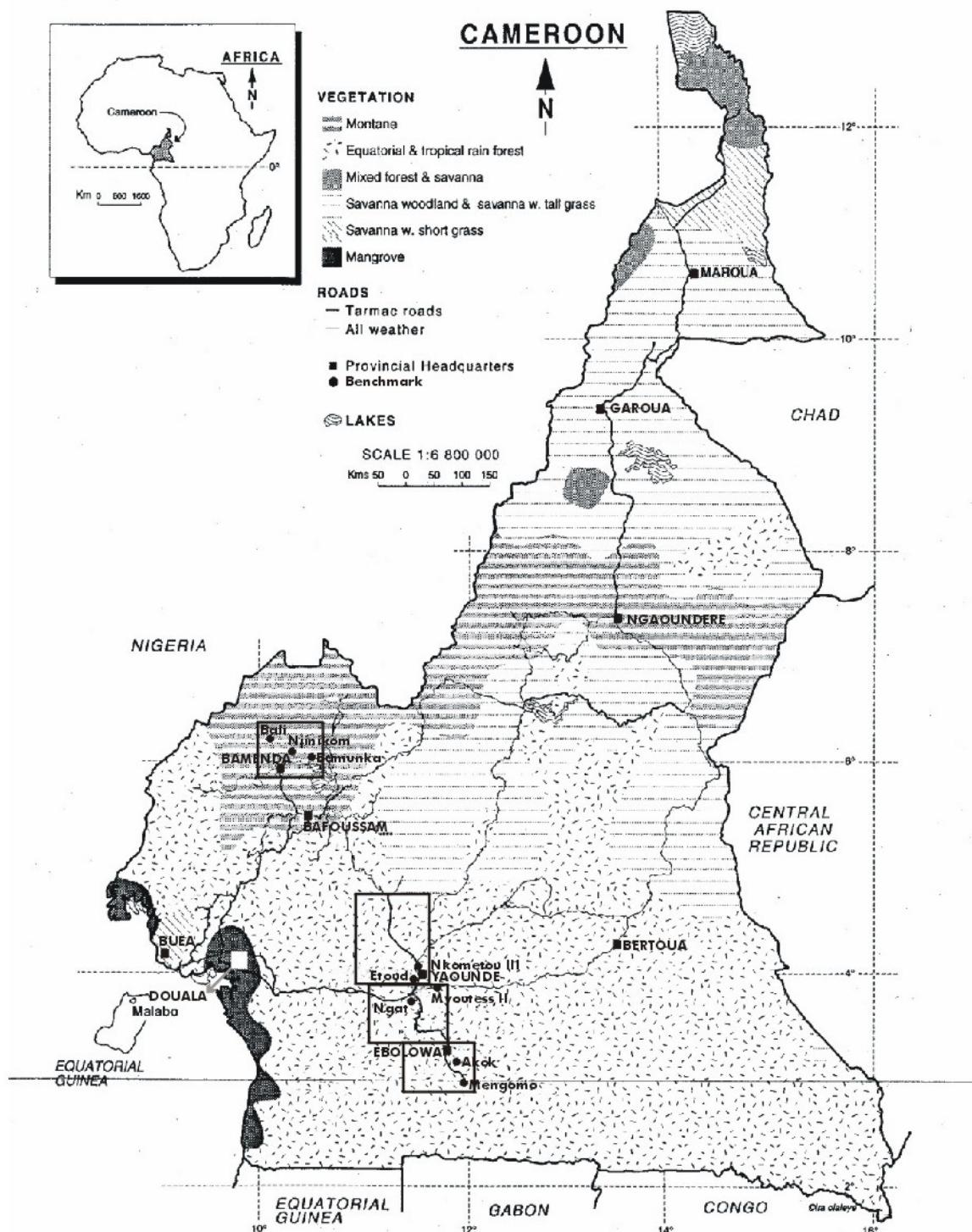
### **Objectives, general methodology and approach**

The objectives of this work were to produce baseline data and identify key interactions in the stem borer ecosystem. To begin with, country-wide surveys to document maize losses due to pests and diseases as well as pinpoint potential trouble areas were carried out in farmers' roadside fields in 1993 (Cardwell et al., 1997).

Next, benchmark locations were selected in the trouble areas, i.e. the forest zone and mid-altitude and more detailed surveys were conducted in farmers fields.

The forest zone benchmark locations for this study were selected as follows: During the 1992 resources management survey conducted by IITA/IRAD Cameroon, the forest zone map was divided into 10 minutes X 10 minutes cells and the centremost village in each of the cells chosen as the sample village. Based on vegetation, agronomic, socio-economic, soil constraints, pests and diseases etc., the sample villages were grouped into blocks namely: the Yaoundé, Mbalmayo, Ebolowa and Ambam blocks. The benchmark locations for this work are from the Yaoundé, Mbalmayo and Ebolowa blocks. Average fallow periods are 3.9 years in the Yaoundé block, 5.4 years in the Mbalmayo block and 7 years in the Ebolowa block. The highest demographics are 88 inhabitants per km<sup>2</sup> in the Yaoundé block, 41 inhabitants per km<sup>2</sup> in the Mbalmayo block and 15 inhabitants per km<sup>2</sup> in the Ebolowa block. The Mbalmayo block is therefore like a transition between the Yaoundé and Ebolowa blocks. Concerning vegetational variables, the forest is more degraded in the Yaoundé than in the Ebolowa block. Two heterogeneous or contrasting villages per block (e.g. chromolaena the dominant vegetation, village is along or off the main road etc.) were chosen making a total of six benchmark locations: Nkometou III and Etoud in the Yaoundé block, Mvoutessi II and Ngat in the Mbalmayo block, and Mengomo and Akok in the Ebolowa block (fig. 4).

The single criterion for choosing benchmark villages in the mid-altitude was cultivation of two maize crops per year. The villages were Bali, Bamunka and Njinikom (fig. 4).



Multivariate analyses were applied to the survey data to generate hypotheses about key interactions among physical (edaphic), crop management and biotic factors (pests, natural enemies, alternative hosts etc.).) These hypotheses were tested in the benchmark sites. In addition socio-economic studies were carried out to assess the importance of maize in an area, and the farmers' perception of the organisms causing crop losses.

This ecosystem analyses approach should lead to the identification of pest management options including biological control and habitat management options that may synergize and reinforce naturally occurring control and host plant resistance.

### **Introduction to subsequent chapters**

The thesis begins with population dynamics studies of *B. fusca* and *E. saccharina* on *Z. mays* and the elephant grass *P. purpureum* (Moench) (Fam.: Poaceae), the most important alternative wild host plant, in the forest zone. These are discussed in chapter two. The objectives are to describe the changes and seasonal abundance pattern of the two insect species, to assess the oviposition preference for plants and growth stages, as well as survival of larvae and number of pupae on the two plant hosts. These studies provide insight into the potential for using *P. purpureum* as a trap plant in the management of *B. fusca* as proposed by Cardwell et al. (1997) and Schulthess et al. (1997a).

Chapter three describes the within plant distribution over time of *B. fusca* and *E. saccharina*, as well as the dispersion of other stem and ear borer species on the two plant hosts in the forest zone, using Taylor's (1961) power law. The information is a pre-requisite for developing sampling procedures with a given reliability level in order to make population estimates more accurate.

In chapter four, the geographical distribution and relative importance of borers in the forest and mid-altitude benchmark sites according to season are described. This will serve to delineate low and high density areas which is a pre-requisite for the identification of factors suppressing or enhancing pest population densities, or pinpoint areas with reliably high pest pressure needed for, e.g., host plant resistance screening and other intervention technologies.

The major objectives of chapter five were to assess the relationships between

individual pest damage parameters and yield in order to allocated the damage cause by an individual pest species and to provide a tool for rapid assessment of the importance of a pest species on a region-wide basis. In addition, the chapter determined if forest zone locations could be grouped according to the pre-selected ‘blocks’ using soil nutrient concentration, and if or how the latter affect pest damage to maize on a block, village and on a per field basis.

In chapter six we assessed the role of the *B. fusca* egg parasitoids, *Telenomus* spp. (Hym: Scelionidae) in suppressing the pest numbers and consequently maize growth and yield. Multiple regressions were applied to the entire survey data to assess the relative importance of the various biotic and abiotic factors on pest numbers and yield.

Chapter seven gives a comprehensive list and distribution of indigenous natural enemies attacking borers on maize and elephant grass in the forest zone. This is the first step towards assessing the importance of individual natural enemy species in the system and for assessing promising candidates for redistribution between African regions.

Finally, chapter eight discusses possible control options and future research to be carried out in order to develop IPM options to achieve sustainable control of *B. fusca*.

## CHAPTER 2

**The seasonal dynamics of lepidopterous stem borers on maize and the elephant grass, *Pennisetum purpureum* (Moench) (Poaceae), in the forest zone of Cameroon with special reference to *Busseola fusca* (Fuller) (Noctuidae)**

**Introduction**

Phytophagous insects are attracted to their host plants by chemical cues emanating from the plant, which vary with plant species (Nordlund et al., 1981; Boethel and Eikenbary, 1986; Whitman, 1988; Van Emden, 1995). Lepidopterous cereal stem borers are known to prefer certain plant species, plant growth stages and parts for oviposition (Phiri, 1995; Kouamé, 1995; Sekloka, 1996; Schulthess et al., 1997a; Gounou, unpubl. data). Some of these studies (Sekloka, 1996; Schulthess et al., 1997a; Gounou, unpubl. data) report wild host plants, namely grasses, as being highly attractive to ovipositing female moths, though survival of immature stages and female fecundity was considerably lower than on maize (Shanower et al., 1993; Sekloka, 1996; Schulthess et al., 1997a). It was concluded that wild host species could act as trap plants (Schulthess et al., 1997a) rather than being a reservoir for pests and responsible for severe attack in crop fields as theorized by Bowden (1976). Consequently, surveys in the forest zone of Côte d'Ivoire and Cameroon showed a strongly negative relationship between abundance of grasses in the vicinity of maize field and borer incidence in the field (Cardwell et al., 1997; Schulthess et al., 1997a). In the present chapter, the seasonal dynamics of *Busseola fusca* (Fuller) (Lep.: Noctuidae), the predominant borer species in Cameroon (Cardwell et al., 1997) and *Eldana saccharina* (Walker) (Lep.: Pyralidae) attacks were studied on two host plants, maize and the elephant grass, *Pennisetum purpureum* (Moench) (Poaceae), which was the most abundant grass species found during the surveys. The objective was to evaluate the potential of this wild host species as trap plant to reduce borer incidence in maize fields.

## Materials and methods

### *Collection of data*

Two 144m<sup>2</sup> maize plots were planted at Minkomeyos and Nkolbisson in the forest zone close to Yaoundé during the first cropping season of 1995. Both locations are open but whereas elephant grass was the only other predominant vegetation apart from maize at Nkolbisson, at Minkomeyos there were pockets of other vegetation, maize and elephant grass. Elephant grass was more abundant at Minkomeyos than Nkolbisson. At Minkomeyos, the maize field was planted next to a *P. purpureum* grass field during the last week in March while at Nkolbisson, the maize plot was surrounded by *P. purpureum* and planted during the first week in May in a farmer's field. The maize variety used was Cameroon Maize Series (CMS) 8704. The maize pockets were spaced at 75 cm between rows and 50 cm within rows, with two plants per pocket. The crop was fertilized with urea, at the rate of 60kg of nitrogen per ha, at four weeks after planting. Two hand weedings were done at four and eight weeks after planting. All plots were stratified into four quadrants. Per quadrant, ten elephant grass tillers including lateral shoots or five maize plants were sampled at each sampling date. In the grass field sampling started when the maize was one week old. Sampling was not done on maize because it was still too young for borer attack. On both host plants, samples were taken every four and two weeks until harvest starting four and three weeks after planting at Minkomeyos and Nkolbisson, respectively. During the August dry spell, one sample was taken from dry maize stalks and elephant grass tillers at Minkomeyos. For each plant or tiller, the number of *B. fusca* egg batches, larvae and pupae, as well as larval size but no distinction between developed stages for other borer species were assessed. Egg batch numbers were only counted for *B. fusca*. *E. saccharina* lays most eggs on debris of the soil and old plant parts (Kaufmann, 1983a; Carter, 1985; Gounou, unpubl. data) making the estimation of egg numbers unreliable, and other species are relatively scarce in the forest zone of Cameroon. For *B. fusca*, larval sizes were scored according to the following size classes: small = less than 0.5 cm, medium = between 0.6 and 1.5 cm, large = between 1.6 and 2.5 cm; and diapausing larvae and/ or pupa.

In the second cropping season, a new maize crop was planted on the same plots

during the third week in August at Minkomeyos, and during the first week in September at Nkolbisson respectively. Sampling started in the grassfield when maize was one week old. Thereafter, beginning two weeks after maize planting, the same sampling procedures as during the first season were used to sample for borers at bi-weekly intervals until harvest of maize ears in December 1995. As from January 1996, one sampling per month was done on maize stalks without ears and grass tillers till March 1996, at both Minkomeyos and Nkolbisson.

Three physiological growth stages were distinguished for maize; the vegetative stage (up to nine weeks after planting), the maturation phase (10 – 16 weeks after planting) and dry maize stalks thereafter.

For each sampling date, the number of tillers (including lateral shoots for *P. purpureum*) were assessed from eight 1 m<sup>2</sup> areas. Means across sampling date and plots are presented in Table 1.

#### *Statistical analysis*

Because of the large differences in tiller numbers between the two host plants, the analyses of insect variables were done on a per m<sup>2</sup> rather than per tiller basis.

Cumulative borer days per m<sup>2</sup>, defined as the mean number of borers per m<sup>2</sup> observed on consecutive sampling dates multiplied by the days between samples and then summed over the whole sampling period, were used to demonstrate differences in pest loads according to species between host plants and season.

An analysis of variance (ANOVA) using the mixed model (SAS, 1997) in repeated measures over sampling dates for the various seasons were used to compare borer counts according to species (for *B. fusca*, *E. saccharina* and *S. calamistis* only) and size/age classes (for *B. fusca* only) between the two host plants. The data were log (x + 1) transformed before analyses.

## **Results**

Although the maize crops were treated alike in both locations, the crop was always stunted at Nkolbisson, possibly due to some soil nutrient deficiency which would most likely influence insect abundance and seasonal trends between locations (Sétamou et al., 1993; Denké, 1995).

### *Species composition and seasonal trends*

At both locations and seasons, the mean number of tillers per m<sup>2</sup> was five to ten times higher for *P. purpureum* as compared to *Z. mays* (Table 1).

**Table 1.** Mean ( $\pm$  SE) number of tillers per m<sup>2</sup> for *P. purpureum* and maize at Minkomeyos and Nkolbisson during the first (S1), second (S2) and dry (D2) seasons of 1995.

Location	Season	Host plant	Mean no of tillers per m <sup>2</sup>
Minkomeyos	S1	<i>P. purpureum</i>	27.3 $\pm$ 2.3
		<i>Z. mays</i>	5.2 $\pm$ 0.1
	S2	<i>P. purpureum</i>	43.8 $\pm$ 2.9
		<i>Z. mays</i>	4.9 $\pm$ 0.1
	D2	<i>P. purpureum</i>	31.5 $\pm$ 4.8
		<i>Z. mays</i>	4.1 $\pm$ 0.1
Nkolbisson	S1	<i>P. purpureum</i>	52.1 $\pm$ 6.5
		<i>Z. mays</i>	5.0 $\pm$ 0.1
	S2	<i>P. purpureum</i>	40.9 $\pm$ 1.5
		<i>Z. mays</i>	3.9 $\pm$ 0.1
	D2	<i>P. purpureum</i>	28.2 $\pm$ 5.1
		<i>Z. mays</i>	3.1 $\pm$ 0.1

The borer species on maize consisted of *B. fusca*, *E. saccharina*, *Sesamia calamistis* (Hampson) (Lep.: Noctuidae), *Cryptophlebia leucotreta* (Meyrick) (Lep.: Tortricidae) and *Mussidia nigrivenella* (Ragonot) (Lep.: Pyralidae). On elephant grass, *B. fusca*, *S. calamistis*, *E. saccharina* and *Poeonoma serrata* (Hampson) (Lep.: Noctuidae) were recorded (Table 2). On the overall, *B. fusca* was the predominant species on both host plants followed by *E. saccharina* and *S. calamistis*. *P. serrata* was never found on maize and *M. nigrivenella* and *C. leucotreta* never on elephant grass thus further analyses were done for the most common three species only.

At Minkomeyos, *B. fusca* pest loads on both host plants, tended to be higher during the second than the first season, whereas at Nkolbisson, it was the reverse (Table 2). Likewise, on maize *E. saccharina* loads were higher during the second than the first season but on elephant grass they were higher during the first (Table 2) whereas *S. calamistis* loads tended generally to be higher during the first season.

#### *B. fusca oviposition on Z. mays and P. purpureum*

On maize at Minkomeyos and for both seasons, egg batches were found almost

**Table 2. Cumulative borer days per m<sup>2</sup> on *Z. mays* and *P. purpureum* at Minkomeyos and Nkolbisson during first and second seasons 1995 in the forest zone**

Location	Host plant	B.f.	Cumulative borer days/m <sup>2</sup>				
			E. s.	S. c.	M. n.	C. l.	P. s.
Minkomeyos	<i>Z. mays</i>	S1	39.3	18.0	73.0	21.9	47.4
		S2	358.9	180.6	15.7	8.5	16.8
	<i>P. purpureum</i>	S1	1038.7	49.5	48.2	0.0	0.0
		S2	7350.2	0.0	74.3	0.0	56.0
Nkolbisson	<i>Z. mays</i>	S1	95.7	51.8	95.9	80.9	167.5
		S2	24.3	72.1	12.7	38.9	37.5
	<i>P. purpureum</i>	S1	2152.8	68.5	27.1	0.0	0.0
		S2	837.1	15.3	15.8	0.0	28.5
							96.2

*S. c.* = *S. calamistis*, *B. f.* = *B. fusca*, *E. s.* = *E. saccharina*, *M. n.* = *M. nigrivenella*, *C. l.* = *C. leucotreta*, *P.s.* = *P. serrata*

exclusively during the vegetative stage, with a peak at eight weeks after planting in the second season, whereas at Nkolbisson, some batches were found during the silking stage but in the first season only and without clear peak for both seasons (Fig. 1). On *P. purpureum* at both locations, there were no clear trends and at Minkomeyos egg batches were collected at almost all sampling dates during the second season (Fig. 1) reflecting the growth habit of this host plant.

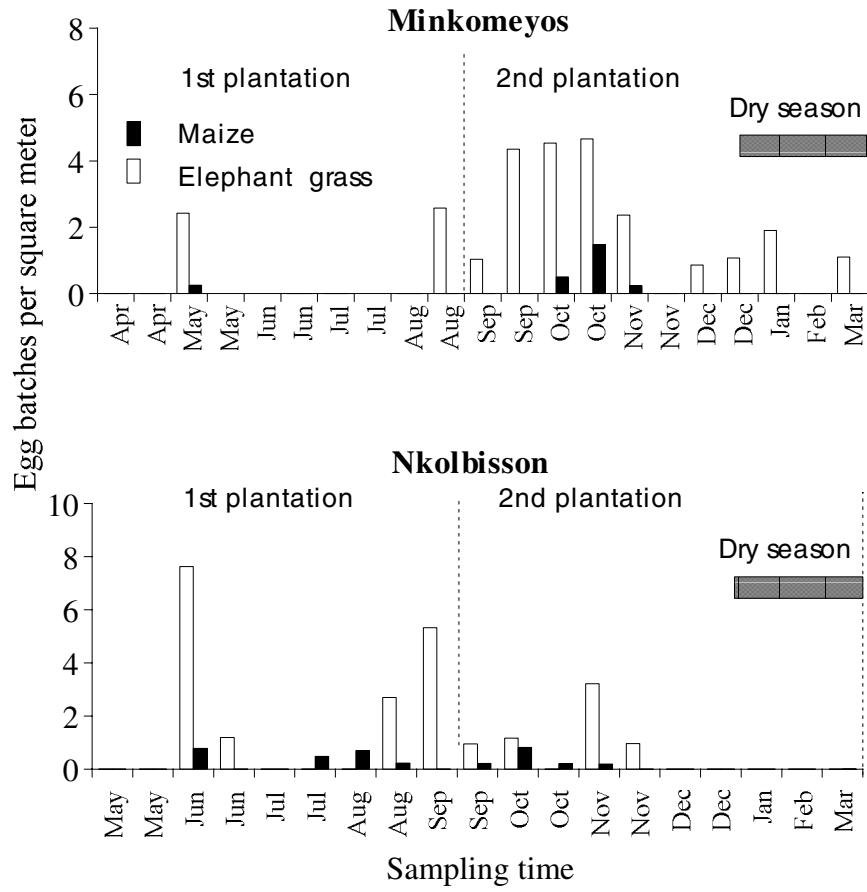
#### *Abundance of B. fusca, E. saccharina and S. calamistis larvae and pupae*

At both locations, significantly, i.e., three to nine times more *B. fusca* immatures (larvae plus pupae) per m<sup>2</sup> were found on *P. purpureum* than on maize during the first and second but not in the dry season (Table 3; Figure 2). For *E. saccharina*, more immatures on maize than elephant grass were found but the differences were only significant at Minkomeyos during the second season and at both sites during the dry season. The same trends were observed for *S. calamistis* but the differences were never significant (Table 3).

At Minkomeyos during both seasons and Nkolbisson during the first season, numbers of *B. fusca* larvae and pupae significantly changed with sampling date on both host plants ( $F = 4.78$ ,  $P = 0.01$ ,  $F = 8.64$ ,  $P < 0.01$ , and  $F = 2.78$ ,  $P = 0.01$ , respectively). At Minkomeyos early in the second season, the counts were higher on both host plants when maize was in the vegetative growth stage. Thereafter, pest densities decreased with onset of the dry season (Fig. 2).

### Distribution of *B. fusca* age classes

Analyzing the *B. fusca* data according to size/age classes (eggs, small, medium, large larvae, diapausing larvae plus pupae), revealed that the mean number of eggs per m<sup>2</sup> between plant hosts was not significant for any of the locations or seasons (Table 4). Numbers of small, medium and large larvae tended to be higher



**Fig. 1. Number of *B. fusca* egg batches per square meter on maize and *P. purpureum* during the first and second season at Minkomeyos and Nkolbisson during 1995**

on *P. purpureum* than on maize but significant differences were only found during the second season at Minkomeyos when densities were high (Table 4). At Nkolbisson, significant differences between plant hosts were only found for medium larvae in the second season. The same trend was observed for diapausing *B. fusca* larvae plus pupae per m<sup>2</sup> but the differences were never significant.

## Discussion

In the forest zone of Cameroon, *B. fusca* has previously been consistently reported as the most important borer species on maize (Cardwell et al., 1997). By contrast, in neighboring Nigeria as well as in most other West African countries *E. saccharina* and *S. calamistis* are the most common species followed by *M. nigrivenella* and much scarcer, *B. fusca* (Harris, 1962; Carter, 1985; Uzakah, 1988; Bosque-Pérez and Mareck 1990; Schulthess et al., 1997a).

**Table 3.** Back transformed least square means after log (count + 1) transformation of counts of larvae and pupae of *B. fusca*, *E. saccharina* and *S. calamistis* per m<sup>2</sup> on *Z. mays* and *P. purpureum* following ANOVA using proc mixed in repeated measures over sampling dates (SAS) at Minkomeyos and Nkolbisson during the first (S1), second (S2) and dry (D2) seasons of 1995.

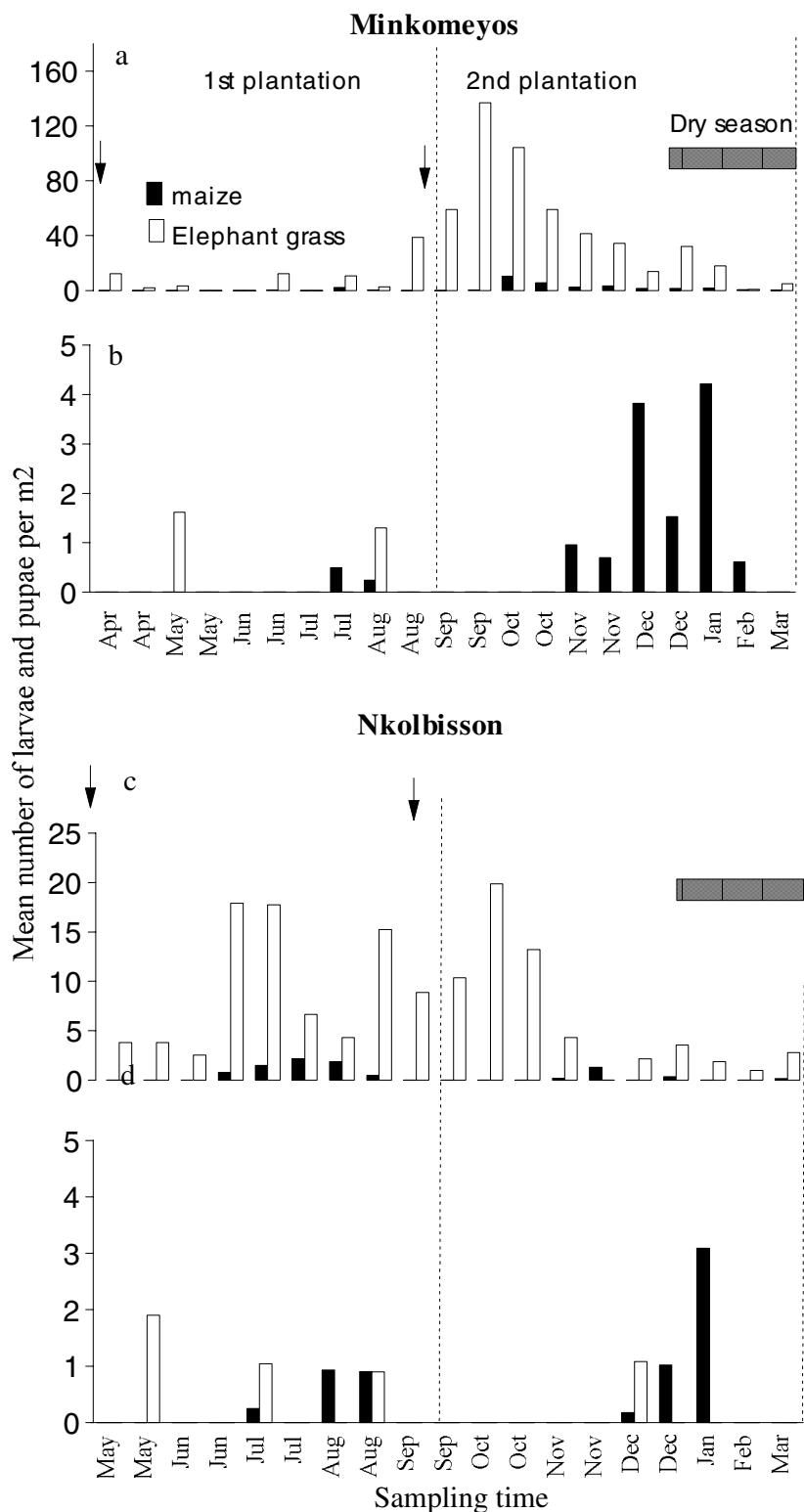
Location	Season	Borer	Host plant	LS means	t	P <sub>diff</sub>
Minkomeyos	S1	<i>B. fusca</i>	<i>P. purpureum</i>	1.16		
			<i>Z. mays</i>	0.19	2.64	0.04*
	S2		<i>P. purpureum</i>	5.96		
			<i>Z. mays</i>	0.98	4.32	0.005*
	D2		<i>P. purpureum</i>	0.54		
			<i>Z. mays</i>	0.34	0.82	0.44
Nkolbisson	S1		<i>P. purpureum</i>	0.76		
			<i>Z. mays</i>	0.23	2.59	0.04*
	S2		<i>P. purpureum</i>	0.72		
			<i>Z. mays</i>	0.08	3.55	0.01*
	D2		<i>P. purpureum</i>	0.25		
			<i>Z. mays</i>	0.00	1.67	0.15
Minkomeyos	S1	<i>E. saccharina</i>	<i>P. purpureum</i>	0.04		
			<i>Z. mays</i>	0.03	0.29	0.78
	S2		<i>P. purpureum</i>	0.03		
			<i>Z. mays</i>	0.29	-5.58	0.001*
	D2		<i>P. purpureum</i>	0.01		
			<i>Z. mays</i>	0.48	-7.16	0.0004*
Nkolbisson	S1		<i>P. purpureum</i>	0.03		
			<i>Z. mays</i>	0.09	-1.34	0.23
	S2		<i>P. purpureum</i>	0.01		
			<i>Z. mays</i>	0.05	-1.41	0.21
	D2		<i>P. purpureum</i>	0.00		
			<i>Z. mays</i>	0.34	-3.87	0.008*
Minkomeyos	S1	<i>S. calamistis</i>	<i>P. purpureum</i>	0.04		
			<i>Z. mays</i>	0.13	-0.95	0.38
	S2		<i>P. purpureum</i>	0.03		
			<i>Z. mays</i>	0.04	-0.30	0.78
	D2		<i>P. purpureum</i>	0.07		
			<i>Z. mays</i>	0.00	1.10	0.31
Nkolbisson	S1		<i>P. purpureum</i>	0.03		
			<i>Z. mays</i>	0.10	-2.08	0.08
	S2		<i>P. purpureum</i>	0.01		
			<i>Z. mays</i>	0.01	0.12	0.91
	D2		<i>P. purpureum</i>	0.09		
			<i>Z. mays</i>	0.09	0.00	1.00

\*Significance was set at P<sub>diff</sub> ≤ 0.05. P<sub>diff</sub> = probability of difference in LS means between *P. purpureum* and *Z. mays*.

The same species composition, with exception of *M. nigrivenella*, was found on *P. purpureum* in other countries (Bowden, 1976), but in some reports in Ghana *Sesamia botanephaga* (Tams & Bowden) (Lep.: Noctuidae), a species never described from Central Africa, was more common than *S. calamistis* and *B. fusca* was generally exceedingly rare (Scheibelreiter, 1980; Sampson and Kumar, 1986; Gounou and Schulthess, unpubl. data). *M. nigrivenella* is a polyphagous species that, besides maize cobs, attacks cotton, phaseolus beans and the fruiting structure of a number of trees of economic importance (Sétamou, 1996). On the other hand, *P. serrata*, also described from elephant grass in Ghana (Bowden, 1976) was never found feeding on maize. Generally, the ranking of species on one host plant does not always reflect its importance on the other. For example, in most of West Africa the most common pest *E. saccharina* is relatively rare on *P. purpureum* on which *Sesamia* spp. are the predominant species.

In the humid tropics of West Africa, stem borers of economic importance such as *E. saccharina* and *S. calamistis* reach peak densities during the second cropping season (Carter, 1985; Uzakah, 1988; Bosque-Pérez and Mareck, 1990; Schulthess et al., 1997a). A minor species such as *B. fusca*, however, is often the predominant species during the first cropping season but becomes scarce during the second season (Schulthess et al. 1997a; Bosque-Pérez, unpubl. data). A similar trend was observed in the present study for *S. calamistis*, a major pest of maize in West Africa but not in Cameroon. In both cases, the reasons for the early decline of pest populations and generally, differences in pest status of various borer species between countries are not known. Schulthess et al. (1997a) theorized that this may be due to differences in human population density - which is especially high in the forest zone of southern Nigeria and the effect of concomitant expansion of agricultural areas on deforestation and thereby, displacement of wild habitats of borers as well as natural enemies. Also, the subsequent changes in plant communities may have favored plants that act as trap plants rather than plants suitable for development of one or the other borer species and vice versa (Schulthess et al., 1997a).

At both locations, *B. fusca* tended to oviposit on maize in the vegetative stage mainly, though at Nkolbisson during the first season some egg batches were



**Fig. 2.** Number of borer larvae and pupae per square meter on maize and elephant grass for a, c) *B. fusca* and for b, d) *E. saccharina* at Minkomeyos and Nkolbisson during 1995 (arrows indicate planting time).

also laid on post-tasseling maize. This corroborates results by Van Rensburg et al.

(1987) who reported that the largest number of *B. fusca* eggs were laid on four to six weeks old maize plants with only 9% of the egg batches laid on older plants. The same trend was observed for *S. calamistis* in field studies in West Africa (Sémeglo, 1997; Sétamou and Schulthess, 1995; Gounou, unpubl. data). Oviposition on plants older than tasseling only took place in laboratory experiments and under overcrowding conditions (Sekloka, 1996). By contrast, *E. saccharina* generally avoids young plants or plant parts (Sekloka, 1996).

Elephant grass did not have significantly higher *B. fusca* egg loads than maize, but mean immature densities per m<sup>2</sup> across age classes were three to nine times higher. This was probably mainly due to higher tiller number as compared to maize. Also, due to its non-deterministic growth pattern, thus continuous availability of plant parts suitable for oviposition and growth and development of young larvae, *P. purpureum* is a much more stable host plant than maize. In addition, larvae have the possibility to emigrate within the same plant or between plants, including maize, in search of more suitable plant parts. Nevertheless, as shown by Shanower et al. (1993), Sekloka (1996) and Sémeglo (1997) in terms of larval survival and adult fecundity of *S. calamistis* and *E. saccharina*, maize is far more suitable than any of the grasses tested. This was partly explained by the high silica content in the leaf epidermis of grasses, which caused high mortality in young larval stages (Sétamou et al., 1993). However, other plant chemicals are also likely to upset physiological balance and may cause incomplete metamorphosis (McDaniel and Berry, 1974; Muthukrishnan and Senthamizhelselvan, 1987 in Senthamizhelselvan and Muthukrishnan, 1991). Thus, if the present data were analyzed according to larval sizes, the differences between the two plant species were not that striking, even considering the much higher number of tillers plus lateral shoots on *P. purpureum*. They were only significant during the second season at Minkomeyos when larval densities were also high. As a net result, numbers of diapausing larvae, which perennuate the pest, and pupae were similar on both plant hosts. Apparently, *P. purpureum* is not an ideal trap plant because larval survival, especially of first instars, is too high. The habit of first instars to migrate to the whorl is very likely a mechanism of dispersion. Thus, if the trap plant is not managed properly, young larvae may even

migrate from the tall grass host onto maize, thereby aggravating the problem. As a consequence, the role of wild grasses and especially *P. purpureum* in the invasion of maize fields by *B. fusca* is more complex than originally thought and may vary with insect and plant host species.

**Table 4. Back transformed least square means after log (count + 1) transformation of counts of *B. fusca*, eggs, larval sizes; small, medium, large and diapausing larvae and pupae per m<sup>2</sup> on *Z. mays* and *P. purpureum* following ANOVA using proc mixed in repeated measures over sampling dates (SAS) at Minkomeyos and Nkolbisson during the first (S1) and second (S2) seasons of 1995.**

	Location	Season	Host plant	LS means	t	P <sub>diff</sub>
Eggs	Minkomeyos	S1	<i>P. purpureum</i>	0.12		
			<i>Z. mays</i>	0.06	0.47	0.65
		S2	<i>P. purpureum</i>	0.46		
	Nkolbisson	S1	<i>Z. mays</i>	0.21	1.48	0.19
			<i>P. purpureum</i>	0.22		
		S2	<i>Z. mays</i>	0.27	-0.34	0.74
Small	Minkomeyos	S1	<i>P. purpureum</i>	0.20		
			<i>Z. mays</i>	0.18	0.13	0.90
		S2	<i>P. purpureum</i>	0.53		
			<i>Z. mays</i>	0.13	2.47	0.05*
	Nkolbisson	S1	<i>P. purpureum</i>	0.14		
			<i>Z. mays</i>	0.06	0.86	0.42
		S2	<i>P. purpureum</i>	0.07		
			<i>Z. mays</i>	0.00	1.70	0.14
Medium	Minkomeyos	S1	<i>P. purpureum</i>	0.31		
			<i>Z. mays</i>	0.02	1.96	0.10
		S2	<i>P. purpureum</i>	1.84		
			<i>Z. mays</i>	0.27	4.10	0.006*
	Nkolbisson	S1	<i>P. purpureum</i>	0.20		
			<i>Z. mays</i>	0.11	1.20	0.28
		S2	<i>P. purpureum</i>	0.32		
			<i>Z. mays</i>	0.00	2.44	0.05*
Large	Minkomeyos	S1	<i>P. purpureum</i>	0.22		
			<i>Z. mays</i>	0.15	0.39	0.71
		S2	<i>P. purpureum</i>	0.86		
			<i>Z. mays</i>	0.16	3.81	0.009*
	Nkolbisson	S1	<i>P. purpureum</i>	0.11		
			<i>Z. mays</i>	0.03	1.17	0.29
		S2	<i>P. purpureum</i>	0.23		
			<i>Z. mays</i>	0.05	2.29	0.06
Diapausing larva plus pupae	Minkomeyos	S1	<i>P. purpureum</i>	0.29		
			<i>Z. mays</i>	0.04	1.72	0.14
		S2	<i>P. purpureum</i>	0.44		
			<i>Z. mays</i>	0.28	1.12	0.31
	Nkolbisson	S1	<i>P. purpureum</i>	0.19		
			<i>Z. mays</i>	0.05	1.62	0.16
		S2	<i>P. purpureum</i>	0.01		
			<i>Z. mays</i>	0.03	-1.06	0.33

\*Significance was set at P<sub>diff</sub> ≤ 0.05. P<sub>diff</sub> = probability of difference in LS means between *P. purpureum* and *Z. mays*.

In life table studies on some common grass species, mortality of early instars of *S. calamistis* and *E. saccharina* are between 97-100% (Shanower et al., 1993; Sekloka, 1996; Séme-glo, 1997), i.e. much higher than indicated by the results

with *B. fusca* on *P. purpureum* in the present study. The presence of alternative (non-crop) host plants can play an important role in the population dynamics of insect pests (Pavuk and Barrett, 1993; Sudbrink and Grant, 1995). Such hosts may hinder control efforts by providing a source of migrants in agricultural fields or by maintaining pests populations when the crop is unavailable. Non-crop hosts can also have a net beneficial effect by providing additional habitats for natural enemies (Messina et al., 1993; Schulthess et al., 1997a; Khan et al., 1997). For example, *S. calamistis* is of low and *B. fusca* of increasing importance in the Dahomey gap in West Africa, characterized by the lack of a forest zone in the south. This is to a large extent due to high *Telenomus* spp. egg parasitism at the beginning of the second season, when maize is attractive to ovipositing female moths and highly susceptible to borer attacks (Sétamou et al., 1995; Chabi-Olaye, 1997; Schulthess et al. 1997a). High parasitism might be due to the high abundance of wild alternative host plants which serve as a reservoir for both borer eggs and parasitoids during the between and the off-season (Schulthess et al., 1997a). In the forest zone, alternative hosts are scarce and egg parasitism erratic (Gounou et al., 1994; See also results of chapter seven). Thus, continuous availability of medium and large larvae on elephant grass would also enhance the activity of larval and pupal parasitoids. Consequently, alternative hosts can act as trap plants, are a reservoir for both pests and natural enemies, or both.

## CHAPTER 3

### **Spatial dynamics of lepidopterous pests on *Zea mays* (Linnaeus) and *Pennisetum purpureum* (Moench) in the forest zone of Cameroon and their implications for sampling schemes**

#### **Introduction**

Sampling procedures for quickly and accurately estimating borer densities with a given reliability are a prerequisite for studies on the effect of key components in a system on the abundance of a pest species, as well as for impact assessments of intervention technologies (Schulthess et al., 1991; Shanower et al., 1991; Gounou et al., 1994; Overholt et al., 1994; Phiri, 1995). Such procedures are usually based on both the within and the between plant distribution (dispersion) of a species. Whereas dispersion is considered a fixed characteristic of a species (Taylor, 1961; Southwood, 1980) the within plant distribution can change over time mostly as a function of the phenology of the plant or of feeding preferences of the various age classes of an insect. This may have implications for the sampling procedures, especially on large plant species for which whole plant sampling is economically not feasible (Southwood, 1980).

Previous studies described the dispersion of various lepidopteran stem and ear borer species on maize and sorghum in West Africa (Schulthess et al., 1991; Shanower et al., 1991), of the pyralid *Chilo partellus* (Swinhoe) at the Kenyan coast (Overholt et al., 1994) and in Malawi (Phiri, 1995). Most of these studies were conducted in Savannah-like environments where alternative wild host plants of borers, mainly grasses, are abundant. However, no data exist for the forest zone where grasses are scarce and maize is probably the main host. In the present work, the within plant distribution and dispersion of various stem borer species with emphasis on *Busseola fusca* (Fuller) (Lep.: Noctuidae) and *Eldana saccharina* (Walker) (Lep.: Pyralidae) on maize and the elephant grass, *Pennisetum purpureum* (Moench) (Poaceae), the most common grass species observed along roads, was studied in the forest zone of Cameroon. Enumerative sampling plans are proposed, based on high and low aggregation indices.

## Materials and methods

### *Data collection*

#### *Population dynamics studies*

Between 1993-95, five 144 m<sup>2</sup> maize plots were planted either surrounded by or adjacent to well established *P. purpureum* fields at two locations, i.e., at Minkomeyos and Nkolbisson in the forest zone close to Yaoundé. In contrast to maize, elephant grass is a profusely tillering species, which also produces lateral shoots. On both plant species, borer populations were followed throughout both cropping seasons and parts of the dry season.

During the last week of August 1993, a maize plot was planted beside a *P. purpureum* field at Minkomeyos. The plots were stratified into four quadrants with ten elephant grass tillers (including lateral shoots) or five maize plants sampled on each sampling date. On both plant species, sampling started three weeks after planting of maize and was carried out at bi-weekly intervals until harvest in December. From January to March 1994, one sample per month was collected on dry maize stalks and elephant grass. In 1995, two maize plots were planted at Minkomeyos and Nkolbisson during the first cropping season. At Minkomeyos, the maize field was planted beside a *P. purpureum* grass field during the last week in March, while at Nkolbisson, the maize plot was surrounded by *P. purpureum* and planted during the first week in May in a farmer's field. For all experiments, the maize variety used was CMS 8704. The maize pockets were spaced at 75 cm between rows and 50 cm within rows with two plants per pocket. The crop was fertilized with urea at a rate of 60kg N/ha four weeks after planting. Two hand weedings were done four and eight weeks after planting. For all experiments a standard sampling protocol was used. Sampling in the grass field started when the maize was one week. On both host plants, samples were taken every four (Minkomeyos) and two weeks (Nkolbisson) until harvest, starting four (Minkomeyos) and three weeks (Nkolbisson) after planting.) During the August dry spell one sample was taken from dry maize stalks and elephant grass tillers at Minkomeyos. For each plant or tiller, the number of *B. fusca* egg batches, larvae and pupae, and numbers of larvae plus

pupae only for other borer species were assessed. *E. saccharina* lays most eggs on debris of the soil and old plant parts (Kaufmann, 1983a; Carter, 1985; Gounou, unpubl. data) making the estimation of egg numbers unreliable. Moreover, other borer species are relatively scarce in the forest zone of Cameroon (Schulthess et al., 1997a; see also results in chapter 2). In the second cropping season, a new maize crop was planted on the same plots during the third week in August at Minkomeyos, and during the first week in September at Nkolbisson. Sampling started in the grassfield when maize was one week old. Thereafter, beginning two weeks after maize planting, the same sampling procedures as during the first season were used to sample for borers at bi-weekly intervals until harvest of maize ears in December 1995. As from January 1996, one sampling per month was done on maize stalks without ears and grass tillers till March 1996, at both Minkomeyos and Nkolbisson.

In 1993/94, insect counts were done on a per plant basis, whereas in the 1995/96 experiments, *B. fusca* egg batches, and *B. fusca* and *E. saccharina* larvae and pupae on maize, and *B. fusca* immatures only on elephant grass, were counted according to feeding sites (referred to as strata). For *P. purpureum* the strata were: 1 = whorl leaves, 2 = stem below the whorl, 3 = green older stem, 4 = partly woody stem, and 5 = woody stem. For maize they were: 1 = whorl leaves, 2 = stem below the whorl before ear formation, 3 = stem below the ear, 4 = stem above the ear, 5 = ear, and 6 = tassels. The larvae and pupae of other borer species were counted on a per plant basis.

Three physiological growth stages were distinguished for maize; the vegetative stage (up to nine weeks after planting ; strata 1-2), the reproductive phase (10 – 16 weeks after planting ; strata 3-6) and dry maize stalks thereafter.

#### *Surveys in farmers' fields*

From May 16 to June 7, 1995 (first season), and October 10 to November 2, 1995 (second season), 148 farmers' fields in the vegetative growth stage were sampled for *B. fusca* egg batches. Fifty maize plants per field were randomly sampled for assessment of number of *B. fusca* egg batches per plant, and proportion of plants infested with egg batches (for more information on the sampling procedure for *B. fusca* egg batches see Sétamou and Schulthess, 1995).

During maize harvest in the second season of 1994, and first and second seasons of 1995, a total of 180 fields were visited and sampled for borer incidence. In each field, fifteen maize plants were sampled at random and assessed for number of borer larvae and pupae according to species.

During the off-seasons of 1995, from August 18 to September 15, and in 1996 from February 5 to 15, the same fields were revisited to assess abundance of borer larvae and pupae in maize stalks after harvest of ears.

#### *Statistical analyses*

##### *Within plant distribution of B. fusca and E. saccharina*

Proc genmod of the Generalized Linear Model (SAS, 1997) was used to analyze the within plant distribution of *B. fusca* egg batches, larvae and pupae on maize and elephant grass, and on maize only for *E. saccharina* across sampling dates at Minkomeyos and Nkolbisson during 1995. For *Z. mays* the analyses of within plant distribution of borers over time were done separately for the vegetative growth stage (strata 1-2), the reproductive phase (3-6) and dry stalks after harvest.

##### *Dispersion and sampling plans*

Taylor's (1961) power law was used to describe the dispersion of *B. fusca* egg batches, and of larvae and pupae of all borer species on maize and elephant grass. This law postulates a consistent relationship between variance  $S^2$  and mean  $m$ :

$$S^2 = am^b \quad (1)$$

where  $b$  is a measure of dispersion of the species, with  $b > 1$  indicating an aggregated distribution,  $b = 1$  randomness and  $b < 1$ , regular distribution, while  $a$  is considered a mere scalar factor without biological meaning. These coefficients were computed by regressing the natural logarithm of the between plant variance ( $\ln S^2$ ) against the natural logarithm of mean density ( $\ln m$ ), for each field or sampling occasion. The General Linear Model (SAS, 1997) was used to compare the  $b$ -values.

Wilson and Room's (1983) incorporated Taylor's coefficients ( $a$  and  $b$ ) in a model that described the relationship between the proportion of infested plants [ $P(I)$ ] and mean density ( $m$ ) where:

$$P(I) = 1 - e^{-m \ln(a m^{b-1}) / (a m^{b-1} - 1)} \quad (2)$$

(e is the base of natural logarithms). According to Wilson (1982), both a and b are needed to describe dispersion of a species, i.e., the more aggregated a species, the smaller P(I) for a given mean. Thus, in addition to comparing slopes the above model was used to visually compare dispersion of age classes and species.

Wilson and Room (1983) also incorporated Taylor's power law in an enumerative sampling procedure by replacing the variance  $S^2$  in Karandino's (1976) equation with  $am^b$ .

$$N = \left( \frac{Z_{\alpha/2}}{D} \right)^2 am^{b-2} \quad (3)$$

where N is the number of samples to be taken, D the reliability level expressed as a fixed proportion of the mean (0.2 and 0.3 for this work), and  $Z_{\alpha/2}$  is the standard normal deviation (1.65 for  $n > 100$ ) and confidence coefficient of 0.9.

The percentage of cases with more than one *B. fusca* egg batch per plant (y) was regressed with egg batch density in a field (x).

### Results and discussion

Five borer species, the stemborer *B. fusca*, *E. saccharina*, *Sesamia calamistis* (Hampson) (Lep.: Noctuidae) and the cobborers *Mussidia nigrivenella* (Ragonot) (Lep.: Pyralidae) and the tortricid *Cryptophlebia leucotreta* (Meyrick) were found on maize while four species, *B. fusca*, *S. calamistis*, *E. saccharina* and *Poenoma serrata* (Hampson) (Lep.: Noctuidae), were found on elephant grass. The within-plant distribution and dispersion of immatures depend to a large extent on the oviposition behaviour of adults. *B. fusca* and *S. calamistis* lay their egg batches on the inner side of leaf sheaths (Kaufmann, 1983a). *S. calamistis* first larval instars bore directly into the stem, whereas *B. fusca* migrate to the whorl, and either disperses or bores into the stem from the top after feeding on the whorl leaves causing the typical 'windows'. *Eldana saccharina* eggs are mainly laid on ground debris (Atkinson, 1980) and young larvae migrate from the ground to the plant. Both *M. nigrivenella* and *C. leucotreta* lay their eggs on husks and silk of the ear, and the larvae enter the ear via the silk channel (Moyal and Tran, 1989). All stem

borers are also feeding in the ear but ear borers are very rarely found in the stems. *P. serrata* is a little known monophagous species which, so far, was only found on *P. purpureum* (Bowden, 1976; Polaszek, 1998; Khan, 1998). This is the first report from Central Africa.

**Table 1. Sources, log likelihood chi square and probabilities for within plant distribution of counts of *B. fusca* egg batches, larvae and pupae and *E. saccharina* larvae and pupae following proc genmod (GLIM) on *P. purpureum* and *Z. mays* at Minkomeyos and Nkolbisson during 1995. Sampling date was used as a continuous variable because sampling time was equally spaced within a season.**

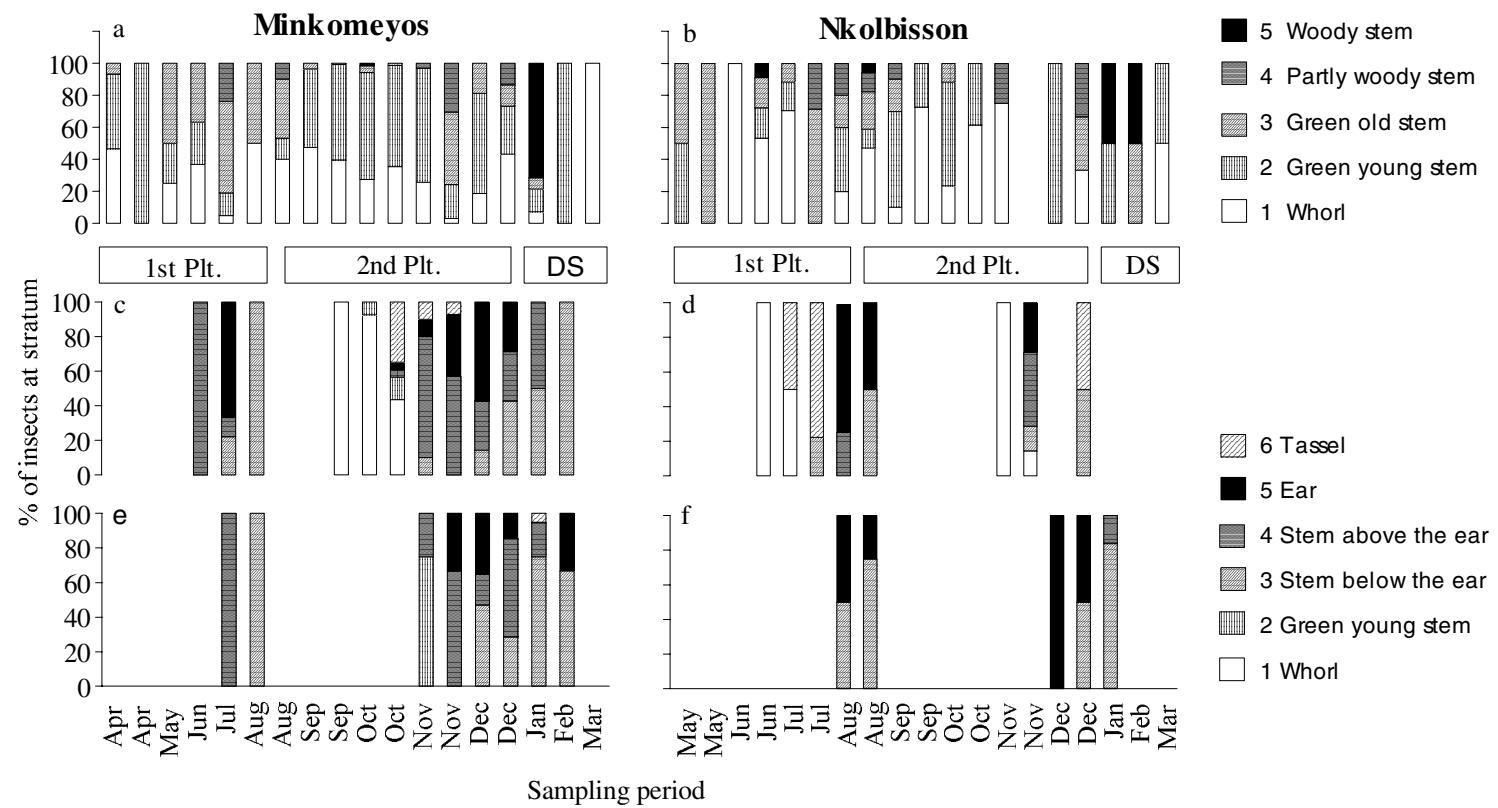
Borer species	Sources	First season				Second season			
		Minkomeyos	Nkolbisson	Minkomeyos	Nkolbisson	Minkomeyos	Nkolbisson	Minkomeyos	Nkolbisson
<i>B. fusca</i>	<b><i>P. purpureum</i></b>	$\chi^2$	P	$\chi^2$	P	$\chi^2$	P	$\chi^2$	P
<b>Egg batches</b>									
Sampling date	id	id	0.76	0.3822	3.44	0.0635	6.94	0.0084	
Stratum	id	id	34.79	0.0001	22.69	0.0001	26.82	0.0001	
Sampling date x Stratum	id	id	1.16	0.8839	0.00	1.0000	id	id	
<b>Larvae and pupae</b>									
Sampling date	6.4	0.0114	2.8	0.0954	49.9	0.0001	18.5	0.0001	
Stratum	40.5	0.0001	33.5	0.0001	326.5	0.0001	70.9	0.0001	
Sampling date x Stratum	id	id	4.3	0.3640	13.6	0.0087	0.2	1.0000	
<b><i>Z. mays</i> vegetative</b>									
<b>Egg batches</b>									
Sampling date	id	id	id	id	10.33	0.0013	5.35	0.0207	
Stratum	id	id	id	id	8.32	0.0039	8.32	0.0039	
Sampling date x Stratum	id	id	id	id	id	id	id	id	
<b>Larvae and pupae</b>									
Sampling date	id	id	5.4	0.0207	82.8	0.0001	id	id	
Stratum	id	id	8.3	0.0039	36.61	0.0001	id	id	
Sampling date x Stratum	id	id	id	id	id	id	id	id	
<b><i>Z. mays</i> reproductive</b>									
<b>Egg batches</b>									
Sampling date			0.54	0.4629					
Stratum			16.64	0.0008					
Sampling date x Stratum			id	id					
<b>Larvae and pupae</b>									
Sampling date	7.4	0.0067	4.0	0.0462	0.9	0.3579	id	id	
Stratum	8.7	0.0332	4.6	0.2001	10.1	0.0176	id	id	
Sampling date x Stratum	3.7	0.2922	id	id	22.5	0.0001	id	id	
<i>E. saccharina</i>	<b><i>Z. mays</i> reproductive</b>								
Sampling date	id	id	0.0	1.0000	7.6	0.0060	id	id	
Stratum	id	id	11.6	0.0089	16.4	0.0009	id	id	
Sampling date x Stratum	id	id	0.5	0.9098	0.3	0.9685	id	id	

Significance was set at P ≤ 0.05, id = data insufficient for generation of analysis

#### *Within plant distribution of B. fusca and E. saccharina over time*

Because of insufficient data due to low insect densities of other species, within plant distribution is described only for *B. fusca* and *E. saccharina* on maize, and additionally for *B. fusca* on elephant grass.

On elephant grass, egg batch numbers varied significantly between plant strata (Table 1) with 74.2 and 24.2% found on green young and green old stem,



**Fig. 1.** Percentage within plant distribution during the first (1st Plt), second (2nd Plt) and dry season (DS) of *B. fusca* larvae and pupae on a, b) *P. purpureum* (Strata 1-5), and on c, d) *Z. mays* (Strata 1-6 with 1-2 vegetative stages) and e, f) percentage within plant distribution of *E. saccharina* larvae and pupae on *Z. mays* at Minkomeyos and Nkolbisso in 1995.

respectively (data not shown). Likewise, *B. fusca* larvae plus pupae numbers varied significantly between strata at both locations (Table 1) except in the dry season when most larvae were in diapause (not shown in table 1). During the cropping season, most larvae and pupae were found in the younger plant parts, indicating a preference for vegetative stems (Fig. 1a and b). However, the dynamics of within plant distribution suggests a movement from younger to older plant parts as the larvae grow older, though the sampling date x stratum interactions were only significant for Minkomeyos during the second season (Table 1). For most sampling dates, larvae were found in the whorl and green young stems. Since only young larvae feed in the whorl after emigrating from the oviposition site between the leaf sheath and the stem (Kaufmann, 1983a), oviposition took place throughout the season. *B. fusca* tends to oviposit on young plant parts only (Chapter 2). *P. purpureum* produces tillers and lateral shoots during the entire season, therefore providing a stable habitat for both pests and natural enemies.

On maize during the second season at both locations, and at silking (reproductive stage) during the first season at Nkolbisson, egg batch numbers varied significantly between plant strata (Table 1), with 61.5 and 38.5% found on green young and green old stem (strata 2 and 3), respectively (data not shown in Table 1). Thus, on both plant species, the within plant distribution indicated a strong oviposition preference for young plant parts, as also shown for *S. calamistis* (Sétamou and Schulthess, 1995). Significant differences in both *B. fusca* and *E. saccharina* larvae plus pupae numbers were found during the vegetative as well as reproductive phases, except for *B. fusca* larvae and pupae in the reproductive phase at Nkolbisson in the first season (Table 1). For Minkomeyos in the first season and Nkolbisson during the second season, data were often not sufficient for a meaningful analysis. Again for *B. fusca*, with increasing age of plant and insect, the borers tended to move from young to old plant parts including the ear (Fig. 1c and d). This was especially so in Minkomeyos during the second season, as shown by the significant sampling date x stratum interaction for larvae and pupae in the reproductive phase. Because maize does not tiller and thus lacks young plant parts suitable for *B. fusca*

oviposition at and after tasseling, occupation of the whorl and the green young stem is restricted to a relatively short period during plant growth (Fig. 1 c, d). Thus maize is an unstable habitat for both the pest and its natural enemies. For *E. saccharina*, significant differences in within plant distribution on maize were found during the first and second season at Minkomeyos and Nkolbisson, respectively (Table 1). No larvae were found in the whorl and rarely in the green young stem (Fig. 1e and f). This insect lays the eggs on debris on the soil or on old leaves and attack before tasseling is rare (Kaufmann, 1983a). This is also shown in Fig. 1 by the zero data during the vegetative period. During the dry season, the non-diapausing *E. saccharina* is often found feeding on dry maize stems showing again its preference for and suitability of older plant parts (Atkinson, 1980; Kaufmann, 1983a). *E. saccharina* was very rarely found on *P. purpureum* and maize is probably its major overwintering host in the forest zone.

For both host plant species, none of the strata proved to be a stable indicator for pest populations. It is therefore recommendable to sample larvae and pupae on whole plant or whole tiller for maize and elephant grass, respectively. However, sampling for *B. fusca* egg batches on maize should be done on green young stems, and the stem below the ear at or after silking, and on elephant grass, on green young stem and the green old stem.

#### *Between plant distribution*

Table 2 gives Taylor's coefficients for immatures of the different borer species on maize at various growth stages and on elephant grass. Only *B. fusca* egg batches on maize and diapausing larvae and pupae of *B. fusca* in dry stalks of maize, showed a random distribution (slopes not significantly different from 1 following t-test; Table 2). In all other cases, an aggregated distribution on both host plant species was recorded, with *M. nigrivenella* on maize exhibiting the highest ( $b = 1.73$ ) and *B. fusca* egg batches on elephant grass the lowest ( $b = 1.15$ ) aggregation (Table 2). Van Rensburg and Pringle (1989) observed an aggregated distribution of *B. fusca* egg batches - as indicated by a significant fit of the negative binomial distribution - on maize in South Africa. By contrast, Sétamou and Schulthess (1995) found that *S. calamistis* egg batch distribution on maize was regular. Thus, female *S. calamistis* very rarely oviposit more than one egg

**Table 2. Taylor's coefficients for lepidopterous borers on maize and elephant grass in the forest zone according to maize growth stage with mean density range and mean density at a proportion of infested plants of 0.90 [mP(0.90)]**

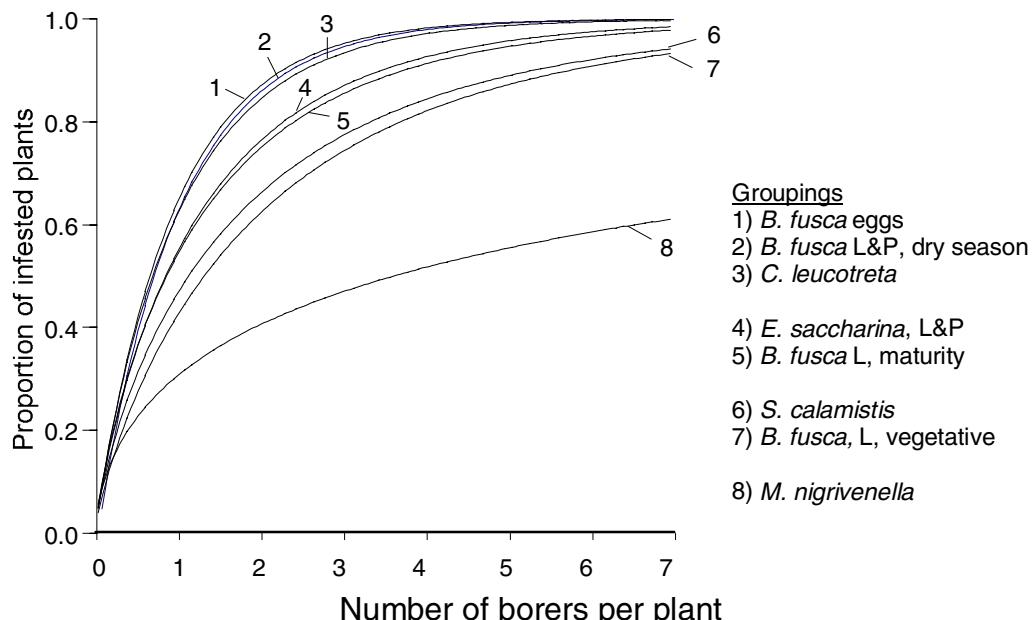
Plant	Species	Stage	Plant stage	a	b	R <sup>2</sup>	P > F	density	m P(0.90)
<i>Z. mays</i>	<i>B. fusca</i>	E	vegetative	1.26	1.06 ± 0.04c*	0.84	0.0001	0 – 0.78	2.7
	<i>B. fusca</i>	L	vegetative	3.62	1.29 ± 0.01b	0.96	0.0001	0 – 3.95	6.6
	<i>B. fusca</i>	L, P	maturity	1.99	1.31 ± 0.03b	0.93	0.0001	0 – 6.93	4.3
	<i>B. fusca</i>	L, P	dry stalks	1.23	1.04 ± 0.07c*	0.83	0.0001	0 – 2.47	2.6
	<i>E. saccharina</i>	L, P	across	2.12	1.27 ± 0.05b	0.89	0.0001	0 – 2.73	4.3
	<i>S. calamistis</i>	L, P	across	2.88	1.36 ± 0.07a	0.92	0.0001	0 – 0.35	6.1
	<i>M. nigrivenella</i>	L, P	reproductive	6.53	1.73 ± 0.05a	0.94	0.0001	0 – 0.87	62.6
	<i>C. leucotreta</i>	L, P	reproductive	1.37	1.12 ± 0.04b	0.91	0.0001	0 – 0.73	2.9
<i>P. purpureum</i>	<i>B. fusca</i>	E	across	1.72	1.15 ± 0.07	0.91	0.0001	0 – 0.20	3.4
	<i>B. fusca</i>	L, P	across	2.04	1.21 ± 0.03	0.90	0.0001	0 – 0.88	4.0
	<i>S. calamistis</i>	L	across	2.05	1.20 ± 0.08	0.94	0.0001	0 – 0.13	3.9
	<i>E. saccharina</i>	L	across	2.16	1.21 ± 0.05	0.90	0.0001	0 – 0.10	4.1
	<i>P. serrata</i>	L, P	across	1.44	1.10 ± 0.05	0.95	0.0001	0 – 0.35	3.0
	Across	E, L, P	across	1.99	1.20 ± 0.02	0.92	0.0001	0 – 0.88	

Significance was set at P ≤ 0.05. \*c= slopes not significantly different from 1 following t-test, but significantly different from the other b-values for borer species on maize, following comparisons using proc GLM (SAS); b-values followed by the same letter were not significantly different from each other following comparisons using proc GLM on SAS within plant species. (E = eggs, L = larvae, P = pupae).

batch per plant and avoid already occupied plants. In the present study, the percentage of cases with more than one *B. fusca* egg batch per plant (y) increased significantly with egg batch density in a field (x) ( $y = 45.28x + 4.29$  ( $r^2 = 0.15$ ,  $P < 0.01$ ). This indicates that multiple egg batches are the result of overcrowding, a situation more likely to occur in the forest zone where suitable host plants are relatively scarce as compared to savanna type situations. More than one egg batch per plant may also mean more than one species and/or egg batches of various ages. Female moths mark their batches to indicate that the plant is already occupied (Kaufmann, 1983a). They may not recognize the kairomones of another species or old markings of the same species. Sétamou and Schulthess (1995) concluded that in view of the limited migration of *S. calamistis* (Kaufmann, 1983a), combined with the low carrying capacity of the natural host plants of borers, i.e., thin-stemmed grasses mainly, the regular distribution of egg batches increases the chances of survival for the larvae. By contrast, *B. fusca* larvae migrate to the whorl and disperse at an early stage. Thus an aggregated distribution of egg batches would not compromise survival of immatures. Likewise, Pats and Ekbom (1992) and Berger (1994) found that the maize plant on which a *C. partellus* female oviposits is not the only resource for her offspring; all other plants within the larval dispersal radius (30-70 cm in their study) can also serve as host plant.

In contrast to *B. fusca* egg batches, aggregation of larvae, during both the vegetative and reproductive stages of maize, tended to be higher on maize than elephant grass. This may be a result of differences in plant architecture, i.e. non tillering versus profusely tillering growth habit of maize and elephant grass, respectively, which facilitates movement of larvae between plants or plant parts on the latter. On dry maize stalks, the dispersion coefficient for *B. fusca* was random. This may have been because of the absence of the ear after harvest, thus removal of borers. However, unsuitable food sources may also initiate diapause or extended developmental time in some individuals which increases the time of exposure to predation or infection by diseases, thereby leading to a more random distribution.

Using Wilson and Room's (1983) model (equation 2), four groupings were identified on maize with *B. fusca* egg batches, *B. fusca* larvae plus pupae on dry stalks and *C. leucotreta* having the lowest and *M. nigrivenella* the highest aggregation (Fig. 2).

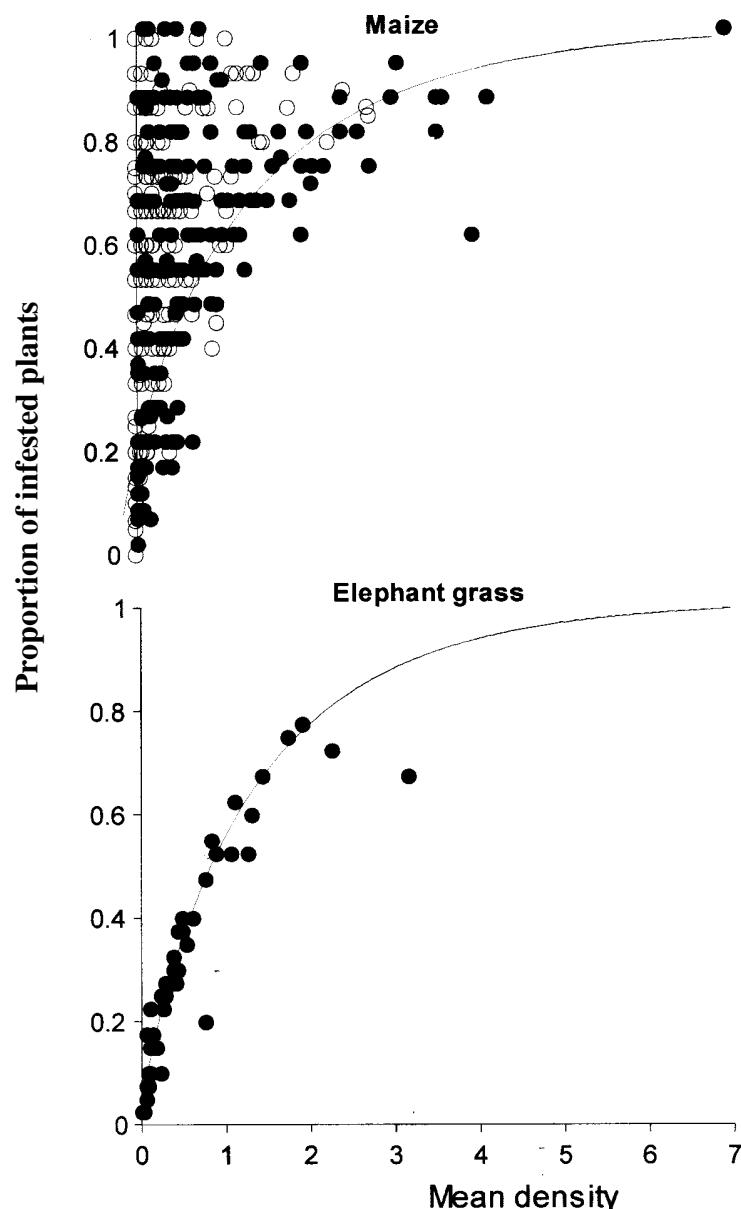


**Fig. 2. Groupings according to aggregation behaviour using Wilson & Room's (1983) model (equation 2 in the text) to describe the relationship between proportion of infested plants and mean density; L = larvae, P = pupae, vegetative and reproductive stage of maize.**

On elephant grass, no groups could be distinguished. These groupings were also confirmed by the calculated mean densities at  $P(I) = 0.90$ , the break off point for binomial sampling as proposed by Schulthess et al. (1991) for stem borers (Table 2). A statistical comparison of b values gave different groupings, though the trends were similar with no significant differences in b's observed on elephant grass (Table 2). With both methods, *S. calamistis* was not in the same group with *B. fusca* and *E. saccharina*, with higher aggregation for the former. Again, the differences in dispersion are the result of differences of migration behaviour of young larvae.

With the exception of *M. nigrivenella* that was highly aggregated on maize, all the other Taylor's coefficients for the various species are comparable to those reported on maize in other parts of West Africa (Schulthess et al., 1991; Shanower

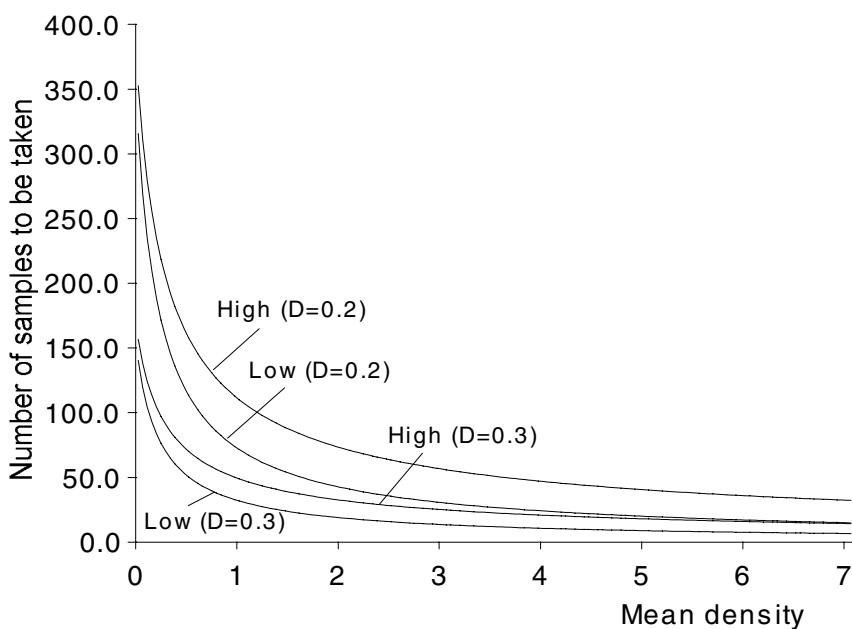
et al., 1991). *M. nigrivenella* is a highly polyphagous species found on 19 hosts, mostly tree species, of 14 different families (Sétamou, 1996). Those host plants are common in the savannas but rare in the forest and transition zone, which may affect its oviposition behaviour and thus dispersion.



**Fig. 3.** Proportion of infested plants as a function of mean density on maize and elephant grass after equation 2; — calculated; ● *B. fusca*; ○ *E. saccharina*

### Sampling plans

In contrast to *P. purpureum*, the fit of Wilson and Room's (1983) model to observed *B. fusca* and *E. saccharina* densities on maize was poor (Fig. 3). Most fields were sampled around harvest when many of the insects had migrated, hatched and left the plant as indicated by the many zero data. Thus for maize, binomial sampling plans based on presence-absence data are probably only useful for the vegetative stage of the plant. When pest populations are in the decline the model does not represent actual but rather past population densities. Also, as *B. fusca* larvae migrate between plants the proportion of infested plants will increase for the same density of pest. During the vegetative stage, assessment of presence of *B. fusca* would be easy because of the typical 'window' damage on leaves caused by young larvae. More data are needed, however, to determine which binomial sampling procedure would accurately estimate pest densities on maize during the vegetative phase. For estimating *B. fusca* densities on *P. purpureum* Wilson and Room's (1983) model can be used and it is proposed to sample 100 tillers for P(I) estimates.



**Fig. 4.** Optimum sample size as a function of mean density for highly aggregated (not including *M. nigrivenella*), and lowly aggregated and randomly distributed insects using precision levels of D=0.2, 0.3

Since *B. fusca* is the most important pest and multiple species infestations are common, *B. fusca*'s Taylor's coefficients during the reproductive stage of maize (Table 2) were used for development of enumerative sampling for all species (Fig. 4). *M. nigrivenella*, a relatively unimportant and highly aggregated species, was not considered in these sampling schemes. For estimating, e.g., a mean density of 1 borer per plant with a precision of  $D = 0.3$  ca 60 and 40 stalks for highly and lowly aggregated insects/stages would be required. For lower densities the number increases exponentially. In small scale farming systems common in the forest zone in Cameroon, such an intensive sampling scheme is only feasible if the farmer has previously been contacted by the researcher and/or is reimbursed for samples taken (Cardwell et al., 1997) and not for fast country-wide survey work. For *B. fusca*, the assessment of the impact of an intervention technology, and especially biological control, should concentrate on egg batch numbers because their random distribution require relatively low numbers of samples for estimating densities accurately and, moreover, with some experience can be done visually without destruction of the plant.

## CHAPTER 4

### **Distribution and relative importance of lepidopterous maize borers in the forest zone and mid-altitude in Cameroon**

#### **Introduction**

Across Africa, there are marked differences in the distribution, incidence and severity of lepidopterous maize borers (Swaine, 1957; Smithers, 1960; Ogwaro, 1983; Van Rensburg et al., 1988; Gebre-Amlak et al., 1989; Seshu Reddy et al., 1990; Bosque-Pérez and Mareck, 1990; Ndemah, 1990; Van den Berg et al., 1991; Gounou et al., 1994; Overholt et al., 1994; Phiri, 1995; Cardwell et al., 1997; Schulthess et al., 1997a). Whereas the occurrence of several *Sesamia* and *Chilo* species is limited to western and eastern Africa, respectively, *Sesamia calamistis* (Hampson) (Lep.: Noctuidae), *Busseola fusca* (Fuller) (Lep.: Noctuidae) and *Eldana saccharina* (Walker) (Lep.: Pyralidae) are found throughout sub-Saharan Africa. Their pest status, however, not only varies with region and ecozone but often between countries within a region (Schulthess et al., 1997a). Possible reasons besides climate are existence of geographic races with different climatic requirements and/or adapted to different host plants, differences in natural enemies complexes, and in human population densities resulting in expansion of agricultural areas and thereby displacement of natural habitats. This may affect the population dynamics of both borers and natural enemies (Schulthess et al., 1997a).

In the past five years, increasing emphasis was given to forms of biological control, especially the 'redistribution' approach (i.e., increasing the geographic range of species or strains of natural enemies) to combat cereal stem borers in Africa (Schulthess et al., 1997a). Given similar climatic conditions, differences in pest status of a given species may indicate presence or absence of biotic control factors (Coppel and Mertins, 1977; Ferris and Ferris, 1985; Schulthess et al., 1997a). Thus a prerequisite for identification of factors suppressing or enhancing pest population densities is the knowledge of the geographic distribution and pest status of individual borer species on a country and region-wide basis. The objectives of the present study were to assess the relative importance, as well as

seasonal fluctuations of several borer species in the forest and mid-altitude zones of Cameroon and to compare them to other countries in Africa. High pressure areas identified will also be used later on for researching and testing implementation technologies including the development of techniques to achieve uniform field infestation required for host plant resistance screening, which are affordable to national programs (Schulthess et al., 1997a; Schulthess and Ajala, 1999).

In Cameroon, past surveys concentrated on roadside fields (Cardwell et al., 1997) which, ecologically and socio-economically, may not be representative for conditions in farms away from major roads. Roadside fields in open, deforested areas are often surrounded by a grassy vegetation, i.e., which might harbor alternative wild hosts of borers, which may affect species composition and the population dynamics of individual borer species and their natural enemies (Cardwell et al., 1997; Schulthess et al., 1997a; Chapter two). Thus, the present work was carried out in fields inside the forest and the key question was how vegetation type affected pest incidence.

## **Materials and methods**

### *Data collection*

#### *Establishment of benchmark sites*

During 1992, a resource management survey was conducted by the International Institute for Tropical Agriculture (IITA) and the Institute of Agronomic Research for Development (IRAD) in the Center and South Provinces of Cameroon. The forest zone map was divided into 10 x 10 minute cells and the centermost village in each of the cells chosen as the sample village. The sample villages were grouped by demography into blocks: Yaoundé, Mbalmayo, Ebolowa and Ambam. In the present work, only the Yaoundé, Mbalmayo and Ebolowa blocks were considered. The highest population density was 88, 41 and 15 inhabitants per km<sup>2</sup> in the Yaoundé, Mbalmayo and Ebolowa block, respectively, with an average fallow period of respectively 3.9, 5.4 and 7 years (EPHTA, 1996). In each block, two villages (herewith referred to as locations) contrasting in population density and fallow period were chosen making a total of

six benchmark locations: Nkometou III and Etoud in the Yaoundé block, Mvoutessi II and Ngat in the Mbalmayo block, and Mengomo and Akok in the Ebolowa block (Table 1).

The forest zone has a bimodal rainfall distribution, the first lasting from March to mid-July (herewith referred to as first season) and the second from mid-August to November (second season), while the unreliable August break is from mid-July to mid-August. The August break is a dry spell between the first and second rainy seasons. The second dry season is from mid-November to end of February. Average annual temperatures are around 23.5°C.

**Table 1. Major characteristics of blocks and benchmark locations in the forest zone**

Block	Benchmark	Major characteristics
Mbalmayo	Ngat	Ngat is off the main road, Mvoutessi II is along the main road. For this block, the highest demographies are 41 inhabitants/km <sup>2</sup> and average fallow periods are about 5.4 years.
	Mvoutessi II	
Yaoundé	Nkometou III	Nkometou III is along the main road, Etoud is off the main road.
	Etoud	Both locations are close to the Yaoundé market. For this block, the highest demographies are 88 inhabitants/km <sup>2</sup> and average fallow periods are about 3.9 years.
Ebolowa	Mengomo	Mengomo is along the main road leading to Gabon, Akok is off the main road. For this block, the highest demographies are 15 inhabitants/km <sup>2</sup> and average fallow periods are about 7 years.
	Akok	

In the mid-altitude, there is uniformly high population density and maize is intensively grown year after year. One block only was established and the single criterion for choosing benchmark locations was cultivation of two maize crops per year. The locations were Bali, Bamunka and Njinikom (Fig. 4, Chapter one). The mid-altitude has unimodal rainfall pattern with two seasons, a rainy season from mid-March to late October and a dry season from November to mid-March. Average annual rainfall range from 1,300 to 4,000 mm. Although two maize crops could be grown in a year, this is done only in a few locations. Usually in August before the crop planted in March/April is ready for dry harvest, the second crop is planted. Average annual temperatures are about 20°C.

#### *1994, 1995 surveys in the forest zone*

Surveys were conducted from May 16 to June 7, 1995 (first season) and October 10 to November 2, 1995 (second season). Fifty maize plants per field

were randomly sampled from 148 farmers' fields (minimum of 12 fields per location chosen at random) in the vegetative stage for assessment of number of *B. fusca* egg batches per plant, egg batch size and percent plants infested with egg batches. *E. saccharina* lays most eggs on debris of the soil and old plant parts (Kaufmann, 1983a; Carter, 1985; Gounou, unpubl. data) making the estimation of egg numbers unreliable, and other species are relatively scarce in the forest zone of Cameroon. Vegetation surrounding each field was categorized as bush fallow, predominantly with *Chromolaena odorata* (Linnaeus) (Asteraceae), young forest, mature forest and 'other' (often other fields cultivated with maize, cassava and/or plantain) using an abundance score ranging from 0 to 4 (0 = none, 4 = 100%). It should be noted that new fields were planted each season, thus mean vegetation scores for a location could change with season.

During the crop reproductive phase (kernel soft dough to maturity) in the second season of 1994, first and second seasons of 1995, a total of 180 fields were sampled in a second survey (Table 2). The 1995 fields were the same ones that were visited during the vegetative phase and 15 maize plants were sampled at random and assessed for number of borer larvae and pupae per species and percent of plants infested following the research protocol developed by Cardwell et al. (1997).

#### *1996, 1997 surveys in the mid-altitude*

In the three locations in the mid-altitude, in the first (May 20-27) and second seasons 1996 (September 16-23), 65 maize fields in the vegetative phase were assessed for *B. fusca* egg batch infestation, batch size, and percent plants infested with eggs as in the forest zone.

During the crop reproductive phase in the first (July 15-20) and second cropping seasons of 1996 (November 24-29), and first cropping season of 1997 (July 14-19) 15 maize plants in each of 91 farmer' fields were assessed for borer larvae and pupae numbers and percent infestation. In 1996 the same fields were revisited during the reproductive phase and the same data parameters were collected.

### *Statistical analyses*

Depending on the analyses, plants, fields, locations or blocks were used as units. Principal component analysis (PCA) was used to determine if vegetation categories were associated with benchmark location and block (Afifi and Clark, 1990). The first two principal component (PC) eigenvalues accounted for more than 80% of the variation in the system for both the first and second seasons, so interpretations were limited to these two eigenvectors only. The level of acceptance for PC coefficients were 0.29, 0.47 for PC1 and PC2 respectively for the first season, 0.26, 0.48 for PC1 and PC2 respectively for the second season calculated according to Afifi and Clark (1990). These values were plotted giving

**Table 2. Plant growth stage and number of fields surveyed according to season and year in the forest zone and mid-altitude**

Zone	Season and year	Maize growth stage	No. of fields surveyed
Forest	Second, 1994	Reproductive	48
	First, 1995	Vegetative	77
	Second, 1995	Reproductive	68
		Vegetative	71
		Reproductive	64
Mid-altitude	First, 1996	Vegetative	35
	Second, 1996	Reproductive	31
		Vegetative	30
	First, 1997	Reproductive	24
		Reproductive	36

an indication of which vegetation variables were more or less prevalent by location in each season. Proximity on the graph indicates that the locations were similar in vegetation category and abundance. For the graph, the x- axis was PC1 and the y- axis, PC2.

A mixed model (SAS, 1997) was used to analyze differences in borer variables (egg batches per plant, eggs per egg mass, percent of plants infested with egg batches, larvae and pupae as well as percent of plants infested at harvest) by season, year, block, and location. Season, year and block were fixed effects while field and location and location interactions were random. Plants were nested within fields, fields within season, season within location and location within blocks. Counts of borer variables were log x + 1 and percentage data were arcsin

square root transformed before analyses.

Pearson correlations were computed to investigate interactions between insect variables within (vegetative/reproductive phase) and between seasons using per field and per location means, respectively.

Canonical correlation analysis (CCA) was used to investigate associations between *B. fusca* egg infestation during the vegetative stage, with borer species at harvest, and surrounding vegetation across locations in the first and second seasons of 1995, in the forest zone only (SAS, 1997).

## Results

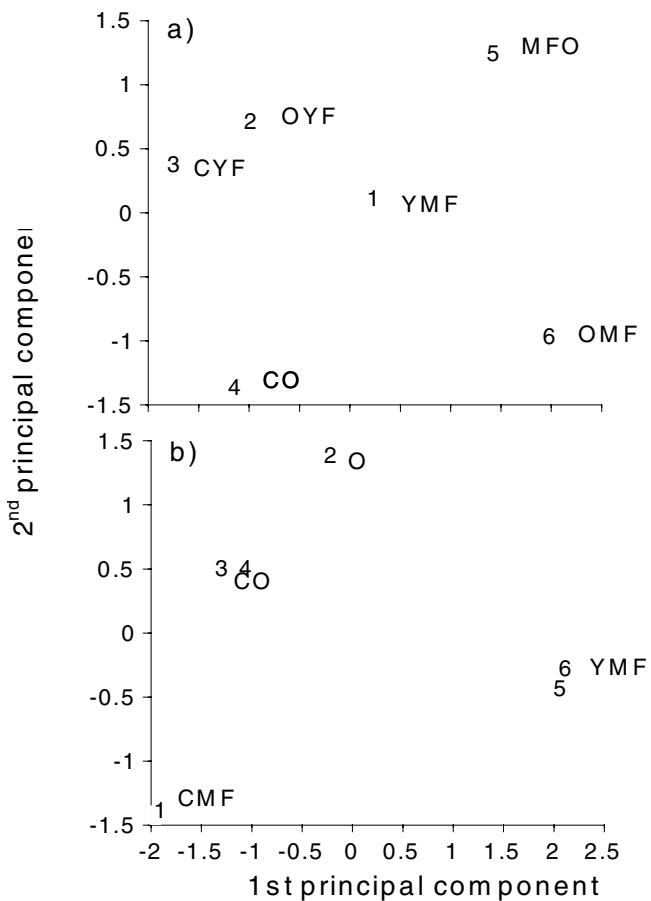
### *Predominance of vegetation types in the benchmarks*

During the first season of 1995 in the forest zone, the six benchmark locations were not similar to each other as far as vegetation in the surroundings of fields was concerned (Fig. 1). For PC1, there was more *C. odorata* as we moved from left to right of the x-axis, while for PC2, there was more of other vegetation type as we moved up the y-axis. In the second season two groupings emerged corresponding to two blocks: the Yaoundé block with Nkometou III and Etoud locations, with predominance of *C. odorata*, and the Ebolowa block with Mengomo and Akok locations, with predominantly young and mature forest in the surroundings of fields (results from PCA not shown; Fig. 1). No grouping was found for the Mbalmayo block, which represents a transition between the two other blocks.

The ANOVA revealed no significant block effects even when crop stage (i.e., time the fields were visited) was included as covariate, which would affect insect variables. For all variables, most of the overall variance (47-99%) could be attributed to within-field variability (Tables 4-7).

### *The relative importance of stem borer species*

In the forest zone, *B. fusca* and *E. saccharina* accounted for more than 80% of all species in almost all locations, followed by the cob borers *Mussidia nigrivenella* (Ragonot) (Lep.: Pyralidae) and *Cryptophlebia leucotreta* (Meyrick)



**Fig. 1. Component scores on principal component axes 1 and 2 for vegetation types in the vicinity of maize fields during the a) first and b) second season in the forest zone of Cameroon (1 = Ngat, 2 = Mvoutessi II, 3 = Nkometou, 4 = Etoud, 5= Mengomo, 6 = Akok, Y, M, F = young, mature forest, C = Chromolaena, O = Other vegetation).**

(Lep.: Tortricidae) (Table 3). *B. fusca* tended to be the most predominant species during the first and *E. saccharina* during the second season, except in Nkometou III where *B. fusca* was always the dominant species. *Sesamia calamistis* was found in almost all locations during the first season, but disappeared in most locations in the second season in 1995.

In the mid-altitude, *B. fusca* was the predominant species, except in Bali where an unknown *Chilo*-like species was the most important during both the first and second seasons. *E. saccharina* was completely absent (Table 3). In many locations, *S. calamistis* was the second most important species and the cob borers *M. nigrivenella* and *C. leucotreta* were of similar importance.

**Table 3. Relative percent of lepidopterous borer species at harvest of maize in 9 benchmark locations in the forest zone (1994, 1995) and mid-altitude (1996, 1997) during the first (S1) and second (S2) seasons.**

Zone	Year	Season	Location	B.f.	E. s.	S. c.	M.n.	C. l.	Oth.
Forest	1994	S2	Ngat	44.9	38.5	0.0	3.4	4.3	9.0
			Mvoutessi II	38.9	46.9	0.0	8.7	1.7	3.8
			Nkometou III	88.3	10.0	0.0	0.0	0.7	1.0
			Etoud	73.0	18.0	1.6	0.0	1.6	5.7
	1995	S1	Ngat	77.0	15.5	2.4	0.3	3.4	1.5
			Mvoutessi II	63.7	27.5	0.0	3.8	4.9	0.0
			Nkometou III	87.2	1.3	0.8	2.5	8.1	0.0
			Etoud	83.3	6.6	0.9	1.0	7.9	0.2
		S2	Mengomo	78.1	9.9	2.0	4.0	6.0	0.0
			Akok	74.4	13.1	2.2	7.0	1.9	1.5
Mid-altitude	1996	S1	Ngat	37.0	46.9	0.0	6.5	7.6	2.0
			Mvoutessi II	32.3	59.5	0.0	4.7	3.4	0.0
			Nkometou III	59.8	23.8	0.0	4.3	11.4	0.7
			Etoud	38.4	51.3	0.6	2.2	5.0	2.6
		S2	Mengomo	11.3	56.7	0.0	7.5	13.2	11.4
			Akok	31.7	52.7	0.0	2.5	10.0	3.2
	1997	S1	Bamunka	62.5	0.0	37.5	0.0	0.0	0.0
			Bali	38.8	0.0	0.0	4.3	13.0	43.8
			Njinikom	69.0	0.0	0.0	0.0	14.3	16.7
		S2	Bamunka	64.8	0.0	13.0	16.7	5.6	0.0
			Bali	26.3	0.0	10.5	15.8	0.0	47.4
			Njinikom	79.4	0.0	0.4	5.7	1.1	13.4
		S1	Bamunka	66.7	0.0	33.3	0.0	0.0	0.0
			Bali	93.3	0.0	0.0	0.0	6.7	0.0
			Njinikom	60.7	0.0	0.0	6.3	26.3	6.7

B. f. = *B. fusca*, E. s. = *E. saccharina*, S. c. = *S. calamistis*, M. n. = *M. nigrivenella*, C. l. = *C. leucotreta*.

#### *Incidence and distribution of *B. fusca* eggs and egg infestation*

Significant differences in number of *B. fusca* egg batches per plant and percent plants infested with egg batches were found between seasons for the forest zone but not for the mid-altitude (Table 4a). Both egg batch numbers and percent plants infested with eggs were about three times higher during the second than the first season (Tables 4a). For random effects in both the forest zone and mid-altitude, the within field or sampling error contributed most to total variation (variables analyzed on a per plant basis), followed by between field variance (Table 4a). For percent plants infested with egg batches as well as at harvest analyzed on a per field basis, between field variance contributed highest to total variability followed by location in the forest zone whereas in the mid-altitude with only one block, the season x location interactions were as important as the residuals or between field variance (Table 4a), indicating that the ranking of locations for the insect variables changed considerably with season (Tables 4b and 5b).

**Table 4a. Result of nested ANOVA using a mixed model of *B. fusca* egg batches per plant (EGBN), egg batch size (EGBSIZE), percent plants infested with egg batches (%PIE) at six benchmark locations during the first and second seasons of 1995 in the forest zone, three benchmark locations for the first and second seasons of 1996 in the mid-altitude. Least square means (LSM) presented were back-transformed.**

	<b>Random effects</b>	EGBN	EGBSIZE	%PIE
Forest	Location (Block)	1.53	1.44	23.50
	Season x Location (Block)	0.00	0.00	2.07
	Between fields (Season x Location (Block))	5.34	1.39	74.42
	Residual or within field variation	93.13	97.18	†
	<b>Fixed effect</b>			
	First season LSM	0.08	21.07	6.92
	Second season LSM	0.24	18.45	21.81
	t	-9.6	4.23	-10.48
	P <sub>diff</sub>	0.003	0.115	0.002
Mid-altitude	<b>Random effects</b>			
	Location (Block)	0.00	0.00	0.00
	Season x Location (Block)	9.33	0.00	43.84
	Between fields (Season x Location)	7.84	4.75	56.16
	Residual or within field variation	82.8	95.25	†
	<b>Fixed effect</b>			
	First season	0.01	7.12	0.17
	Second season	0.07	21.6	3.53
	t	-1.40	-3.76	-1.72
	P <sub>diff</sub>	0.29	0.16	0.23

Significance is set at P ≤ 0.05. † = per field means used in the ANOVA, thus there is no within field variation.

Plants infested, egg batch density and size ranged between 2.7-11.3%, 0.03-0.27 batches/plant, and 16.7-33.4 eggs/batch, respectively, during the first season, versus 11.8-28.5%, 0.13-0.60 batches/plant and 15.7-22.9 eggs/batch, respectively, during the second season (Table 4b).

#### *Distribution of borer larvae and pupae at harvest*

In the forest zone, significant differences in larvae plus pupae numbers of *B. fusca* and *E. saccharina* were found between seasons, with *B. fusca* about three times more abundant in the first season whereas *E. saccharina* was four times more abundant in the second season. There were no significant differences between seasons for *S. calamistis*, *M. nigrivenella* and *C. leucotreta* (Table 5a). There was a significant season x location interaction for *M. nigrivenella* and a significant location effect for *C. leucotreta*.

In the mid-altitude, there were no significant differences in numbers of borer larvae and pupae between seasons (Table 5b) and overall *B. fusca* densities were considerably lower than in the forest zone (> 0.4 versus < 0.2 for most locations;

**Table 4b. Season by location distribution of means for percentage of plants infested with *B. fusca* egg batches (%PIE), egg batches per plant (EGBN) and number of eggs per egg mass (EGBSIZE) during the vegetative phase of maize in nine benchmark locations during the first (S1) and second (S2) seasons in the forest zone (1995) and mid-altitude (1996).**

Zone	Season	Location	% PIE	EGBN	EGBSIZE
Forest	S1	Ngat	10.6 ± 1.8	0.27 ± 0.01	33.4 ± 1.0
		Mvoutessi II	4.8 ± 0.4	0.06 ± 0.00	24.9 ± 0.3
		Nkometou III	8.7 ± 1.6	0.11 ± 0.00	24.4 ± 0.4
		Etoud	11.3 ± 1.1	0.15 ± 0.00	32.7 ± 0.3
		Mengomo	2.7 ± 0.8	0.03 ± 0.00	16.7 ± 0.2
		Akok	10.6 ± 2.3	0.12 ± 0.00	19.7 ± 0.2
	S2	Ngat	28.5 ± 3.2	0.60 ± 0.02	21.2 ± 0.2
		Mvoutessi II	25.8 ± 2.8	0.28 ± 0.00	18.4 ± 0.1
		Nkometou III	27.5 ± 3.8	0.37 ± 0.01	22.9 ± 0.2
		Etoud	24.3 ± 2.5	0.30 ± 0.01	20.4 ± 0.2
		Mengomo	11.8 ± 2.2	0.13 ± 0.00	15.7 ± 0.2
		Akok	19.2 ± 1.5	0.23 ± 0.00	19.8 ± 0.3
Mid-altitude	S1	Bamunka	0.0 ± 0.0	0.00 ± 0.00	0.0 ± 0.0
		Bali	1.5 ± 0.7	0.02 ± 0.00	14.1 ± 1.8
		Njinikom	0.6 ± 0.3	0.01 ± 0.00	10.0 ± 2.0
	S2	Bamunka	12.8 ± 4.3	0.18 ± 0.01	25.5 ± 0.9
		Bali	0.6 ± 0.4	0.01 ± 0.00	22.7 ± 6.2
		Njinikom	5.8 ± 2.0	0.06 ± 0.00	19.6 ± 1.4

Table 5b) whereas the other species were of equal importance, except for *E. saccharina*, which was entirely absent. For both zones, no significant differences were found between years (data not shown). When comparing between seasons, growth stage was significant for *E. saccharina* and *M. nigrivenella* numbers in the forest, and *B. fusca* in the mid-altitude, ( $P = 0.004$ ,  $0.0001$  and  $0.003$ , respectively, results not shown) indicating that these species attack older plants.

For random effects, within field variation was highest for all the borer species in both the forest zone and mid-altitude and tended to be higher for species that were rare. For both zones, between field variation contributed considerably more to total variability than location (Table 5b). Again, the season x location interaction contribution was high for *B. fusca* in the mid-altitudes. A comparison between years, yielded similar trends except that the year x location interaction was not important and the data are not shown here.

**Table 5a. Result of nested ANOVA using a mixed model for counts of immatures excluding eggs and percent infested plants [P(I)] according to borer species at six benchmark locations during the first and second seasons of 1995 in the forest zone, three benchmark locations for the first and second seasons of 1996 in the mid-altitude. Least square mean (LSM) presented were back-transformed.**

Zone Forest	<b>Random effects</b>	Percent of variation explained					
		<i>B. fusca</i>	<i>E. saccharina</i>	<i>S. calamistis</i>	<i>M. nigrivenella</i>	<i>C. leucotreta</i>	% P(I)
	Location (Block)	1.30	2.78	0.15	0.08	0.00	8.32
	Season x Location (Block)	0.87	1.90	0.28	0.00	0.00	0.00
	Between fields (Season x Location (Block))	13.04	12.19	2.93	3.43	6.06	91.68
	Residual or within field variation	84.80	83.12	96.64	96.49	93.94	†
	<b>Fixed effect</b>						
	First season LSM	0.73	0.08	0.01	0.03	0.05	57.10
	Second season LSM	0.22	0.31	0.00	0.02	0.04	63.52
	t	6.62	-4.33	2.06	0.50	0.61	-1.51
	P <sub>diff</sub>	0.007	0.023	0.132	0.652	0.587	0.23
Mid-altitude	<b>Random effects</b>						
	Location	4.56	-	0.43	0.00	0.00	0.00
	Season x Location	17.06	-	0.00	0.00	0.48	52.92
	Between fields (Season x Location)	6.16	-	3.33	1.49	0.00	47.08
	Residual or within field variation	72.22	-	96.24	98.51	99.52	†
	<b>Fixed effect</b>						
	First season LSM	0.07	-	0.00	0.00	0.01	17.14
	Second season LSM	0.22	-	0.01	0.03	0.01	42.30
	t	-1.05	-	-1.20	-3.37	0.75	-1.54
	P <sub>diff</sub>	0.403	-	0.352	0.078	0.53	0.26

Significance is set at P ≤ 0.05. † = per field means used in the ANOVA, thus there is no within field variation.

**Table 5b. Year, season by location distribution of means for counts of lepidopterous borer species per plant and percent of infested plants [P(I)] at soft dough to maturity of maize in nine benchmark locations during the first (S1) and second (S2) seasons in the forest zone (1994, 1995) and mid-altitude (1996, 1997).**

Year	Season	Location	<i>B. fusca</i>	<i>E. saccharina</i>	<i>S. calamistis</i>	<i>M. nigrivenella</i>	<i>C. leucotreta</i>	P(I)
1994	S2	Ngat	0.17 ± 0.02	0.15 ± 0.01	0.00 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	63.6 ± 5.4
		Mvoutessi II	0.16 ± 0.01	0.19 ± 0.01	0.00 ± 0.00	0.04 ± 0.00	0.01 ± 0.00	66.1 ± 6.2
		Nkometou III	0.38 ± 0.02	0.03 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.00	59.4 ± 7.3
		Etoud	0.44 ± 0.02	0.14 ± 0.01	0.01 ± 0.00	0.00 ± 0.00	0.01 ± 0.00	63.9 ± 5.2
1995	S1	Ngat	1.53 ± 0.09	0.19 ± 0.01	0.05 ± 0.01	0.01 ± 0.00	0.05 ± 0.01	64.4 ± 3.9
		Mvoutessi II	0.73 ± 0.04	0.33 ± 0.02	0.00 ± 0.00	0.02 ± 0.00	0.03 ± 0.00	42.4 ± 6.3
		Nkometou III	2.67 ± 0.13	0.02 ± 0.01	0.01 ± 0.00	0.05 ± 0.01	0.12 ± 0.00	74.5 ± 5.0
		Etoud	1.87 ± 0.06	0.11 ± 0.01	0.03 ± 0.00	0.03 ± 0.00	0.17 ± 0.02	78.6 ± 4.4
		Mengomo	0.53 ± 0.04	0.04 ± 0.00	0.02 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	34.4 ± 8.0
		Akok	0.76 ± 0.05	0.12 ± 0.01	0.02 ± 0.00	0.08 ± 0.01	0.01 ± 0.00	47.6 ± 4.9
1995	S2	Ngat	0.51 ± 0.02	0.66 ± 0.03	0.00 ± 0.00	0.14 ± 0.02	0.08 ± 0.00	73.9 ± 4.7
		Mvoutessi II	0.40 ± 0.05	0.87 ± 0.05	0.00 ± 0.00	0.05 ± 0.00	0.05 ± 0.01	66.6 ± 9.9
		Nkometou III	0.41 ± 0.03	0.18 ± 0.02	0.00 ± 0.00	0.02 ± 0.00	0.07 ± 0.01	58.8 ± 6.2
		Etoud	0.46 ± 0.01	0.92 ± 0.07	0.01 ± 0.00	0.03 ± 0.00	0.06 ± 0.01	67.4 ± 7.9
		Mengomo	0.09 ± 0.01	0.30 ± 0.02	0.00 ± 0.00	0.05 ± 0.01	0.04 ± 0.00	45.2 ± 3.9
		Akok	0.20 ± 0.01	0.49 ± 0.05	0.00 ± 0.00	0.02 ± 0.00	0.07 ± 0.01	57.3 ± 6.6
1996	S1	Bamunka	0.04 ± 0.01	-	0.02 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	8.0 ± 2.6
		Bali	0.16 ± 0.02	-	0.00 ± 0.00	0.01 ± 0.00	0.03 ± 0.00	31.8 ± 3.5
		Njinikom	0.15 ± 0.02	-	0.00 ± 0.00	0.00 ± 0.00	0.03 ± 0.01	23.3 ± 6.2
	S2	Bamunka	0.14 ± 0.02	-	0.03 ± 0.00	0.08 ± 0.01	0.01 ± 0.00	43.8 ± 8.2
		Bali	0.07 ± 0.01	-	0.01 ± 0.00	0.03 ± 0.00	0.00 ± 0.00	20.0 ± 2.7
		Njinikom	0.93 ± 0.04	-	0.01 ± 0.00	0.05 ± 0.01	0.01 ± 0.00	65.3 ± 6.6
		Bamunka	0.01 ± 0.00	-	0.01 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	12.8 ± 3.9
1997	S1	Bali	0.09 ± 0.01	-	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.00	38.3 ± 4.6
		Njinikom	0.22 ± 0.01	-	0.00 ± 0.00	0.02 ± 0.00	0.07 ± 0.00	46.7 ± 6.4

*Interactions among borer variables between vegetative and reproductive stages,  
and seasons*

No significant relationships were found for *S. calamistis*, *M. nigrivenella* and *C. leucotreta*, thus the results are not shown in Table 6. During the first season in the forest zone, significant correlations were found among all *B. fusca* egg variables during the vegetative stage, and between egg variables and *B. fusca* numbers and percent plants infested [%P(I)] at harvest (Table 6a). The strong correlation between number of *B. fusca* and %P(I) indicate that at the time the fields were visited most *B. fusca* had not yet reached adulthood and also that during the first season, mainly *B. fusca* was responsible for infestation at harvest.

**Table 6:** Pearson's correlation coefficients for *B. fusca* egg infestation during the vegetative growth of maize, borers at maize soft dough to maturity during the a) first and b) second cropping season of 1995 and the c) first and d) second cropping season of 1996 in the mid-altitude in the forest zone of Cameroon.

a)	1	2	3	4	5	6	c)	1	2	3	4	5
1	1.0						1	1.0				
2	.92*	1.0					2	.96*	1.0			
3	.45*	.31*	1.0				3	.95*	.86*	1.0		
4	.27*	.28*	.34*	1.0			4	.11	.05	.06	1.0	
5	.07	.02	.19	.06	1.0		5	.40*	.37*	.39*	.40*	1.0
6	.40*	.35*	.38*	.80*	.11	1.0						
b)							d)					
1	1.0						1	1.0				
2	.91*	1.0					2	.89*	1.0			
3	.18	.15	1.0				3	.60*	.36*	1.0		
4	.49*	.51*	.21	1.0			4	.45*	.31	.20	1.0	
5	.07	.00	.25*	.14	1.0		5	.50*	.43*	.36*	.78*	1.0
6	.25*	.18	.32*	.51*	.61*	1.0						

1=Percent plants infested with *B. fusca* egg batches; 2=Number of *B. fusca* egg batches per plant; 3=Number of eggs per mass; 4= Total *B. fusca* larvae and pupae at harvest; 5= Total *E. saccharina* larvae and pupae at harvest; 6 =Percent plants infested at harvest (\* significant at P≤0.05)

1=Percent plants infested with *B. fusca* egg batches; 2=Number of *B. fusca* egg batches per plant; 3=Number of eggs per mass; 4= Total *B. fusca* larvae and pupae at harvest; 5=Percent plants infested at harvest (\* significant at P≤0.05)

In the second season in the forest zone, egg batch size was not correlated with egg batch number or %plants infested with eggs (Table 6b). Both *B. fusca* and *E. saccharina* numbers were significantly correlated with %P(I). The correlation between *B. fusca* numbers and %P(I) (0.51) is less than that during the first season (0.80), indicating that by the time the plants were harvested many of the insects had already hatched or were killed by natural enemies.

In the mid-altitude, the same relationships as in the forest were found during both seasons (Table 6c, d), except that *B. fusca* numbers at harvest were not related to egg numbers earlier in the season. The weak relationship between larval numbers and %P(I) during the first season indicate that the plants were sampled when many insects had already hatched or had been killed by natural enemies.

Using location means, no correlation was found between seasons for any of the insect variables with exception of egg batch numbers and size during the first season in the mid-altitude which negatively correlated with percent plants infested with eggs during the second seasons ( $P = 0.04, 0.01$ , respectively).

#### *Association between borers with vegetation types in the vicinity of fields*

In the first season, at both the vegetative growth stage and harvest of maize and second season at harvest in the forest zone, there were no significant correlations between borers and vegetation types in the surroundings of maize fields.

During the second season at the vegetative growth stage of maize, significant canonical correlations was obtained between vegetation types in the vicinity of fields and %plants infested (canonical correlation = 0.42,  $P > r = 0.03$ ) as well as number of eggs per plant (canonical correlation = 0.41,  $P > r = 0.03$ ). In both relationships, the *B. fusca* egg variables were lower in young and mature forests but higher with *C. odorata* (Table 7).

**Table 7. Canonical correlations (squared multiple correlations) between surrounding vegetation and *B. fusca* egg infestation and number of eggs per plant during the vegetative growth of maize in the second season of 1995 in the forest zone.**

Correlation surrounding vegetation with <i>B. fusca</i> egg infestation at vegetative growth of maize canonical	Correlation <i>B. fusca</i> egg infestation at vegetative growth of maize with surrounding vegetation canonical	Correlation surrounding vegetation with <i>B. fusca</i> eggs per plant canonical	Correlation <i>B. fusca</i> eggs per plant with surrounding vegetation canonical
Chromolaena	0.20	%PIE	0.42
Young forest	-0.31		
Mature forest	-0.27		
Other vegetation	0.11		
Canonical correlation = 0.42, $P = 0.03$		Canonical correlation = 0.41, $P = 0.03$	
Chromolaena	0.20	No of eggs/plant	0.41
Young forest	-0.31		
Mature forest	-0.26		
Other vegetation	0.10		

#### Discussion

In terms of vegetation, the three blocks in the forest zone were not heterogeneous enough to show significant effects on pest species composition and in mean pest densities.

As expected for insect species with aggregated distribution, (see chapter three) within field sampling error explained most of the variation in insect densities. Under the prevailing pest densities (Table 5b) the number of samples of 15 plants per field was far below the optimum number calculated for *B. fusca* and *E. saccharina* (40-100 for a precision level of 0.3 as a fixed proportion of the mean, and a density of 0.5-1/plant; Chapter three). In the forest, between field variability was second and between location variability the least important in explaining the variance. Thus, if the aim of a sampling scheme is to maximize precision of estimates of insect densities (e.g., for pest/natural enemies interactions studies at low to medium pest densities) the number of samples per field and numbers of fields should be increased whereas numbers of locations should be reduced and the blocks can be ignored. This may not be appropriate for multidisciplinary work, however, when socio-economic concerns such as population density and accessibility to markets are playing a role, which may be location or block specific.

The low variability between locations within and between years, combined with the lack of relationship between first and second season infestations within location, indicates that none of the locations had reliably high pest infestations ideal for host plant resistance screening. Though the overall percentage of infested plants were high, and in the forest mostly above 60%, complimentary techniques have to be used to improve uniformity of pest infestations. Spreader rows help to build up uniform pest populations, with the last one planted one borer life span before the test rows. Pressure can be increased by direct infestations of test rows with young plants from spreader rows showing 'window' damage. Synchronizing planting with peak adult flight times, using light or pheromone traps, would also increase borer pressure on breeder trials. Because young *B. fusca* larvae migrate, <10% of egg incidence (Table 4b) lead to a >60% larval infestation later at harvest during the first season (Table 5b) indicating that not all plants have to be infested with eggs to achieve a high uniformity of infestation. During the second season, however, a >20% egg incidence lead to a considerably lower percentage of infested plants at harvest, taking into consideration the relative importance of *B. fusca* (36.6% of all species; Table 3). This weak correlation between plants

infested with eggs and P(I) ( $r = 0.40$  and  $0.25$  for first and second season, respectively; Table 6) may indicate an increase in biological control activity from the first to the second season. It is therefore recommended to do host plant resistance screening for *B. fusca* during the first and for *E. saccharina* and mixed species during the second season. The screening should be done in the forest zone where pest densities are higher and more reliable than in the mid-altitude (in the mid-altitude the season x location interactions was often the second most important effect for some variable in explaining variance).

The pest status of individual species, and especially of *B. fusca*, in Cameroon, differs greatly from other western African countries. Schulthess et al. (1997a) summarizing results from various country-wide surveys in West Africa and results by other authors (Carter, 1985; Uzakah, 1988; Bosque-Pérez and Mareck, 1990) concluded that in West Africa, *E. saccharina* is the economically most important species followed by *S. calamistis*. By contrast, 30 years ago in the humid forest of south-western Nigeria, *B. fusca* was generally the most common species while *S. calamistis* was dominant in some localities during some years (Harris, 1962; Usua, 1968; Adeyemi, 1969). In Cameroon, *B. fusca* is not only the most important pest across ecological zones and altitudes, it also needs only one season to reach high infestation levels. In the forest zone, *B. fusca* was predominant during the first season and *E. saccharina* became more important during the second, but other species, particularly *S. calamistis*, were of no importance. Thus, in Cameroon, *E. saccharina* follows the typical infestation pattern of *E. saccharina* and *S. calamistis* in West Africa, where it takes two season to build up damaging population levels for both species (Bosque-Pérez and Mareck, 1990; Gounou et al., 1994). By contrast, in our study numbers of *B. fusca* larvae, were higher during the first season. Most likely, in the second season, high mortality occurred during the egg and/or young larval stage resulting in a significant reduction of pest numbers at harvest as compared to the first season. Similarly, in the lowland humid tropics of West Africa, *B. fusca*, though of no economic importance, is more common in the first than the second season (Schulthess et al., 1997a). Thus, under both density conditions some yet unknown factor, probably egg parasitoids, cause *B. fusca* populations to decline at the beginning of the

second season, but in Cameroon they are still high enough to affect yields (Cardwell et al., 1997; Chapter five). Since *B. fusca* and *S. calamistis* share many natural enemies species (Polaszek, 1998) they may be responsible for the low importance of *S. calamistis* in these ecologies. Moreover, *S. calamistis* does not diapause and for overwintering depends on alternative and mostly inferior hosts, which cause populations to decline to close to zero by the first season (Shanower et al., 1993; Kouamé, 1995; Schulthess et al., 1997a; Séme-glo, 1997; Chapter two). The few females emerging from such hosts are small with low fecundity as shown by various authors (Shanower et al., 1993; Sétamou et al., 1995). *E. saccharina*, on the other hand, is more adapted to drought conditions and older plants, and is often found feeding on old maize stalks long after harvest (Kouamé, 1995; Chapter two).

In Eastern and Southern Africa, *B. fusca* is a pure mid-altitude/highland species, and the only important pest above 1000m a.s.l., while in the lowlands the exotic pyralid *Chilo partellus* Swinhoe prevails (Swaine, 1957; Smithers, 1960; Ogwaro, 1983; Van Rensburg et al., 1988; Gebre-Amlak et al., 1989; Seshu Reddy et al., 1990; Van den Berg et al., 1991; Overholt et al., 1994; Phiri, 1995). *Sesamia calamistis* and *E. saccharina* are of low importance to maize but in the Republic of South Africa *E. saccharina* is the major key pest of sugarcane (Atkinson, 1980; Conlong, 1997). By contrast, *E. saccharina* was never found on any cultivated crop in Malawi but, as in South Africa, easily on the wild host *Cyperus papyrus* (Linnaeus) (Cyperaceae) (Phiri, 1995). In West Africa, *E. saccharina* is rarely found on either hosts. Information about lepidopterous borers in Central Africa is largely lacking. However, in Zaire, Vogel et al. (1993) working in the Lumumbashi area found mostly *B. fusca* on maize.

The reasons for the differences in distribution and economic importance of stem borer species among African regions, ecozone or even within the same ecozone between neighboring countries (e.g., Nigeria and Cameroon) are not well understood. The occurrence of several *Sesamia* spp. is limited to West Africa, and the fact that *C. partellus* is not present in western and most of central Africa indicates little exchange of planting material (the main culprit for invasion of pests into new areas) between the two regions. Geographical barriers (mountain

ranges and forest) allow for the development of distinct geographical races that vary in their climatic requirements (*B. fusca*) and host plant preferences (*E. saccharina*). Another reason put forward by Schulthess et al. (1997a) is the implications of increasing human population pressure resulting in the displacement of natural habitats for the population dynamics of the borers and their natural enemies. Life table studies of *S. calamistis* and *E. saccharina* using wild grass hosts and maize showed maize to be the best host for survival and fecundity of borers while on wild hosts mortalities were close to a 100% though adult female preferred some grass species over maize for oviposition (Shanower et al., 1993; Semeglo, 1997; Sekloka, 1996). Typically, borer incidence in maize fields was always negatively related to grass abundance in the vicinity of the field, indicating that most grasses act as trap plants rather than being reservoirs responsible for outbreaks in crop fields (Schulthess et al., 1997a; S. Gounou, IITA-Benin, unpubl. data). Consequently, deforestation and the concomitant increase in C4- plant species, e.g., grasses, should lower pest infestations. In the present study, the gradient of human population density from 15 to 88 people/km<sup>2</sup> was obviously not sufficient to affect vegetation type to an extent that it affected pest species composition and infestation as theorized by Schulthess et al. (1997a) for Nigeria and shown for Côte d'Ivoire. However, the degree of deforestation in the forest zone of Côte d'Ivoire (mainly due to large-scale plantation of cash crops) is much more drastic than in the forest benchmark sites of Cameroon. Furthermore, the average country-wide population density in Cameroon is ca 23 vs. 100 inhabitants/km<sup>2</sup> in Nigeria where highest population densities are found around major cities in the south. As a result, the climax vegetation in south, mostly tropical rain forest, is now largely destroyed.

In the present study, mean stem borer incidence in forest fields was more than 60% which was considerably higher than the mean of 48% found in the 1993 survey in roadside fields (Cardwell et al., 1997). Moreover, in forest fields across seasons, *E. saccharina* accounted for 30% of the species versus 15% in 1993. Thus, as human population pressure increases more market roads will be opened, especially in the vicinity of larger towns, so the situation may still change. By contrast, in the western highlands where intensive and large-scale maize

cultivation has been the norm for a long time, borer infestations and species composition were about the same as recorded in 1993. As in mid-altitude/highland zone of eastern Africa the major species is and probably always was *B. fusca* whereas *E. saccharina* was largely absent, probably due to the cool climate.

The results of canonical correlation analyses were not very conclusive: During the second season only, forest vegetation lowered numbers and incidence of *B. fusca* egg batches while *C. odorata* had the opposite effect, but no relationships were identified with larval infestations. *Chromolaena odorata*, an exotic weed, is one of the first invaders in freshly cleared forest together with grasses. It finally displaces thin-stemmed but not large stemmed grass species such as *Pennisetum purpureum* (Moench) (Fam.: Poaceae) which are alternate hosts of *B. fusca*. Very likely maize is presently the major host determining population dynamics of major pests inside the forest, and those species were probably very rare before the introduction of this crop into the area. The lower proportion of *E. saccharina* during the 1993 surveys in roadside fields compared to forest fields may be because *P. purpureum*, a grass species especially unsuitable for *E. saccharina* but less so for *B. fusca* (See chapters two and three), was the most common species (Cardwell et al., 1997). This emphasizes again that road side ecologies are special and not automatically representative for both ecological and socio-economic conditions encounter at greater distances to roads.

The present work focussed on the relative importance of stem borers in two ecological zones in Cameroon. In future work, emphasis will be given to the effect of soil nutrients on both maize production and stem borer abundance, and the role of natural enemies in the forest ecology of Cameroon. The present results suggest that natural enemies play an important role in controlling *S. calamistis* and to a lesser extent *B. fusca*.

## CHAPTER 5

### **The effect of lepidopterous stem borers on growth and yield of maize in Cameroon with special reference to interactions between soil nutrients, maize and pest abundance in the forest zone**

#### **Introduction**

In Cameroon, *Busseola fusca* (Fuller) (Lep.: Noctuidae) is the most important insect pest of maize across ecozones and altitudes (Cardwell et al., 1997). In the humid forest zone, however, *Eldana saccharina* (Walker) (Lep.: Pyralidae) can become the predominant species during the minor season, from September - December (Chapter four). On-farm research carried out in the mid-altitude and forest zone showed that stem borer densities varied strongly between fields and to a lesser extent between locations (i.e., villages). In the forest zone, no significant differences were found between 'blocks', representing gradients in human population density and associated varying lengths of fallow period (Chapter four). It was concluded that those gradients and resulting degradation of the natural habitats of the pests were not strong enough to cause a large-scale shift in the relative importance of a pest species (Schulthess et al., 1997a). Thus, forest fields in Cameroon still represent islands within non-cultivated habitats, and associated pests are strongly affected by edaphic, microclimatic, and biotic factors such as natural enemies and alternative wild host plants, in and in the vicinity of a field (Schulthess et al., 1997a; Cardwell et al., 1997; Chapter four). Alternative host plants of stem borers, such as grasses and sedges, which buffer maize fields against severe stem borer attacks (Schulthess et al., 1997a; Cardwell et al., 1997; Chapter two), are scarce in forest fields, however, and contribute little to population dynamics of the pest and their beneficials. Likewise, using a crude vegetation score (See chapter four) gave no meaningful interactions between surrounding vegetation and pest infestation.

As shown by various researchers, individual soil nutrients not only affect plant growth but they may have both a negative or positive effect on stem borer survival and fecundity, which, in turn, affects yield of the plant they inhabit and dynamics of future populations of pests and natural enemies (Sétamou et al., 1993; Allsop et al., 1993; Sétamou et al., 1995; Sétamou and Schulthess, 1995; Phelan et al.,

1995; Denké, 1995). A major objective of the present work was to determine if forest zone locations could be grouped according to the pre-selected 'blocks' (See chapter four), using soil nutrient concentration, and if or how the latter affect pest damage to maize on a block, village and on a per field basis.

In addition, the relationships between individual pest damage parameters and yield were examined from field data of both the forest and mid-altitude zone, in order to provide a tool for rapid assessment of the importance of a pest species on a region-wide basis.

## **Materials and methods**

### *Data collection*

#### *1994, 1995 surveys in the forest zone*

The procedures for selecting benchmark locations in the forest zone and mid-altitude are described in chapter four. From May 16 to June 7, 1995 (first season) and October 10 to November 2, 1995 (second season), soil samples were collected from 148 farmers' mixed food crop fields at the benchmark locations during the vegetative growth stage of maize. Five  $5 \times 5\text{m}^2$  quadrates were randomly pegged in different parts of each field and the total number of maize plants and numbers of dead hearts were recorded in each. Soil samples were taken from depths of 0-5cm and 5-10cm (one sample per quadrate), and 10-20cm and 20-30cm (one from one randomly selected quadrate per field). The samples were brought to the laboratory of the Humid Forest Station of the International Institute of Tropical Agriculture (IITA), Nkolbisson, for analysis of pH, calcium, magnesium, potassium, phosphorus, percent total nitrogen and carbon at each soil depth. pH was determined using  $\text{H}_2\text{O}$ , Ca, Mg and K was measured in milli-equivalents per 100g of soil; P in micro-grams per gram of soil and N, C were expressed as percentages.

In the second season of 1994, and first and second seasons of 1995, a total of 180 maize fields in the reproductive stage (between soft dough and maturity) were visited. In each field 15 maize plants were sampled at random for assessment of plant growth stage, total plant height without tassel and height at first ear. The number of larvae and pupae per borer species, number of holes, and cm of stem

tunneled below and above the ear as well as percent cob damage and cob weight without husk were measured for each plant following the protocol developed by (Gounou et al., 1994; Cardwell et al., 1997). For each plant, the growth stage was scored using a scale of 1-9, with 1 = emergence and 9 senescence, 5 = silking, 6 = cob formation, 7 = milk stage, 8 = hard dough.

#### *1996, 1997 surveys in the mid-altitude*

In the three mid-altitude locations (See chapter four), during the first (May 20-27) and second seasons 1996 (September 16-23), 65 maize fields in the vegetative phase were visited. In each field two  $5 \times 5m^2$  quadrates were randomly pegged for assessment of plant density and percentage of plants with *B. fusca* leaf feeding damage.

During the reproductive phase in the first (July 15-20) and second cropping seasons of 1996 (November 24-29), and first cropping season of 1997 (July 14-19) 15 maize plants in each of 91 farmers' fields were sampled and processed as in the forest zone.

#### *Statistical analyses*

Depending on the analyses the units were plants, fields, locations or blocks. In regression analyses, weighted means of soil nutrients were used. Thereby, mean per field values at 0-5cm and 5-10 cm were multiplied by 5, and values at 10-20cm and 20-30cm by 10, then summed up and divided by 30. For assessment of the effect of block, location, between and within field variability on soil nutrients, means soil nutrient concentrations at 0-10 cm for each quadrat were used. A mixed model (Harville and Mee, 1984; Littell et al., 1996; SAS, 1997) was applied using a nested design to analyze differences in soil nutrients, plant damage and yield variables. Year, season and block were fixed effects while field, location and location interactions were random. Random effects are qualitative while fixed effects are quantitative.

Correlation analyses and stepwise regressions were done for maize yield (both on a per plant basis and per  $5 \times 5m^2$  quadrates depending on analysis), pest numbers, damage variables and soil nutrients to elucidate relationships between the various biotic and abiotic components.

Counts were log x+1 transformed and percentage data for damage variables were arcsin square root transformed before analyses.

## Results

### *Soil nutrients*

Across locations and seasons, soil nutrient levels were very low and the ranges were all within those characteristic of poor soils (Vinh An and Boko, 1978). No significant differences between blocks were found except for Mg which varied significantly between the three blocks ( $P = 0.006$ ,  $df = 2$  mean value across two seasons of 1.7, 2.3 and 0.9 mili-equivalents per 100g of soil for the Mbalmayo, Yaoundé and Ebolowa block, respectively) whereas season had a significant effect on K and P (Tables 1). For all soil nutrients, within-field (between quadrates) variation explained most of the variance, ranging between 37% for pH and 79% for K (Table 1), and except for K between field variation was generally more important than location.

**Table 1 . Effect of location\* and season on soil pH, carbon and nutrients during the first and second seasons of 1995 in the forest zone.**

	Percent of variation explained						
	pH	Ca	Mg	K	P	N	Carbon
<b>Random effects</b>							
Location (Block)	26.86	13.22	0.00	14.22	8.01	4.49	3.08
Season x Location (Block)	8.67	0.00	4.07	0.00	6.24	7.68	0.00
Between fields (Seas. x Loc. (Block))	27.47	26.29	27.29	6.77	26.57	26.57	25.93
Between quadrat (Field)	37.00	60.49	68.39	79.01	59.18	61.25	70.99
<b>Fixed effect</b>							
First season LSM	5.84	4.85	1.52	0.26	13.71	0.17	2.56
Second season LSM	5.76	4.81	1.73	0.34	8.92	0.16	2.42
t	0.58	0.14	-1.74	-3.98	3.08	0.88	1.74
P <sub>diff</sub>	0.59	0.90	0.18	0.03	0.05	0.44	0.18

\*Legend: blocks = 3 (fixed); locations = 2 per block; fields minimum of 12 per location, 5 quadrates/field. Significance was set at  $P \leq 0.05$ . LSM = Back transformed least square means

### *Cob weight, plant density and damage*

In the forest zone, there were no significant differences between plant and field means in blocks or season for cob weight and plant density, respectively (Table 2a). Numbers of plants per pocket and per ha varied greatly and ranged between 1-8 and 1,200-24,800, respectively. Consequently, most of the variation could be explained by between or within field variance. Major crops interplanted with

**Table 2a. Locational\* and season effects on cob weight, plants per pocket, plants per 25m<sup>2</sup>, %dead hearts (%DH), %stem tunneled (%STT) and %cob damage (%COBD) in the forest in 1995 and in the mid-altitude in 1996.**

Forest	<b>Random effects</b>	Cob weight	Plt/pocket	Plt/25m <sup>2</sup>	%DH	% STT	% COBD
	Location (Block)	0.00	0.00	11.80	9.24	9.29	0.00
	Season x Location (Block)	3.89	0.00	2.73	0.00	0.00	0.00
	Between fields (Season x Location (Block))	25.42	100.00	85.52	90.76	9.61	10.18
	Residual or within field variation	70.68	†	†	†	81.10	89.82
	<b>Fixed effects</b>						
	First season LSM	142.02	3.78	18.38	0.04	1.84	1.04
	Second season LSM	147.22	3.80	23.54	0.50	2.76	0.37
	t	-1.60	-0.08	-2.22	-4.47	-2.49	3.91
	P <sub>diff</sub>	0.59	0.94	0.92	0.021	0.08	0.03
Mid-altitude	<b>Random effects</b>						
	Location	0.00	-	-	-	0.00	0.77
	Season x Location	3.08	-	-	-	13.52	1.47
	Between fields (Season x Location)	22.98	-	-	-	11.12	2.78
	Residual or within field variation	73.94	-	-	-	75.36	94.99
	<b>Fixed effects</b>						
	First season LSM	140.46	-	-	-	0.27	0.02
	Second season LSM	102.00	-	-	-	1.47	0.25
	t	3.10	-	-	-	-1.35	-2.38
	P <sub>diff</sub>	0.09	-	-	-	0.31	0.14

\*Legend: blocks = 3, locations = 2 per block, fields: minimum of 12 per location, N = 15 plants/field. Significance was set at P ≤ 0.05; † = per field means used in the ANOVA, thus there is no within field variation. LSM= Back transformed least square means.

maize were cassava and groundnut and minor cocoyam, melon, young plantain and okra, all non-hosts of maize stem borers. Likewise, block was not significant for plant damage variables and > 80% of variance was within field. Percent plants with dead hearts was significantly higher during the second season whereas cob damage was lower (Table 2a). Both were generally very low with mean seasonal maxima of 1.3 and 2.2% for dead hearts and with cob damage mostly below 3% in both seasons.

In the mid-altitude with only one block, no significant seasonal effects were found for ear weight nor damage variables. The season x location interactions were strong (Table 2a), indicating that the ranking of locations for this damage variable changed considerably with season. Stem damage tended to be higher in the forest zone as compared to the mid-altitude whereas cob damage was about the same for both zones.

In both ecozones, no differences in cob weight, stem and cob damage were found between years (Table 2b).

**Table 2b. Between year analysis of locational effects\* for cob weight, %stem tunneled, %cob damage comparing second season 1994 & 1995 (forest zone) and first season 1996 & 1997 (mid-altitude).**

Zone		Percentage of variation explained		
Forest	<b>Random effects</b>	Cob weight	% STT	% COBD
	Location (Block)	3.62	1.61	0.00
	Year x Location (Block)	1.12	0.00	0.06
	Between fields (Yr x Loc. (Block))	18.43	16.37	2.42
	Residual or within field variation	76.79	82.02	97.58
	<b>Fixed effect</b>			
	1994 LSM	155.73	2.15	0.27
	1995 LSM	151.56	3.21	0.42
	t	0.50	-1.20	-1.57
	P <sub>diff</sub>	0.67	0.20	0.25
Mid-altitude	<b>Random effects</b>			
	Location	12.76	12.17	0.13
	Year x Location	0.00	0.24	0.00
	Between fields (Year x Loc.)	19.89	11.64	2.42
	Residual or within field variation	67.34	75.94	97.63
	<b>Fixed effect</b>			
	1996 LSM	151.15	0.29	0.03
	1997 LSM	160.30	0.57	0.13
	t	-1.06	-1.41	-2.99
	P <sub>diff</sub>	0.40	0.29	0.09

\*Legend: blocks = 3, locations = 2 per block, minimum of 12 fields per location, N = 15 plants per field.  
Significance was set at P ≤ 0.05; LSM= Back transformed least square means.

*Interactions between yield and damage variables*

As expected cob weight always increased with plant growth stage (Table 3). In the forest zone during the first season as well as across the first and second seasons of 1995, cob weight per plant (y) was significantly negatively related with cob damage and percent stem tunneled below the ear (Table 3) whereas in the

**Table 3. Effect of plant growth stage and borer damage variables on cob weight (g) during (a) first, (b) second seasons of 1995, (c) first and second seasons of 1995 pooled in the forest zone; (d) first, (e) second seasons of 1996, (f) first season of 1997, (g) first and second seasons of 1996 pooled in the mid-altitude. Mean ± SE plant stage and damage variables.**

		b	F	Mean ± SE
a)	Y cob weight			
	X <sub>1</sub> stage	21.82	93.94*	7.01 ± 0.02
	X <sub>2</sub> %cob damage	-33.15	11.08*	3.71 ± 0.26
	X <sub>3</sub> %stem below ear tunneled	-23.70	5.31*	3.57 ± 0.04
	Intercept = -8.67, R <sup>2</sup> = 0.10, N = 1018			
b)	Y cob weight			
	X <sub>1</sub> stage	11.00	25.18*	7.57 ± 0.03
	X <sub>2</sub> %cob damage	-38.68	5.25*	1.79 ± 0.16
	Intercept = 71.48, R <sup>2</sup> = 0.03, N = 925			
c)	Y cob weight			
	X <sub>1</sub> stage	16.35	121.57*	7.28 ± 0.02
	X <sub>2</sub> %cob damage	-36.94	17.80*	2.80 ± 0.16
	X <sub>3</sub> %stem below ear tunneled	-14.37	3.83*	4.43 ± 0.25
	Intercept = 31.03, R <sup>2</sup> = 0.07, N = 1942			
d)	Y cob weight			
	X <sub>1</sub> stage	35.58	86.69*	7.34 ± 0.04
	X <sub>2</sub> %stem above ear tunneled	-61.83	4.92*	1.34 ± 0.31
	Intercept = -113, R <sup>2</sup> = 0.18, N = 434			
e)	Y cob weight			
	X <sub>1</sub> stage	12.89	27.35*	6.83 ± 0.05
	X <sub>2</sub> %stem below ear tunneled	-29.58	5.01*	4.01 ± 0.66
	Intercept = 11.04, R <sup>2</sup> = 0.08, N = 379			
f)	Y cob weight			
	X <sub>1</sub> stage	19.92	33.69*	7.75 ± 0.04
	X <sub>2</sub> %total stem tunneled	-93.46	18.83*	2.52 ± 0.27
	Intercept = 17.11, R <sup>2</sup> = 0.09, N = 526			
g)	Y cob weight			
	X <sub>1</sub> stage	29.05	153.50*	7.10 ± 0.03
	X <sub>2</sub> %total stem tunneled	-48.07	10.75*	2.93 ± 0.28
	Intercept = -79.40, R <sup>2</sup> = 0.18, N = 813			

\*F – values significant at P ≤ 0.05.

second season of 1995, only cob damage was significant. In the mid-altitude, cob weight decreased with percent stem tunneled above and below the ear during the first and second season, respectively, of 1996, and total stem damage during first season of 1997 and across both seasons of 1996. No relationship was found for %

cob damage in the mid-altitude. The percentage of variance in cob weight explained by plant stage and damage variables was very low for both the forest zone and mid-altitude, indicating that other factors may be more important (Table 3).

#### *Contribution of individual stem borer species to stem and ear damage*

As indicated by the slopes of stepwise regressions and mean densities (Tables 4a, b), *B. fusca* was the most damaging stem and ear feeding species across years,

**Table 4a. Assessment of the relative importance of stem borer species to % stem damage using stepwise multiple regressions, during (a) second season of 1994, (b) the first, (c) second seasons of 1995, (d) first and second seasons of 1995 pooled in the forest zone, (e) first, (f) second seasons of 1996, (g) first season of 1997, (h) first and second seasons of 1996 pooled in the mid- altitude. Mean  $\pm$  SE numbers of borers in the plant.**

Zone			b	F	Mean $\pm$ SE
Forest	a)	Y %stem tunneling			
		X <sub>1</sub> no. of <i>B. fusca</i>	0.27	338.40*	0.29 $\pm$ 0.03
		X <sub>2</sub> no. of <i>E. saccharina</i>	0.12	32.18*	0.13 $\pm$ 0.02
		Intercept = 0.08, R <sup>2</sup> = 0.35, N = 719			
	b)	Y %stem tunneling			
		X <sub>1</sub> no. of <i>B. fusca</i>	0.17	816.68*	1.28 $\pm$ 0.07
		X <sub>2</sub> no. of <i>E. saccharina</i>	0.11	48.08*	0.13 $\pm$ 0.02
		X <sub>3</sub> no. of <i>S. calamistis</i>	0.15	14.85*	0.04 $\pm$ 0.01
		Intercept = 0.03, R <sup>2</sup> = 0.47, N = 1018			
Mid-altitude	c)	Y %stem tunneling			
		X <sub>1</sub> no. of <i>B. fusca</i>	0.19	301.00*	0.35 $\pm$ 0.03
		X <sub>2</sub> no. of <i>E. saccharina</i>	0.16	343.90*	0.56 $\pm$ 0.04
		Intercept = 0.08, R <sup>2</sup> = 0.44, N = 924			
	d)	Y %stem tunneling			
		X <sub>1</sub> no. of <i>B. fusca</i>	0.16	958.21*	0.84 $\pm$ 0.04
		X <sub>2</sub> no. of <i>E. saccharina</i>	0.17	508.94*	0.34 $\pm$ 0.02
		X <sub>3</sub> no. of <i>S. calamistis</i>	0.15	15.85*	0.01 $\pm$ 0.00
		Intercept = 0.06, R <sup>2</sup> = 0.43, N = 1942			
	e)	Y %stem tunneling			
		X <sub>1</sub> no. of <i>B. fusca</i>	0.22	107.13*	0.11 $\pm$ 0.03
		Intercept = 0.03, R <sup>2</sup> = 0.20, N = 434			
	f)	Y %stem tunneling			
		X <sub>1</sub> no. of <i>B. fusca</i>	0.23	154.71*	0.42 $\pm$ 0.05
		Intercept = 0.07, R <sup>2</sup> = 0.28, N = 390			
	g)	Y %stem tunneling			
		X <sub>1</sub> no. of <i>B. fusca</i>	0.20	59.94*	0.11 $\pm$ 0.02
		Intercept = 0.06, R <sup>2</sup> = 0.10, N = 537			
	h)	Y %stem tunneling			
		X <sub>1</sub> no. of <i>B. fusca</i>	0.24	326.56*	0.26 $\pm$ 0.03
		Intercept = 0.05, R <sup>2</sup> = 0.28, N = 824			

\*F – values significant at P  $\leq$  0.05.

seasons and ecozones. *Eldana saccharina* was the second most important stem borer in the forest zone, and in second season of 1995 its numbers exceeded

**Table 4b. Assessment of the relative importance of lepidopteran species to % cob damage using stepwise multiple regressions, during (a) second season of 1994, (b) the first, (c) second seasons of 1995, (d) first and second seasons of 1995 pooled in the forest zone, (e) first, (f) second seasons of 1996, (g) first season of 1997, (h) first and second seasons of 1996 pooled in the mid-altitude. Mean ± SE numbers of borers in the ear.**

Zone		b	F	Mean ± SE
Forest	a)	Y %cob damage		
		X <sub>1</sub> no. of <i>B. fusca</i>	0.37	162.3*
		X <sub>2</sub> no. of <i>E. saccharina</i>	0.40	32.6*
		X <sub>3</sub> no. of <i>M. nigrivenella</i>	0.16	7.6*
		Intercept = 0.03, R <sup>2</sup> = 0.22, N = 720		
	b)	Y %cob damage		
		X <sub>1</sub> no. of <i>B. fusca</i>	0.21	923.5*
		X <sub>2</sub> no. of <i>S. calamistis</i>	0.19	9.2*
Mid-altitude	c)	X <sub>3</sub> no. of <i>M. nigrivenella</i>	0.05	3.2*
		Intercept = 0.03, R <sup>2</sup> = 0.48, N = 1019		
	d)	Y %cob damage		
		X <sub>1</sub> no. of <i>B. fusca</i>	0.22	1446.2*
		X <sub>2</sub> no. of <i>E. saccharina</i>	0.08	31.3*
		X <sub>3</sub> no. of <i>S. calamistis</i>	0.17	9.0*
		X <sub>4</sub> no. of <i>M. nigrivenella</i>	0.10	35.4*
		Intercept = 0.02, R <sup>2</sup> = 0.36, N = 1943		
	e)	Y %cob damage		
		X <sub>1</sub> no. of <i>B. fusca</i>	0.32	308.6*
		Intercept = 0.31, R <sup>2</sup> = 0.44, N = 435		
	f)	Y %cob damage		
		X <sub>1</sub> no. of <i>B. fusca</i>	0.31	164.9*
		X <sub>2</sub> no. of <i>M. nigrivenella</i>	0.11	7.8*
		Intercept = 0.02, R <sup>2</sup> = 0.32, N = 390		
	g)	Y %cob damage		
		X <sub>1</sub> no. of <i>B. fusca</i>	0.32	308.7*
		Intercept = 0.01, R <sup>2</sup> = 0.42, N = 540		
	h)	Y %cob damage		
		X <sub>1</sub> no. of <i>B. fusca</i>	0.31	396.9*
		X <sub>2</sub> no. of <i>M. nigrivenella</i>	0.11	15.4*
		Intercept = 0.01, R <sup>2</sup> = 0.24, N = 825		

\*F – values significant at P ≤ 0.05.

*B. fusca* although *B. fusca* contributed more to stem tunneling damage (Table 4a; Chapter four). *Sesamia calamistis* caused significant stem tunneling during the first season of 1995, but mean densities/plant were low. In the mid-altitude, the only species that caused significant stem damage was *B. fusca*.

Stem damage per larva was highest for *B. fusca*, and higher in the mid-altitude than in the forest, indicating that the larvae were larger or had fed longer. Cob damage in both zones followed similar trends except that *Mussidia nigrivenella*

(Ragonot) (Lep.: Pyralidae) contributed significantly during most seasons although mean densities were very low (Table 4b). Cob damage per larvae tended to be highest for *B. fusca* and was similar in both zones.

*Interactions between soil nutrients, stem borers and plant damage in the forest zone*

Few correlations were found between gram cob weight and soil nutrients. During the second season of 1995 only, both K and N were positively related with weight with  $r$  of 0.43 and 0.30 ( $r>0.23$  significant at  $P\leq 0.05$ ), respectively, whereas P was negative with  $r = -0.33$ . By contrast, *B. fusca* numbers at harvest significantly increased with Mg during both the first and second season (Table 5a). They were positively related to C in the first season and negatively with K and P in the second season though not significantly (Tables 5a).

**Table 5a. Relationships between numbers of *B. fusca* and soil nutrients during (a) first, (b) second seasons of 1995 and (c) first and second seasons of 1995 pooled in the forest zone. Mean  $\pm$  SE of concentration of soil nutrients**

		b	F	Mean $\pm$ SE
a)	Y no. of <i>B. fusca</i>			
	X <sub>1</sub> Mg	0.32	7.31*	0.88 $\pm$ 0.05
	X <sub>2</sub> C	0.26	2.88	1.55 $\pm$ 0.05
	Intercept = 0.04, R <sup>2</sup> = 0.16, N = 68			
b)	Y no. of <i>B. fusca</i>			
	X <sub>1</sub> Mg	0.11	7.30*	1.08 $\pm$ 0.07
	X <sub>2</sub> K	-0.30	2.27	0.21 $\pm$ 0.01
	X <sub>3</sub> P	-0.03	2.77	4.26 $\pm$ 0.19
	Intercept = 0.33, R <sup>2</sup> = 0.26, N = 62			
c)	Y no. of <i>B. fusca</i>			
	X <sub>1</sub> Mg	0.13	3.91*	0.98 $\pm$ 0.05
	Intercept = 0.37, R <sup>2</sup> = 0.03, N = 130			

\*F – values significant at  $P \leq 0.05$ .

During the first season and across seasons, percent stem tunneled significantly decreased with pH and K, but increased with Mg (Table 5b). In the second season, stem damage was positively and negatively related with N and P, respectively, whereas ear damage increased and decreased with Ca and P, respectively (Table 5b).

## Discussion

As previously shown for vegetation and pest densities the gradient in human population density and resulting varying lengths in fallow period were not strong

**Table 5b. Relationships between soil nutrients, and stem and cob damage during (a) first, (b) second seasons of 1995, (c) first and second seasons of 1995 pooled, (d) second season of 1995. Mean  $\pm$  SE of concentration of soil nutrients.**

		b	F	Mean $\pm$ SE
a)	Y %stem tunneled			
	X <sub>1</sub> pH	-0.06	11.02*	5.40 $\pm$ 0.08
	X <sub>2</sub> Mg	0.13	18.50*	0.88 $\pm$ 0.05
	X <sub>3</sub> K	-0.39	6.09*	0.17 $\pm$ 0.01
	Intercept = 0.46, R <sup>2</sup> = 0.24, N = 68			
b)	Y %stem tunneled			
	X <sub>1</sub> P	-0.01	4.43*	4.26 $\pm$ 0.19
	X <sub>2</sub> N	0.70	2.54	0.12 $\pm$ 0.00
	Intercept = 0.19, R <sup>2</sup> = 0.10, N = 62			
c)	Y %stem tunneled			
	X <sub>1</sub> pH	-0.04	9.62*	5.44 $\pm$ 0.06
	X <sub>2</sub> Mg	0.08	19.03*	0.98 $\pm$ 0.05
	X <sub>3</sub> K	-0.13	2.69	0.19 $\pm$ 0.01
	Intercept = 0.40, R <sup>2</sup> = 0.13, N = 130			
d)	Y %cob damage			
	X <sub>1</sub> Ca	0.01	2.62	2.88 $\pm$ 0.24
	X <sub>2</sub> P	-0.01	7.30*	4.26 $\pm$ 0.19
	Intercept = 0.15, R <sup>2</sup> = 0.16, N = 62			

\*F – values significant at P  $\leq$  0.05.

enough to show block differences in soil nutrients nor in plant damage, which can be indirectly affected by nutrients such as N and K (Sétamou et al, 1995; Sétamou and Schulthess, 1995; Denké, 1995). Likewise, yield on a per plant basis did not vary significantly between blocks within the forest zone, but plant densities were highly variable which would result in large yield/area differences. Between quadrate variation explained most of the variance in soil nutrient concentrations followed by field. This explains the relatively weak relationships between soil nutrient, plant and insect variables because the plant sampling was done at random without consideration for quadrates. In future work, the plants should be sampled from within the quadrates.

The seasonal effects were mostly not significant except for K that was higher in the second season. However, the time the samples were taken (e.g., after burning followed by a heavy rain) may affect K concentrations in the first 10 cm from which the samples were taken. By contrast, P was higher in first season. This was mainly due to large seasonal differences in the villages Mvoutessi II and Ngat (11.9 vs. 4.1, 7.9 vs. 2.7 micrograms/gram for the first and second season, respectively) and is probably an artifact due to the sampling procedure. Percent dead hearts was lower in the first than the second season which does not make

much sense since *E. saccharina*, which attacks the plants late at and after tasseling, was the predominant species in the forest during the second season (Chapter four). Overall, however, the %dead hearts were probably too low to have an effect on the per area yield considering plant stand compensation. Because maize is usually mono-cropped and plant densities high, per plant yields were lower in the mid-altitudes than the forest zone.

As for stem borer densities (Chapter four) no differences in yield and plant damage were found between years in the forest, suggesting that the forest locations are yet relatively stable habitats. But as pointed out in Chapter four, this may change with increasing destruction of natural habitats.

As also shown by Usua (1968), Bosque-Pérez and Mareck (1991), Gounou et al. (1994), Sétamou et al. (1995) and Sétamou et al. (1998) for various borer complexes, both stem and ear damage reduced yield in the forest zone whereas ear damage was not significant in the mid-altitude. In two instances, stem bored below the ear was more important than total stem bored corroborating results by Cardwell et al. (1997). Thus, for a quick assessment of stem damage and especially for genotypes with long stems that are common in the forest and the highlands it is recommended to use the stem below the ear only. For first season maize in the mid-altitude, stem damage above the ear was negatively related with yield. By penetrating into the stem via the whorl, *B. fusca* often destroys the tassel before pollen formation. According to C. Thé (IRAD, Nkolbisson, Cameroon, pers. comm.) dead tassels can prevent pollination and thereby grain fill. *B. fusca* contributed most to stem and ear damage and thereby yield loss followed by *E. saccharina*, corroborating results on the relative importance of the individual stem borer species in Cameroon (Cardwell et al., 1997; Chapter four). Damage per larvae was lower for *E. saccharina* than for *B. fusca*. This may be due to the generally smaller size of *E. saccharina* larvae and the fact that this species attacks the plant during and after tasseling, thus it feeds for a relatively shorter time. *Mussidia nigrivenella*, the most voracious ear feeding pest in the Republic of Benin (Sétamou et al., 1998), was of low importance though it contributed significantly to cob damage during most seasons in both the forest zone and mid-altitude.

*Busseola fusca* numbers as well as plant damage decreased with soil K and P and increased with Mg. K is reported to affect herbivore survival and development by its effects on plant morphology and metabolism (Perrenoud, 1990). A sufficient K and P supply tend to harden plant structures. This hardening of plant structures is generally considered to improve mechanical resistance to penetration by pathogens and to feeding by insects (See overview by S. Perrenoud, 1990). Also, an adequate K nutrition increases the content of total phenols and ortho-dihydroxy phenols in plants. Phenols play a beneficial role in host plant resistance (Perrenoud, 1990; Price, 1997). Sétamou and Schulthess (1995) also found a negative relationship between *S. calamistis* numbers and soil K during surveys in farmers' fields in Benin. Subsequent life table studies carried out on plants subjected to varying K fertilizer dosages yielded a curvilinear relationship between K dosages and intrinsic rate of increase and a strong negative relationship with fecundity of both *S. calamistis* and *E. saccharina* (Denké, 1995). Thus, for diapausing species under isolated conditions such as forest fields, K may have a long term effect on population densities via reduced fecundity. The amount of available K in the soil affects the ability of plants to extract Mg and vice versa (J Wendt, pers. comm.). Thus, since Mg is antagonistic to K, high Mg concentration will render the plant susceptible to pest attack and damage, thus the relationship between *B. fusca* numbers as well as stem damage was often positive. Also an insufficient K supply results in the accumulation of soluble low molecular compounds such as soluble N-compounds and carbohydrates and this is often accompanied by increased herbivory (Trolldonier and Zehler, 1976 in Perrenoud, 1990).

*Busseola fusca* was the only species responding significantly to soil nutrient concentrations. Most other species were relatively scarce (See chapter four). *Eldana saccharina*, which in the forest is common during the second season, attacks the plant late when maize roots are already below the 30cm depth, from which the samples were taken, thus not allowing for quantification of interactions with more soluble nutrients such as K and N. Likewise, Sétamou and Schulthess (1995) found relationships for *S. calamistis* only which, like *B. fusca*, attacks the plant at an early growth stage. No relationships were found with N or with the

C/N ratio for any of the species. This is in contrast to results of fertilizer trials and life table studies by Sétamou et al. (1993, 1995) which showed that N increased both survival and fecundity of *S. calamistis* and promoted field infestations by *E. saccharina*. In the present study, however, N concentrations were generally very low and, moreover, the plants were not sampled from within the quadrates from which the soil samples were taken thereby diluting the effect of N on plant and pests

The mean yield losses calculated via equations in Table 3 were between 1.2 and 12% and maximum losses (using maximum stem and ear damage values) between 23.8 and 60.7%. Regression analyses are useful for assessing the relative importance of an insect species on a region-wide basis or to show drastic changes in the pest status of a species. When compared with results from exclusion trials, however, the yield loss estimates produced are considerably lower. As shown by Gounou et al. (1994) and Sétamou et al. (1995) the relationship between stem borer numbers and yield are often positive because survival is higher on vigorous plants or the numbers increase with age of the plant. The latter is especially true for species attacking the plant late (e.g., *E. saccharina* and *M. nigrivenella*). For species whose larvae migrate within and between plants such as *B. fusca* the stem damage to yield relationships were never as strong as for, e.g., *S. calamistis* (Gounou et al., 1994; Sétamou et al., 1995; G. Bigirwa, NARO, Uganda, pers. comm.). Also, in the forest zone, maize is mostly consumed as a fresh vegetable, and green ears with borers cannot be sold. Often the second ear is completely destroyed by *B. fusca*, thus, ear damage is underestimated because it is assessed from surviving maturing cobs only. In addition ears damaged by stem borers are early colonized by storage pest and molds causing increased contamination of mycotoxins such as aflatoxin and fumonisin (Sétamou et al., 1998; Cardwell et al., submitted). In order to get more realistic yield estimates entire quadrates should be harvested in future work, which would include plants without cobs. Ideally, half of the quadrates would be treated with an insecticide. Resulting yield differences including soil nutrient data from the same quadrates would give more realistic production equations.

## CHAPTER 6

**Multi-trophic interactions in maize cropping systems in the forest zone of Cameroon with special reference to the noctuid stalk borer *Busseola fusca* (Fuller) and *Telenomus* spp. (Hym: Scelionidae) egg parasitoids**

**Introduction**

*Busseola fusca* (Fuller) (Lep.: Noctuidae) is the most important maize pest in the humid forest zone of Cameroon, though the pyralid *Eldana saccharina* (Walker) can become predominant during the second season, from September onwards (Cardwell et al, 1997; Chapter four). Previous research showed that pest densities and plant damage varied greatly within and between fields as well as between seasons (Chapters four and five). No significant differences were found, however, between pre-selected ‘blocks’, representing gradients in human population density and thus length of fallow period. The gradients appeared not to be strong enough to produce marked between-block differences in vegetation and soil nutrient concentrations, which, in turn, would affect yield and pest infestations (Sétamou et al., 1993, 1995; Sétamou and Schulthess, 1995; Schulthess et al., 1997a; Denké, 1995). Thus, forest fields in Cameroon represent islands within non-cultivated habitats. Some of the variability within field was attributed to soil nutrients but the explained variance of multiple regression between soil, plant and pest variables was low (Chapter five). This was partly due to high within-field variability in nutrient concentrations, the sampling procedure chosen, and time of sampling which determined availability of some nutrients in the first 30cm depth from which the samples were taken. Not included in these studies were biotic control factors. In West Africa, the most commonly found natural enemies of noctuid stem borers are *Telenomus busseolae* (Gahan) and *T. isis* (Polaszek) (Hym.: Scelionidae), egg parasitoids of *B. fusca* and *Sesamia* spp. (Polaszek and Kimani, 1990; Polaszek et al., 1993; Sétamou and Schulthess, 1995; Bosque-Pérez et al. 1994). Egg parasitism is recognised to be an important source of mortality as the pest is killed before it damages the crop (Temerak, 1981). In southern Benin which consists mostly of derived savanna these parasitoids are thought to be the most important natural control factors of *S.*

*calamistis* on maize (Sétamou and Schulthess, 1995; Chabi-Olaye et al., 1997; Schulthess et al., 1997a). At the beginning of the second cropping season, mean egg parasitism in farmers' fields was more than 95%. As a result pest incidence is <20% as compared to >50% in the forest zone in other countries (Nigeria and Ghana) (Schulthess et al., 1997a). In contrast to West Africa, pest infestations in the forest zone of Cameroon do not drastically increase in the course of the rainy season (Cardwell et al., 1997; Chapter 4). In 1995, for example, *B. fusca* larva densities were considerably lower during the second than the first season, although egg batch incidence was significantly higher (Chapter four). It was speculated that egg parasitism played an important role. Thus, the present study puts emphasis on assessing the effect of egg parasitoids on *B. fusca* infestations in the humid forest zone. Finally, an attempt is made to allocate the direct and indirect effect of the different components of the system such as vegetation as affected by human population pressure, including alternative hosts of pests, soil nutrients, and natural enemies on yield of maize. Such an in-depth analysis of the pest's ecosystem, as begun in chapters four and five, is the first step towards developing a biologically based sustainable pest management strategy for intractable problems such as *B. fusca* (van Emden, 1989; Smith et al., 1993; Phiri, 1995; Schulthess et al., 1997a, 1997b).

## Materials and methods

### *Data collection*

This work utilises biotic (maize growth, pest damage and numbers according to species, vegetation including alternative hosts, densities of hosts and non-hosts, natural enemies) and abiotic (soil nutrients) data collected during surveys in farmers' fields at six benchmark locations in the humid forest zone in Cameroon, during the first and second season of 1995. (The procedures for selecting benchmark locations in the forest zone, vegetation scores, sampling procedures for plants and borers are described in chapter four, and for assessment of densities of maize and other crops as well as for soil nutrients in chapter five.)

Egg parasitism was assessed during the vegetative growth stage of maize from May 16 to June 7, 1995 (first season) and October 10 to November 2, 1995

(second season). Fifty maize plants from 148 fields were sampled randomly (77 for first season and 71 for second season). After counting the eggs, each batch was kept in an individual plastic container in the laboratory in Nkolbisson for six weeks during which either larvae or parasitoids had emerged and died (Sétamou and Schulthess, 1995). The numbers of emerged parasitoids per egg batch were counted, and *Telenomus* spp. were identified and sexed using the key by Polaszek et al. (1993). Parasitization was assessed per batch (number of parasitoids per batch, including non-hatched/total number of eggs per batch) and for egg batches per field (egg batches with parasitoid/total egg batches found in a field) to obtain information about the searching capacity of a parasitoid (Bin and Vinson, 1990; Sétamou and Schulthess, 1995). A large proportion of the parasitoids reached adulthood but failed to hatch. For logistic reasons, non-hatched eggs could not be dissected for identification of species, thus the results presented for individual species are based on hatched parasitoids only which underestimates the real values. Parasitoid mortality was expressed as a percentage of parasitoids not hatched on total numbers. ‘Mixed parasitism’ refers to fields in which more than one species was found. For each species, sex ratio was calculated as the proportion of females over the total number of adult parasitoids.

For each season and field, the percentage of *B. fusca* larvae found at harvest over numbers of eggs at the vegetative stage was calculated. Since in the forest most maize is harvested in the soft dough stage, few borers had reached adulthood at the time of sampling. Thus, it is assumed that those percentages represent *B. fusca* immature mortality, probably mostly due to egg parasitism and to the effect of rainfall on eggs and first larval instars (Schulthess et al., submitted).

In addition to general vegetation scores (See Chapter four), the abundance of alternative hosts such as grasses surrounding each field was scored from 0 to 3, with 0 = no grasses and 3 = 100% grasses.

#### *Statistical analyses*

Analyses of variance with a mixed model procedure (SAS, 1997) was used in a nested design to assess differences in the various parasitism variables. Season and block were fixed effects while field, location and location interactions were random.

Correlation analysis and stepwise multiple regressions were computed to assess interactions between the different abiotic and biotic components of the system. (Relationships among plant, pests and soil nutrients were presented in chapter five and are not shown in the correlation matrix in Table 2). Counts were log (x+1) transformed and percentage data and rates arcsin  $\sqrt{p}$  transformed before analyses.

## Results

### *Importance of B. fusca egg parasitism according to block, location, field and season*

During the first and second season, respectively, 386 and 1000 egg batches were collected. The only egg parasitoid species found were *T. busseolae* and *T. isis* with the former as the predominant species.

For all egg parasitoid variables between field variation explained most of the variance, whereas location played a minor role (Table 1). No significant differences were found between blocks with the exception of parasitoid mortality, with across season and location means of 59.3% in the Mbalmayo and 40.5% in both the Ebolowa and Yaoundé blocks ( $P<0.05$ ).

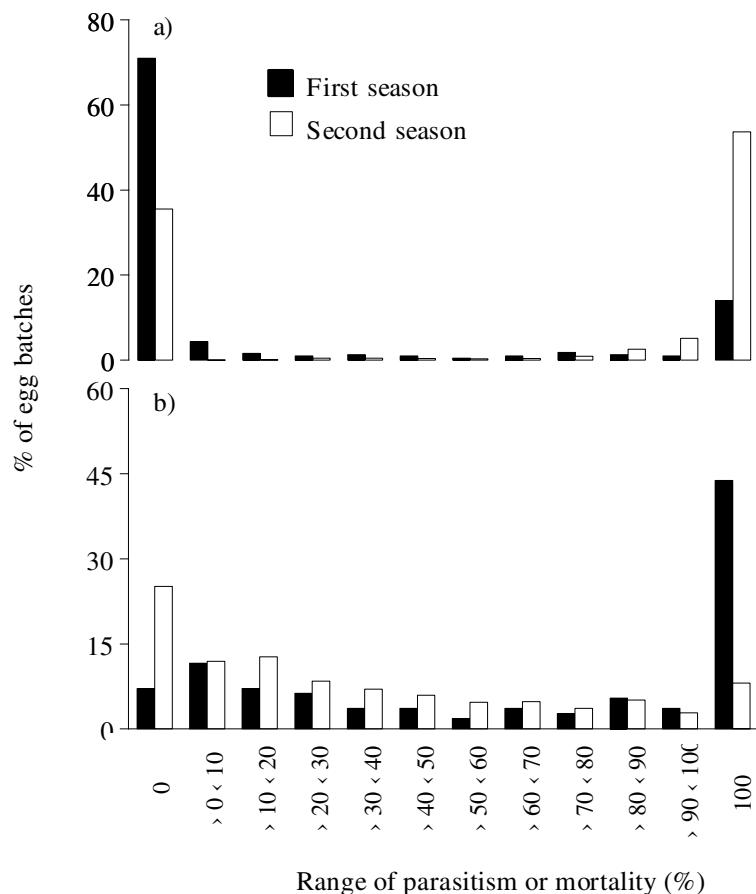
**Table 1. Effect of location\* on total egg parasitism, sex ratio, egg masses parasitized (EMP), parasitoid mortality (BM) and immature mortality of *B. fusca* (BfM) in the first and second season of 1995 in the forest zone of Cameroon. Values of individual species are based on hatched parasitoids only.**

<b>Random effects</b>	% parasitism				Sex ratio				%EMP	%PM	%BfM
	Total	<i>T. isis</i>	<i>T. buss.</i>	Mixed	Total	<i>T. isis</i>	<i>T. buss</i>				
Location (Block)	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0
Season x Loc. (Bl.)	28.6	4.2	0.0	5.5	14.6	30.9	0.0	16.9	21.1	0.0	0.0
Between fields	71.4	95.8	100	94.5	81.3	69.0	100	83.1	78.9	100	100
<b>Fixed effect</b>											
First season LSM	19.9	1.2	0.2	0.06	0.21	0.40	0.01	17.6	59.4	60.5	
Second season LSM	66.9	2.2	23.9	0.03	0.67	0.06	0.44	67.9	35.5	93.2	
t	-5.9	-0.8	-10.8	0.40	-3.72	2.21	-7.08	-5.6	2.1	-8.5	
P <sub>diff</sub>	0.01	0.49	0.002	0.71	0.033	0.11	0.006	0.01	0.12	0.003	

\*Blocks = 3 (fixed); locations = 2 per block; fields = minimum of 12 per location; plants per field = 50; Significance was set at  $P \leq 0.05$ .

In the first and second season, parasitized eggs were found in, respectively, 45.8 and 98.6% of the fields. Egg and egg batch parasitism as well as sex ratio of the species complex and of *T. busseolae* but not *T. isis* were significantly and considerably higher during the second than the first season (Table 1). Concomitantly, immature mortality of *B. fusca* increased significantly from 60.5

to 93.2%. By contrast, unexplained mortality (difference between total parasitism and *B. fusca* mortality) decreased from 40.6% during the first to 26.3% during the second season. In the first season, 71% of the batches had zero and 14% had hundred percent of the eggs parasitized. In the second season, the situation was reverse with 35 and 56.7%, respectively (Fig. 1). The percentages of fields yielding both parasitoids (mixed parasitism) were low with 21.2 and 2.9% during the first or second season, respectively, or <1% if fields without parasitoids were included (Table 1).



**Fig. 1. Frequency distribution for a) parasitism and b) parasitoid mortality within egg batch during the fist and second season 1995 in the forest zone of Cameroon**

**Table 2. Pearson's correlations for yield, *B. fusca* egg infestation, egg parasitism, *B. fusca* numbers at harvest and damage across the first and second seasons in six benchmarks in the forest zone.**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1.00																	
2	.03	1.00																
3	-.11	.00	1.00															
4	-.03	.92*	.08	1.00														
5	.20*	.38*	-.32*	.42*	1.00													
6	.19*	.42*	-.34*	.48*	.91*	1.00												
7	.14	-.16	.09	-.14	-.19*	-.04	1.00											
8	.14	-.02	-.13	.00	.18	.20*	.08	1.00										
9	.07	.56*	-.22*	.61*	.51*	.60*	-.08	-.42*	1.00									
10	.07	-.32*	-.01	-.37*	-.26*	-.26*	.31*	.85*	-.72*	1.00								
11	.10	.40*	.19	.49*	.29*	.39*	-.03	-.70*	.90*	-.72*	1.00							
12	-.25*	-.08	.44*	-.12	-.42*	-.45*	-.04	-.03	-.34*	-.17	-.35*	1.00						
13	-.11	.32*	.28*	.36*	.12	.19*	-.13	.08	.15	-.03	-.08	.50*	1.00					
14	-.11	-.13	.33*	-.11	-.30*	-.27*	-.14	-.07	-.18*	-.03	-.13	.76*	.54*	1.00				
15	.18	.41*	-.42*	.45*	.53*	.53*	.02	-.01	.44*	-.25*	.46*	-.73*	-.25*	-.52*	1.00			
16	-.09	-.28*	.08	-.34*	.02	-.15	-.16	-.22*	-.39*	-.07	-.18	.16	-.09	.08	-.27*	1.00		
17	-.05	.13	.07	.19*	.19*	.21*	.01	.00	.28*	-.10	.14	-.01	.22*	-.01	-.01	-.23*	1.00	
18	-.04	-.17*	.23*	-.16*	-.29*	-.24*	.01	-.05	-.14	.02	.00	.18*	-.05	.06	-.19*	-.03	-.07	1.00

Significance was set at P ≤ 0.05.

1) Cob weight 2) Number of egg batches per plant 3) Number of eggs per mass 4) Percent plants infested with egg batches 5) Total percent egg batches parasitized 6) Total percent eggs parasitized 7) *Telenomus* spp. sex ratio 8) *T. isis* parasitism 9) *T. busseolae* parasitism 10) *T. isis* sex ratio 11) *T. busseolae* sex ratio 12) Mean number of *B. fusca* per plant 13) Total percent stem tunneled 14) Percent cob damage 15) *B. fusca* egg-larvae mortality 16) Parasitoid mortality 17) Mean number of maize plants per 25m<sup>2</sup> 18) Abundance of grasses in the vicinity of fields.

Parasitoid mortality was high during both seasons (Table 1). In the first and second season, respectively, 43.8 and 8.1% of the parasitized egg batches had 100% parasitoid mortality and 25.8 vs. 49.7% with 0-20% mortality (Fig. 1).

#### *Interactions between *B. fusca* egg infestation and parasitism*

As results of correlation analyses showed similar trends for both seasons a pooled analysis was done and presented in Table 2. Across both seasons, egg parasitism was positively correlated with egg batch parasitism, and both with egg and egg batch density but negative with egg batch size (Table 2). If analysed separately for species, *T. busseolae* parasitism was strongly correlated with egg density and *Telenomus* spp. parasitism variables whereas *T. isis* was only related to egg batch parasitism. (Since the two species were rarely found in the same field and parasitism and sex ratios per species were based on hatched individuals only, interactions between them are not further discussed.) Parasitoid mortality was negatively related to egg batch and egg density. Abundance of grasses in the vicinity of the field was negatively related to egg batch numbers and incidence as well as egg and egg batch parasitism but positively to egg batch size.

#### *Effect of biotic and abiotic factors on *B. fusca* numbers at harvest*

Stepwise regressions showed that in the first season *B. fusca* numbers were positively related to number of eggs per plant and soil carbon and negatively to egg batch parasitism, respectively (Table 3). During the second season, egg batch incidence was positive and *Telenomus* spp. sex ratio and density of the non-host cassava were negatively related to *B. fusca* numbers at harvest. Similar trends as in the first season were found when the analysis was done combined for both seasons. In the correlation analysis, *T. busseolae* parasitism and sex ratio were both negatively related with *B. fusca* but no relationships were found with *T. isis* (Table 2).

In stepwise regressions, immature mortality of *B. fusca* during the first season increased with egg batch parasitism and decreased with maize density and soil Mg whereas during the second season, egg batch incidence and soil pH were negative and parasitoid sex ratio and soil P were positive (Table 4).

**Table 3. Effect\* of egg infestation, egg parasitism, abundance of grasses around fields, mean number of maize and cassava plants per 25m<sup>2</sup> and soil nutrients on *B. fusca* infestations at harvest during (a) the first, (b) second, and (c) across the first and second seasons.**

		b	F	Mean ± SE
a)	Y no. of <i>B. fusca</i> at harvest			
	X <sub>1</sub> no. of eggs per plant	0.28	9.82*	2.2 ± 0.2
	X <sub>2</sub> %parasitized egg batches	-0.26	4.52*	25.6 ± 2.9
	X <sub>3</sub> P	-0.02	2.31	6.8 ± 0.5
	X <sub>4</sub> C	0.51	11.34*	1.6 ± 0.1
	Intercept = -0.08, R <sup>2</sup> = 0.33, N = 64			
b)	Y no. of <i>B. fusca</i> at harvest			
	X <sub>1</sub> %plant infested with egg batches	0.80	14.86*	23.0 ± 1.3
	X <sub>2</sub> <i>Telenomus</i> spp. sex ratio	-0.43	10.10*	0.7 ± 0.0
	X <sub>3</sub> no. of maize plants per 25 m <sup>2</sup>	0.01	3.19	23.5 ± 1.9
	X <sub>4</sub> no. of cassava plants per 25 m <sup>2</sup>	-0.01	7.55*	31.1 ± 2.2
	Intercept = 0.39, R <sup>2</sup> = 0.44, N = 41			
c)	Y no. of <i>B. fusca</i> at harvest			
	X <sub>1</sub> no. of eggs per plant	0.17	5.36*	3.4 ± 0.2
	X <sub>2</sub> % parasitized eggs	-0.53	23.92*	40.7 ± 2.6
	X <sub>3</sub> C	0.23	4.46*	1.6 ± 0.0
	Intercept = 0.31, R <sup>2</sup> = 0.22, N = 107			

\*Stepwise multiple regressions; F values significant at P ≤ 0.05.

**Table 4. Effect\* of plant stage, egg infestation, egg parasitism, soil nutrients as well as mean number of maize and cassava plants per 25m<sup>2</sup> on *B. fusca* immature mortality during (a) the first, and (b) the second seasons 1995.**

		b	F	Mean ± SE
a)	Y %mortality of <i>B. fusca</i>			
	X <sub>1</sub> plant stage	-0.16	2.56	7.0 ± 0.1
	X <sub>2</sub> % parasitized egg batches	0.30	5.67*	25.6 ± 2.9
	X <sub>3</sub> no. of maize plants per 25 m <sup>2</sup>	-0.01	4.29*	18.0 ± 0.9
	X <sub>4</sub> Mg	-0.21	4.51*	0.9 ± 0.1
	Intercept = 2.32, R <sup>2</sup> = 0.30, N = 49			
b)	Y %mortality of <i>B. fusca</i>			
	X <sub>1</sub> %plants infested with egg batches	-0.38	6.76*	23.0 ± 1.3
	X <sub>2</sub> <i>Telenomus</i> spp. sex ratio	0.31	14.86*	0.7 ± 0.0
	X <sub>3</sub> pH	-0.06	3.67*	5.7 ± 0.0
	X <sub>4</sub> P	0.02	7.08*	7.8 ± 0.3
	Intercept = 0.34, R <sup>2</sup> = 0.72, N = 41			

\*Stepwise multiple regressions; F values significant at P ≤ 0.05.

#### *Biotic and abiotic factors that affect yields of maize*

Across the first and second season, cob damage was positively correlated with egg batch size and numbers of *B. fusca* at harvest and negatively with *Telenomus* spp. egg and egg batch as well as *T. busseolae* parasitism (Table 2). By contrast, the relationship between egg parasitism and tunnelling was not negative as expected from the negative relationship with *B. fusca* numbers. For the first season, stepwise regression yielded a negative relationship between cob weight and eggs per plant at vegetative stage and soil Mg and a positive relationship with egg batch parasitism and plant growth stage (Table 5). During the second season,

plant growth stage and *Telenomus* spp. sex ratio were both positive (Egg parasitism remained in the equation but was not significant at  $P \leq 0.05$ ). Using pooled data across both seasons, none of the parasitoid variables was significant.

**Table 5. Effect\* of plant stage, *B. fusca* egg infestation, egg parasitism, *B. fusca* and *E. saccharina* numbers at harvest and soil nutrients on cob weight during (a) the first and (b) second season.**

		b	F	Mean ± SE
a)	Y Cob weight			
	X <sub>1</sub> plant stage	15.74	4.46*	7.0 ± 0.1
	X <sub>2</sub> eggs per plant	-17.23	6.17*	2.2 ± 0.21
	X <sub>3</sub> %parasitized egg batches	23.55	7.53*	25.6 ± 2.9
	X <sub>4</sub> Mg	-17.98	4.33*	0.9 ± 0.1
	Intercept = 51.5, R <sup>2</sup> = 0.33, N = 65			
b)	Y Cob weight			
	X <sub>1</sub> plant stage	17.55	5.06*	7.6 ± 0.1
	X <sub>2</sub> %parasitized eggs	-32.87	2.40	64.3 ± 2.3
	X <sub>3</sub> <i>Telenomus</i> spp. sex ratio	49.34	3.87*	0.7 ± 0.0
	Intercept = 2.2, R <sup>2</sup> = 0.12, N = 61			

\*Stepwise multiple regressions; F values significant at  $P \leq 0.05$ .

## Discussion

As indicated by the low contribution of block and locational effects to overall variance, forest fields constitute rather isolated habitats where pest populations are affected by edaphic, microclimatic and biotic factors such as natural enemies and alternative host as well as non-host plants in the vicinity of the field (Cardwell et al., 1997; Schulthess et al., 1997a; Chapters four, five). This is corroborated by the fact that most fields harboured only one or the other egg parasitoid species indicating that little interactions occurred between fields of the same location.

The present findings showed that in spite of a 70% higher egg batch density at the beginning of the second season, which should have lead to severe borer attacks in October-November, typical for the forest zone in West Africa (Carter, 1985; Uzakah, 1988; Gounou et al., 1994; Schulthess et al., 1997a), *B. fusca* larval infestations at harvest were only one third of those found during the first season, as a result of egg parasitism averaging 67%. Thus, in the forest zone of Cameroon parasitism by *Telenomus* spp. was one of the key mortality factors of *B. fusca*, and thereby positively affected maize yields during both cropping seasons. Taking into consideration that the species were determined from hatched individuals only *T. busseolae* was the predominant species especially during the second season.

Peak egg parasitism, however, was considerably lower than the 95% found

across southern Benin on *S. calamistis* (Schulthess et al., 1997a; Schulthess et al., submitted). In Benin, a continuous availability of alternative host plants (grass scores are typically between 2-3 versus <0.3 in the present work), and thereby prey, probably stabilises the system thereby allowing for a gradual increase in parasitization rates during the cropping season. Thus besides acting as trap plants (Schulthess et al., 1997a; Cardwell et al., 1997) wild hosts may constitute also a reservoir for hosts of egg parasitoids. Typically, in areas with high abundance of alternative host, *S. calamistis* and *B. fusca* have the status of occasional pests only (Schulthess et al., 1997a). By contrast, in the forest zone of Cameroon, *B. fusca* is of economic importance during both seasons, but unlike *S. calamistis* and *E. saccharina* in West Africa, more so during the first. *B. fusca* diapauses during periods of food scarcity, i.e., the dry season when populations of non-diapausing species such as *S. calamistis* and *E. saccharina* crash to close to zero (Kouamé, 1995; Schulthess and Ajala, 1999). Thus, initial egg densities produced by the emerging female *B. fusca* in spring were obviously too high to be controlled by *Telenomus* spp., as shown by an average parasitism of only 19.9%, resulting in high infestations during the first season. By contrast, non-diapausing species have to start from close to zero, and females emerging in the first season from wild hosts mainly are small with low fecundity (Shanower et al., 1993; Sétamou et al., 1993). Thus, they reach damaging levels during the second season only.

In the present study, the sex ratio of *Telenomus* spp. varied between 0.21 in the first season and 0.67 in the second season. A similar seasonal trend was observed in Benin, but the ratios were considerably higher ranging between 0.65-0.85 for both species (Schulthess et al., submitted). A low sex ratio, i.e., low proportion of females, may be an adaptation to low pest densities, thus, stabilising the system for the parasitoid by preventing over-exploitation of hosts and thereby local eradication of both pest and natural enemies. This is especially crucial for isolated ecologies such as maize fields in the forest.

During both seasons, parasitoid mortality as indicated by failed emergence was high. In the first season when egg batch density was low, 44% of the batches had 100% mortality vs. 8.1% in the second season when egg batch densities were high (Fig. 1). Parasitoid mortality may have been due to handling, diseases and/or

superparasitism, possibly as a result of overcrowding. In Benin, Schulthess et al. (1997a; Schulthess et al., submitted) reported up to three species emerging from the same *S. calamistis* egg batch and suspected superparasitism. Superparasitism can be an adaptive reproductive strategy for parasitoids when hosts are scarce and the likelihood of finding unparasitized host is low (Charnov and Skinner, 1985; van Alphen and Visser, 1990). Recent work by Agboka et al. (submitted) showed self-, intra- and interspecies superparasitism for both *Telenomus* spp. on *S. calamistis*, but the two species recognized their own as well as each others marking and avoided superparasitism if non-parasitized eggs were available. If the two species parasitized shortly after each other *T. busseolae* was always the winner. If the second individual parasitized 24 hours later, the first species predominated but parasitoid mortalities were around 40%. This could explain the prevalence of *T. busseolae* but not the high parasitoid mortality in the forest zone in Cameroon since egg as well as egg batch parasitism, especially during the first season, were low. Moreover, there was no correlation between parasitoid mortality and egg or egg batch density, a negative indicating overcrowding. Mortality due to handling cannot be excluded but would not explain the difference in frequency distribution among the two seasons (Fig. 1). The high percentage of batches with 100% mortality points to diseases. Whatever the cause, parasitoid mortality during the first season may not be a disadvantage. Given the isolated conditions of maize fields in the forest, the lack of alternative host plants and the habit of *B. fusca* to go into diapause when climatic conditions and the food source are suboptimal (Adeyemi, 1969), high parasitism combined with high sex ratio and low parasitoid mortality during the first season would lead to local extinction of the parasitoid. Theoretically this should lead to higher *B. fusca* density during the second season - and actually, that's exactly what may cause the high densities in the first season.

As shown in Fig. 1, most egg batches had either 0 or 100% of the eggs parasitized, resulting in low and high egg batch parasitism during the first and second season, respectively. Egg batch parasitism of only 17.6% in the first season indicates difficulties in host finding due to low host numbers whereas the low egg parasitism of 19.9% was probably due to low female fecundity as a result

long searching time and consequent resorption of eggs. As shown by Chabi-Olaye et al. (1997) for *T. busseolae*, if the female was prevented from laying eggs for more than ten days total parasitism decreased linearly but longevity increased. The same trends were observed for *T. isis* but fecundity was only about half of *T. busseolae* (Chabi-Olaye, unpubl. data). These experiments were done in the laboratory with continuous supply of honey as a food source. Thus, it can be expected that the decrease in fecundity is much more drastic under natural conditions and especially in forest ecologies where both host plants and borers are scarce and a lot of energy is spent on host finding. Because of increased availability of hosts, which reduced searching time, the percentage of batches completely parasitized increased from 14% in the first season to 53.7% during the second season and vice versa for batches with zero parasitism. The tendency of *Telenomus* spp. to fully exploit an egg batch was also reported by Sétamou and Schulthess (1995) from *S. calamistis* in Benin. This oviposition strategy – putting all eggs in one basket- together with the long egg retention capacity (Chabi-Olaye et al., 1997) indicates that *Telenomus* spp. are adapted to rapidly changing environmental conditions leading to scarcity of eggs and difficulties in host finding.

The present data do not allow interpretation of interactions between *Telenomus* species because non-hatched parasitoids were not identified. In Benin, for *T. isis* only a strong positive relationship with *S. calamistis* egg batch density was found and it was concluded that *T. busseolae* must have an alternative host (Schulthess et al., submitted). In the present study, only *T. busseolae* was positively correlated with *B. fusca* egg batch density. This may indicate that *T. isis* is more adapted to *S. calamistis* whereas *T. busseolae* coevolved with *B. fusca* and may be the key mortality factor for this species in the Dahomey gap and vice versa for *S. calamistis* in Cameroon (See chapter four). This is corroborated by the fact that *T. busseolae* is the only of the two *Telenomus* species occurring in East and Southern Africa (Polaszek et al., 1998) where *B. fusca* is the most important indigenous cereal pests (Swaine, 1957; Smithers, 1960; Ogwaro, 1983; van Rensburg et al., 1988; Gebre-Amlak et al., 1989; Seshu Reddy et al., 1990; van den Berg et al., 1991; Overholt et al., 1994; Phiri, 1995).

Whatever inferences we make about the evolution of these parasitoids, we have to take into consideration that the present data were obtained from human made ecologies and that maize is not only exotic to the system but in terms of nutritional quality far superior to the wild hosts (Shanower et al., 1993; Sekloka, 1996; Sémeleglo, 1997). Thus, during the cropping season maize is probably the most important key component affecting the population dynamics of the borer and its natural enemies whereas wild hosts play a minor although a significant role. In the forest, most grasses are thin-stemmed, therefore not allowing borers to complete a life cycle, and abundance scores were very low with means of  $0.28 \pm 0.05$  and  $0.11 \pm 0.03$  for the first and second season. The present findings and the negative relationship between grass abundance and borer incidence in maize fields found in road side fields in Cameroon, Côte d'Ivoire and Ghana (Cardwell et al., 1997; Schulthess et al., 1997a; Schulthess, unpubl. data) suggest that alternative host plants not only act as trap plants for borer larvae but they also stabilize the system for egg parasitoids and thereby may reduce damage to maize.

The only significant soil nutrient factor that entered the multiple regression equations were P and Mg, which were negatively and positively related with *B. fusca* densities, respectively. The amount of available Mg in the soil affects the ability of plants to extract K and vice versa. A sufficient supply of both K and P tends to harden plant structures which is considered to improve mechanical resistance to penetration by pathogens and to feeding by insects (See overview by S. Perrenoud, 1990). Also adequate K-nutrition increases the content of total phenols and ortho-dihydroxy phenols in plants. Phenols play a beneficial role in host plant resistance (Perrenoud, 1990; Price, 1997). Sétamou and Schulthess (1995) found a negative relationship between *S. calamistis* numbers and soil K during surveys in farmers' fields in Benin. Subsequent life table studies carried out on plants subjected to varying K fertilizer dosages yielded a curvilinear relationship between K dosages and intrinsic rate of increase and a negative relationship with fecundity of both *S. calamistis* and *E. saccharina* (Denké, 1995). Thus, as put forward in chapter five, for diapausing species under isolated conditions such as forest fields, K may have a long-term effect on population densities via reduced fecundity. Trials are planned for derived savanna ecologies

in Benin and Nigeria, and for forest ecologies in Cameroon to assess the impact of a combination of N and K on plant and pests.

The relationships between *B. fusca* larval density and maize (positive) and cassava (negative) plant densities was probably a result of, respectively, enhanced and reduced host finding. First instar *B. fusca* move to the whorl and either penetrate into the stem or let themselves be dispersed by wind. Under high maize density conditions, the chance to land on a suitable host are high, whereas a high density of cassava, which is a non-host, would cause high mortality as a result of starvation or predation. Thus, further studies are proposed to evaluate the effect of cropping densities (number of plants per area) and arrangement (number of plants per hole and area) of hosts and non-hosts such as cassava and groundnut which are commonly intercropped with maize in the forest zone.

The seasonal differences in ‘unexplained mortality’ (immature mortality minus total parasitism) was probably due to rainfall mortality- i.e., drowning of young larval instars in the whorl- which, in accordance with the rainfall pattern, is expected to be higher during the first cropping season. Typically, farmers in West African countries often confound first season attacks of *B. fusca* with drought (Schulthess, unpubl. data).

## CHAPTER 7

**Natural enemies of lepidopterous borers on maize and elephant grass in the forest zone of Cameroon with special reference to *Busseola fusca* (Fuller)**  
**(Lep.: Noctuidae)**

**Introduction**

The exchange or ‘redistribution’ of natural enemies between regions of a continent to control lepidopterous cereal stem borers has been proposed by several authors (Rao, 1965; Mohyuddin and Greathead, 1970; Mohyuddin et al., 1981; Mohyuddin, 1991; Schulthess et al., 1997a). Several candidates have been proposed including the tachinids *Sturmiosis parasitica* Currant and *Descampsina sesamiae* Mesnil against *Eldana saccharina* Walker (Lep.: Pyralidae) on sugarcane in South Africa, *Psilochalcis soudanensis* Steffan (Hym: Chalcididae) against *Chilo* spp. within eastern Africa, and the scelionid *Telenomus isis* Polaszek against the noctuid *Busseola fusca* (Fuller) in East and Southern Africa. More recently, a coastal strain of the braconid larval parasitoid *Cotesia sesamiae* (Cameron) from Kenya was released and established on the noctuid *Sesamia calamistis* Hampson in southern Benin (Schulthess et al., 1997a).

Establishment of a catalogue of natural enemies and their geographic distribution is the first step in identifying promising candidates of redistribution. Such catalogues exist for various countries and crops (See Jerath, 1968; Mohyuddin and Greathead, 1970; Ingram, 1983; Conlong, 1990; Bosque-Pérez et al., 1994; Kfir, 1995; Phiri, 1995) and the findings have been summarized by Polaszek (1998). Vast areas, in especially Central Africa are still blank spots on the map. The present work is an attempt to establish a catalogue of natural enemies of stem borers on maize in the forest zone of Cameroon. In addition, the temporal distribution of natural enemies of the noctuid *B. fusca*, the economically most important borer species in Cameroon (Cardwell et al., 1997; Chapter four), was studied on both maize and the wild host *Pennisetum purpureum* at two locations.

## Materials and methods

### *Data collection*

#### *Sampling of *B. fusca* egg parasitoids*

Eggs of other species than *B. fusca* are difficult to detect and density estimates are therefore unreliable. Moreover, *S. calamistis*, the other species that lays the eggs between the leaf sheaths and the stem, was very rare (Chapter four). Thus, the present work focuses on *B. fusca* eggs only. The sampling procedures for *B. fusca* egg batches on maize and elephant grass at Minkomeyos and Nkolbisson in 1995 are given in chapters two and three, respectively, and in maize fields at six benchmark locations during the first and second cropping seasons of 1995 in chapter three. After counting the eggs, each batch was placed individually in small round plastic containers, well closed in the laboratory for six weeks during which either larvae or parasitoids had emerged and died (Sétamou and Schulthess, 1995). The numbers of emerged parasitoids per egg batch were counted. The percentage parasitization was assessed from the total number of parasitized eggs including non-hatched parasitoids. All parasitoids collected were preserved in small vials containing 70% alcohol. *Telenomus* spp. and their sexes were identified using the keys provided by Polaszek et al. (1993).

#### *Sampling of larval/pupal parasitoids*

The sampling procedures for lepidopterous borer larvae and pupae on maize and elephant grass during 1995 at Minkomeyos and Nkolbisson, and on maize in the benchmark sites are described in chapter two and three, and chapter four respectively. During each sampling date, all the borer larvae and pupae collected were identified according to species. At each sampling date all the larvae of the same species from the same quadrate or field per location were counted and placed in rearing wide mouth jam bottles. Young succulent stem and ear pieces of maize were given as diet. The bottles were labeled according to species and location. The bottles were then covered with white lace cloth for proper aeration using elastic rings fastened around their mouth. The maize diet was changed every other day. The larvae were reared in this manner until pupation or parasitoid emergence. When the diet was changed, dead larvae were placed individually in

small round plastic containers and kept in the laboratory for parasitoid emergence. Pupae collected were kept individually in small round plastic containers for parasitoid or adult moth emergence. Parasitoid emerging from borer larvae and pupae were collected, counted according to species and preserved in 70% alcohol for identification by Dr. G. Goergen, IITA, Cotonou, Benin.

## Results

The borer species encountered were, in order of importance, *B. fusca*, *E. saccharina*, the ear boring pyralid *Mussidia nigrivenella* (Ragonot), and *S. calamistis* (See chapter two and four). On *P. purpureum* in the Minkomeyos/Nkolbisson experiment, *B. fusca* accounted for 96.1% of all species whereas on maize the figures were 43.7, 27.2 and 16.5% for *B. fusca*, *E. saccharina* and *S. calamistis*, respectively. Similarly, in the benchmark locations on maize, *B. fusca* accounted for 57.3% followed by 30.9% for *E. saccharina* and lowest of 1% for *S. calamistis* (See chapters two and four). Fifteen hymenopterous, two dipterous parasitoids and one fungal species were found. Among those were six pupal, six larval and four hyperparasitoids; the ichneumonid *Enicospilus sesamiae* Delobel was obtained from both larvae and pupae. Two of the hymenoptera, the eurytomid *Eurytoma braconidis* Ferrière and the ceraphronid *Aphanogmus reticulatus* (Fouts), are hyperparasitoids obtained from an unknown parasitoid host and *Bracon sesamiae* (Cameron), respectively, attacking *B. fusca*. The species belonging to the *Tetrasticus atriclavus* complex are both parasitoids and hyperparasitoids. All species found are not specific to one host (See Polaszek, 1998). The fact that so many were recovered from *B. fusca* reflects the predominance of this borer species in the forest zone of Cameroon (Cardwell et al., 1997; Chapter four). The only species found in all eight sites were the scelionid egg parasitoids *Telenomus busseolae* Gahan and *T. isis*. Species belonging to the *T. atriclavus* complex were found at six sites and were the only parasitoids recovered from all four borer species.

The majority as well as the most common larval and pupal parasitoid species belongs to the ingress-and-sting guild (Table 1; Smith et al., 1993). Thereby, the parasitoid is attracted to the tunnel entrance by odor from hosts or frass, whereafter it enters the tunnel and attacks the host. As stem borers are usually

**Table 1. Species of parasites found on lepidopterous borers on maize and elephant grass and their geographic distribution in the forest zone of Cameroon.**

Species	Order: Family	Month	Location	Host plant	Host	Guild	H'stage
<i>Actia ? antiqua</i>	Dip.: Tachinidae	2,8,12	Ng, Mv, Nk	Zm	Es, Sc	PI?	L
<i>Antrocephalus crassipes</i>	Hym.: Chalcididae	2	Mv	Zm	Mn	IS?	P
<i>Aphanogmus reticulatus</i>	Dip.: Ceraphronidae	12	Ng	Zm	Bf,Braccon		
<i>Bracon sesamiae</i>	Hym.: Braconidae	2,9,12	Ak, Et, Nk, Ng	Pp, Zm	Mn, Bf, Sc	DS	L
<i>Cordyloceps</i> sp.	Sphaeriales: Clavicipitaceae	8,10	Mi	Pp	Bf		L
<i>Cotesia sesamiae</i>	Hym.: Braconidae	7,8,11	Mi, Nk	Pp, Zm	Bf	IS	L
<i>Enicospilus sesamiae</i>	Hym.: Ichneumonidae	7,10	Mi, Nko	Zm	Bf	IS?	L, P
<i>Eurytoma braconidis</i>	Hym.: Euritomidae	12	Ng	Zm	Bf,host?		L
<i>Lathromeris ovicida*</i>	Hym.: Trichogrammatidae	11	Mi	Pp	Bf	DA	E
<i>Nemoraea? discoidalis</i>	Hym.: Tachinidae	12	Mi	Pp	Bf	PI	P
<i>Paracentrobria</i> sp.*	Hym.: Trichogrammtidae	9	Mi	Zm	Bf	DA	E
<i>Procherochasmias nigromaculatus</i>	Hym.: Ichneumonidae	7, 9,12	Mi, Nk, Ak, Et, Me	Pp, Zm	Bf, Sc	IS	P
<i>Telenomus busseolae</i>	Hym.: Scelionidae	1,3,5,9,10	Mi, Nk, Mv, Et, Ng, Me, Ak, Nko	Pp, Zm	Bf	DA	E
<i>Telenomus isis</i>	Hym.: Scelionidae	1,3,5,9,10	Mi, Nk, Mv, Et, Ng, Me, Ak, Nko	Pp, Zm	Bf	DA	E
<i>Tetrastichus atriclavus</i>	Hym.: Eulophidae	2,7,9,12	Ak, Et, Nk, Nko, Ng, Mv	Pp, Zm	Mn,Bf,Es Sc	IS	L, P
<i>Tetrastichus</i> sp.	Hym.: Eulophidae	7	Ak	Zm	Bf, Sc	IS	P
<i>Trichospilus</i> sp.	Hym.: Eulophidae	12	Ak	Zm	Es	IS	P
Undetermined	Hym.: Mymaridae	10	Ak	Zm	Bf	DA	E

Ak= Akok, Ng= Ngat, Mi = Minkomeyos, Mv = Mvoutessi II, Nk=Nkolbisson, Et = Etoud, Me = Mengomo, Nkom = Nkometou III, Pp = *P. purpureum*, Z m =*Z. mays*, Bf = *B. fusca*, Es = *E. saccharina*, Sc = *S. calamistis*, Mn = *M. nigrivenella*, E = eggs, L = larvae, P = pupae. IS=Ingress-and-Sting; DA= Direct attack; PI= Planidial ingress; Drill-and-sting; collected in 1993 and identified by Dr. A. Polaszek, CABI, Ascot, UK

hidden deep inside the maize stem the two tachinids *Actia* sp. and *Nemoraea* ? *discordalis* (Villeneuve) probably belong to the planidial ingress guild, i.e., the female larviposits mobile, planidial, first-instar maggots at the tunnel entrance, which search for the borer in the tunnel. The only parasitoid belonging to the drill-and-sting guild was *B. sesamiae*. In addition, two parasitoids, *Lathromeris ovicida* (Risbec) and *Paracentrobia* sp. were collected in 1993 from *B. fusca* eggs on *P. purpureum* and maize, respectively (Ndemah, unpubl. data).

*Temporal distribution of natural enemies of B. fusca on elephant grass and maize*

During the months December to April both egg batches and *Telenomus* spp. egg parasitoids were scarce (Table 2). Egg parasitism tended to increase from the first to the second growing season. There was no clear pattern according to host plant. *P. purpureum* had more egg batches and parasitoids during the second season at Minkomeyos whereas in Nkolbisson maize was the more important host plant during the first season.

Though host in form of diapausing larvae were available, parasitoids were virtually absent during the dry season and early parts of the first cropping season until June. During July and December larval and pupal parasitoids were more common though during more than 50% of the sampling occasions no parasitoids were recovered. Parasitism was mostly less than 15% and high rates were often based on one specimen per sampling date only. Seven parasitoid and one fungus species were obtained from *P. purpureum* vs. two only from maize (Table 2). With exception of specimens of the *T. atriclavus* complex all species were larval parasitoids. Eight *C. sesamiae* cocoons masses were recovered from *P. purpureum* and one from maize (Table 2). Three larvae infected with *Cordyloceps* sp. (Sphaeriales: Clavicipitaceae) were recovered from *P. purpureum*. The remaining species were the tachinids *N. ? discoidalis* and *Actia* sp., the ichneumonids *Enicospilus sesamiae* (Delobel) and *Procerochasmias nigromaculatus* (Cameron), and a braconid *B. sesamiae*. The only other borer species yielding parasitoids was *S. calamistis* on maize, with one *B. sesamiae* and one *Actia* ? *antiqua* in August 1995 (Not shown in Table 2).

**Table 2 . Percentage parasitization of *B. fusca* eggs by *Telenomus* spp., percentage and number ( ) of borer larvae and pupae parasitized over time on *P. purpureum* and *Z. mays* at Minkomeyos and Nkolbisson during 1995 cropping and dry seasons.**

Location	Host plant	Host and parasitoid species	% of <i>B. fusca</i> eggs, % and number ( ) of borer larvae and pupae parasitized											
			Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Minkomeyos	<i>P. purpureum</i>	<b><i>B. fusca</i> eggs</b>												
		<i>Telenomus</i> spp.	-	-	-	-	0	27.2	74.9	57.1	0	46.2	-	-
		<i>Z. mays</i>	<i>Telenomus</i> spp.	-	100.0	-	-	-	-	43.9	0	-	-	-
Nkolbisson	<i>P. purpureum</i>	<i>Telenomus</i> spp.	-	-	0	-	0	11.5	100.0	66.7	-	-	-	-
		<i>Z. mays</i>	<i>Telenomus</i> spp.	-	13.0	33.3	24.2	92.6	-	30.0	100.0	-	-	-
<hr/>														
<b><i>B. fusca</i> larvae and pupae</b>														
Minkomeyos	<i>P. purpureum</i>	<i>Cordyloceps</i> sp.	0	0	0	0	5.9(2)	0	0.4(1)	0	0	0	0	0
		<i>C. sesamiae</i>	0	0	0	4.6 (1)	2.9(1)	0	0	3.3(4)	0	0	0	0
		<i>N. discoidalis</i>	0	0	0	0	0	0	0	0	3.5(2)	0	0	0
		<i>P. nigromaculatus</i>	0	25.0(1)	0	0	0	0	0	0	0	0	0	0
		<b>Total parasitization</b>	<b>0</b>	<b>25.0(1)</b>	<b>0</b>	<b>0</b>	<b>8.8(3)</b>	<b>0</b>	<b>0.4(1)</b>	<b>3.3(4)</b>	<b>3.5(2)</b>	<b>0</b>	<b>0</b>	<b>0</b>
		<i>E. sesamiae</i>	0	0	0	0	0	0	1.6(1)	0	0	0	0	0
Z. mays		<i>C. sesamiae</i>	0	0	0	4.4(1)	0	0	0	0	0	0	0	0
		<b>Total parasitization</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>4.4(1)</b>	<b>0</b>	<b>0</b>	<b>1.5(1)</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
Nkolbisson	<i>P. purpureum</i>	<i>T. atriclavus</i> complex	-	0	0	0	0	12.5(1)	0	0	0	0	0	0
		<i>C. sesamiae</i>	-	0	0	3.5(1)	16.7(1)	0	0	0	0	0	0	0
		<i>B. sesamiae</i>	-	0	0	0	0	0	0	0	25.0(1)	0	0	0
		<b>Total parasitization</b>	<b>-</b>	<b>0</b>	<b>0</b>	<b>3.5(1)</b>	<b>16.7</b>	<b>12.5(1)</b>	<b>0</b>	<b>0</b>	<b>25.0(1)</b>	<b>0</b>	<b>0</b>	<b>0</b>
		<i>C. sesamiae</i>	-	0	0	0	50.0(1)	0	0	0	0	0	0	0
<hr/>														
Z. mays		<b>Total parasitization</b>	<b>-</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>50.0(1)</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>

- no host found

*Seasonality of stem borer parasitoids on maize in the forest benchmark locations*

*B. fusca egg parasitism*

Egg parasitoids were the most common natural enemies of *B. fusca* and found in all the locations though they did not occur in all fields (Table 3). During the first season, mean parasitism was low ranging from 3.1% at Nkometou III and 26.6% at Etoud (Table 3). *T. busseolae* was the dominant species in all the locations but Etoud, where *T. isis* was the more abundant. Only two locations had both species. During the second season, parasitism increased considerably in all the locations with means ranging from 54.4% at Etoud to 87.4% Mengomo. Egg parasitoids were found in all the fields (Table 3) and *T. busseolae* was always the most important species accounting for 66-88%. The percentage of fields with both parasitoid species was again very low, i.e. less than 5%.

**Table 3. Percentage of *B. fusca* eggs parasitism, sex ratio and species composition of emerged parasitoids at six benchmark locations in the forest zone of Cameroon, during first and second cropping seasons of 1995. 'Mixed' refers to the percentage of fields having both parasitoids.**

Season	Location	Parasitism Mean	Range	Relative importance		
				<i>T. b</i>	Mixed	<i>T. i</i>
S1	Ngat	24.13	1.4 – 57.1	100.0	0.0	0.0
	Mvoutessi II	12.89	0 – 60.7	86.7	0.0	13.3
	Nkometou III	3.11	0 – 22.8	100.0	0.0	0.0
	Etoud	26.56	0 – 57.1	37.2	10.0	52.8
	Mengomo	14.29	0 – 61.9	100.0	0.0	0.0
	Akok	22.71	0 – 100.0	62.9	8.8	28.2
S2	Ngat	63.64	33.6 – 89.8	65.6	3.2	31.2
	Mvoutessi II	65.39	42.9 – 92.5	66.6	1.2	32.2
	Nkometou III	61.30	24.4 – 85.2	76.6	4.8	18.6
	Etoud	54.41	32.1 – 82.3	72.2	3.1	24.7
	Mengomo	87.35	58.0 – 100.0	74.5	0.0	25.5
	Akok	55.59	26.3 – 82.4	88.3	0.0	11.7

Mixed = represents the situation of both parasitoids found within the same field in a location. Within egg batch mixed parasitism was very rare. *T. b* = *T. busseolae*, *T. i* = *T. isis*

*Larval and pupal parasitism*

In Ngat no parasitoids were recovered until the second growing and the dry season, whereas in Mvoutessi II they were only found during the dry season (Table 4). By contrast, in the Yaoundé (Nkometou III and Etoud) and Ebolowa (Mengomo and Akok) block they were virtually absent during the dry season. During the off-seasons, most parasitoids were collected from *E. saccharina* and *M. nigrivenella*. Most species found on maize in the benchmark locations were pupal parasitoids. In accordance with the importance of the species, most parasitoids were obtained from *B. fusca*, *E. saccharina* and *M. nigrivenella*. The

most common species on *B. fusca* were from the *T. atriclavus* complex and *P. nigromaculatus*. The former was also recovered from *E. saccharina*, *M. nigrivenella* and *S. calamistis*, and the latter from *S. calamistis* (Table 4).

**Table 4.** Percentage and number () of lepidopterous borer larvae and pupae parasitized and overall species composition of parasites on *Z. mays* in six benchmark locations at harvest during the first and second (S1, S2) cropping seasons of 1995, the August dry spell and dry season (D1, D2) of 1995.

Location	Borer	Parasitoid species	% and no () of larvae and pupae parasitized				
			S1	D1	S2	D2	Overall sp. composition
Ngat	<i>Bf</i>	<i>E. braconidis</i>		1.1(1)	0	50.0	
		<i>B. sesamiae</i>		1.1(1)	4.4(1)	50.0	
	<i>Es</i>	<i>T. atriclavus</i> complex		0.8(1)	0	33.3	
		<i>A. ? antiqua</i>		0.8(1)	0.5(1)	66.7	
	<i>Mn</i>	<i>T. atriclavus</i> complex			0.9(3)	100.0	
Mvoutessi II	<i>Es</i>	<i>A. ? antiqua</i>			1.1 (2)	100.0	
		<i>T. atriclavus</i> complex			3.9 (4)	80.0	
	<i>Mn</i>	<i>A. crassipes</i>			1.0 (1)	20.0	
Nkometou III	<i>Bf</i>	<i>P. nigromaculatus</i>		3.0 (2)		66.7	
		<i>E. sesamiae</i>	0.2(1)		0	33.3	
	<i>Mn</i>	<i>T. atriclavus</i> complex			2.4 (1)	100.0	
Etoud	<i>Bf</i>	<i>B. sesamiae</i>		3.60 (4)		57.1	
		<i>T. atriclavus</i> complex	0.7(2)			28.6	
	<i>Es</i>	<i>P. nigromaculatus</i>			1.6(1)	14.3	
		<i>T. atriclavus</i> complex	6.3(1)			100.0	
	<i>Sc</i>	<i>T. atriclavus</i> complex			100.0 (1)	100.0	
Mengomo	<i>Bf</i>	<i>T. atriclavus</i> complex		9.1 (2)	25.0 (1)	100.0	
		<i>P. nigromaculatus</i>	2.4(1)		8.3(1)	50.0	
	<i>Akok</i>	<i>Tetrastichus</i> sp.	1.8(3)			50.0	
Akok	<i>Bf</i>	<i>B. sesamiae</i>		2.3(1)	3.1(1)	33.3	
		<i>P. nigromaculatus</i>	0.6(1)			16.7	
	<i>Es</i>	<i>Trichospilus</i> sp.			1.3(1)	100.0	
		<i>Tetrastichus</i> sp.	25.0(1)			50.0	
	<i>Sc</i>	<i>P. nigromaculatus</i>			100.0(1)	50.0	
		<i>T. atriclavus</i> complex	6.8(6)	66.7(2)		88.9	
	<i>Mn</i>	<i>B. sesamiae</i>	1.1(1)			11.1	

*Bf* = *B. fusca*, *E s* = *E. saccharina*, *S c* = *S. calamistis*, *Mn* = *M. nigrivenella*.

*Actia* sp. was obtained from *E. saccharina* and *B. sesamiae* from *B. fusca* mainly and from one *M. nigrivenella* larva. The only new species was the chalcidid *Antrocephalus crassipes* (Masi) recovered from a *M. nigrivenella* pupa. Generally, larval and pupal parasitism was mostly <5%, irrespective of borer species.

## Discussion

The natural enemy fauna of *B. fusca* was richer on *P. purpureum* than on *Z. mays* beside it. As shown in chapter two, mean immature densities of *B. fusca* per m<sup>2</sup> were 3 to 9 times higher on *P. purpureum* than on maize. This was mainly a result of higher tiller number as compared to maize. Also, because of its non-deterministic growth pattern and, thereby, continuous availability of plant parts

suitable for oviposition and growth and development of young larvae, *P. purpureum* is a much more stable habitat for both pests and natural enemies than maize. The differences in species composition and abundance between plant species could also be attributed to accessibility of the insect hosts. On elephant grass, *B. fusca* was the most common species and was mainly found in the whorl leaves and inside the stem below the whorl (Chapter three); only few older instar larvae were found deeply embedded in the green older stem. By contrast, on maize the larvae were mostly found in the whorl leaves during the vegetative stage and well protected in the stem or ear during the maturation phase. Thus, probably because of higher accessibility of the host larval parasitoids were more common on *P. purpureum*. By contrast, on maize in the benchmark sites, pupal parasitoids predominated. Stem borers pupate close to the tunnel exit or even partly outside the stem (Smith et al., 1993), which increases their accessibility to parasitoids.

In southern Benin, which consists mostly of derived savanna, *T. busseolae* and *T. isis* are thought to be the most important natural control factors of *S. calamistis* on maize (Sétamou and Schulthess, 1995). At the onset of the second season, mean parasitization rates are more than 90% (Schulthess et al., 1997a). In the present work, parasitism of *B. fusca* eggs was considerably lower. *S. calamistis*, however, breeds throughout the year and therefore availability of host eggs is assured. Thus, Bosque-Pérez et al. (1994) and Schulthess et al. (1997a) commonly found both *T. busseolae* and *T. isis* on *S. calamistis* during the dry season in Nigeria and Benin, respectively. By contrast, most *B. fusca* diapause as larvae during the dry season (Adeyemi, 1969) and hosts become scarce. This may explain the low and erratic egg parasitization rates in the benchmark location during the first cropping season. During the second season, however, the rates increased to more than 60% in most locations. Thus, egg parasitism was probably the main reason for the relatively low *B. fusca* densities found during that season in the forest (Chapter four). So far, Cameroon is the only country outside West Africa from which *T. isis* was reported (Polaszek, 1998. The present study and results by Schulthess et al. 1997a) suggest that both species are needed to have an

impact on noctuid stem borers, emphasizing the suitability of *T. isis* as a redistribution candidate.

The most common parasitoids, in the benchmark site, besides *Telenomus* spp., belong to the *T. atriclavus* complex, which according to Boucek (1988) attacks both the larval and pupal stage. They can be both primary and hyperparasitoids and were recovered from all borer species. This is not astonishing. Given the insular character of forest fields and the scarcity of alternative host plants, the most successful strategy would be facultative hyperparasitism, combined with low specificity for life stage and host. A species specific to *B. fusca* would have little chance to get established, since cues needed for host finding such as frass or synomones emitted by the damaged plant (Kajita and Drake, 1969; van Leerdam et al., 1985; Mohyuddin, 1971; Potting, 1995) are not produced during the off season when the borer diapauses in the larval stage. By contrast, the other species common in the forest do not diapause, and *E. saccharina* was found feeding in dry maize stems long into the dry season (Chapter two; D. Conlong, SASEX, South Africa, pers. comm.)

In East and Southern Africa, *C. sesamiae* is the most commonly recovered larval parasitoid of *B. fusca*, *Chilo* spp. and *S. calamistis* (Ullyett, 1935; Ingram, 1958; Mohyuddin and Greathead, 1970; Mathez, 1972; Kfir, 1992; Kfir and Bell, 1993). Overholt reported that in Kenya parasitism was typically less than 0.5% whereas in South Africa parasitism of *B. fusca* on sorghum was found to be as high as 75% and *C. sesamiae* is thought to keep *S. calamistis* under control (Kfir and Bell, 1993; Kfir, 1995). In the 1995/96 field trials, 8 *C. sesamiae* cocoons masses only were recovered from *P. purpureum* and 1 from maize (Table 2) while the parasitoid was not recovered from any of the maize fields in the benchmark sites (Table 4). Similarly, in 1993, the parasitoid was only found on *P. purpureum* (R. Ndemah, unpubl. data). This corroborates results from country-wide surveys on maize carried out in several West African countries by IITA scientists who showed that *C. sesamiae* was exceedingly rare in all wet and humid ecologies (See Gounou et al., 1994; Schulthess et al., 1997a; Bosque-Perez et al., 1994; D. Conlong, SASEX, Durban, South Africa, unpubl. data). *Cotesia* spp. are known to have a high genetic plasticity in terms of host suitability or choice of host plant

preference (Mohyuddin et al. 1981; Carl, 1982; Hailemichael et al., 1997). In Benin and Nigeria, the International Institute of Tropical Agriculture (IITA) is currently investigating the feasibility of using East African strains of *C. sesamiae* against *S. calamistis* and *B. fusca*, and a coastal strain from Kenya is being recovered in southern Benin since its accidental release in 1994 (Schulthess et al., 1997a).

*Actia* spp. are relatively rare larval parasitoids of various stem borer species in East Africa mainly (Polaszek, 1998). In West Africa, it was never recovered during any of the surveys carried out by IITA (see Schulthess et al., 1997a) though Jordan (1966 in Polaszek, 1998) recorded *A. cuthbertsoni* Curran from *Chilo 'zaleukos'* (=*Chilo zacconius*) in Sierra Leone. Nonveiller (1984) reported *A. ? antiqua* from *B. fusca*, *S. calamistis* and *E. saccharina* on maize at Nkolbisson. More recently, around 150 *Actia* sp. specimens were collected from *E. saccharina* in the same benchmark locations during the dry season 1998 (D. Conlong, unpubl. data) with mean per field location parasitism between 12-28%. *Actia* sp. has never been reported in South Africa and could be a re-distribution candidate for *E. saccharina* on sugar cane.

In West Africa, no parasitoids were ever obtained from *M. nigrivenella* on annual crops such as maize, cotton, Jackbean, velvet and phaseolus bean, (Moyal, 1988; Gounou et al., 1994) but *Antrocephalus crassipes* Masi (Calchididae) was commonly found on *Gardenia* spp. (Rubiaceae) (Sétamou, 1996). In addition to the three species found in the present study, Nonveiller (1984) collected *Syzeuctus* sp. from *M. nigrivenella* maize ears at Nkolbisson. The most common species found in the present study belonged to the *T. atriclavus* complex, which, according to Polaszek (1998), includes six species. Further studies are required to clarify the taxonomy of *T. atriclavus* before any conclusions about their status as a redistribution candidate can be drawn. Moreover, the introduction and use of facultative hyperparasitoids in biological control is highly controversial (Ehler, 1979; Wesloh et al., 1979). Several authors showed the possible benefits when using facultative hyperparasitoids as biological control agents (Ehler, 1979; May and Hassel, 1981; Cock, 1986). However, as pointed out by Kfir and Bell (1993) a facultative hyperparasitoid should be evaluated according to whether its

hyperparasitic behaviour is predominant or only occasional. Little information exists about the preferences of species of the *T. atriclavus* complex but in the present study most were obtained from borer pupae.

Most larval and/or pupal parasitoids found belong to the ingress-and-sting and in the case of tachinids probably to the planidial ingress guild (Smith et al., 1993). This is not surprising. In the large stemmed maize plant the larvae and pupae are probably beyond the reach of the parasitoid ovipositor. A successful parasitization is only possible if the larva is close to the stem surface, about to migrate or pupate. Drill-and-sting parasitoids would be more successful on thin-stemmed grasses. In many forest fields, however, grasses are not only scarce (Chapter six) but they are often too small to allow development of borer larvae, though they may serve as reservoirs of egg for parasitoids such as *Telenomus* spp. In ecologies such as inland valley, where maize is grown in the dry season, fields close to major roads and, generally, in the vicinity of larger towns, where large-scale deforestation occurred, grasses are more common. Lumber is one of the major commodities of Cameroon and the forest is disappearing at an alarming rate. Thus, as already indicated by the differences in species composition in the different experiments the natural enemy fauna may change, as grasses become more common in the forest zone. As put forward by Schulthess et al. (1997a), because of the relative short duration of the maize crop in the field and its susceptibility to borer attacks (maize cannot compensate for stem damage by tillering) biological control of stem borers very likely has to take place in the wild habitat. Thus, increase in wild grass habitats may also enhance the efficiency of larval parasitoids such as *C. sesamiae* and generally of species belonging to the drill-and-sting guild.

## CHAPTER 8

### **Synthesis: Towards development of a pest management strategy for maize stem borers in Cameroon with special reference to *B. fusca* in the forest zone**

#### **Introduction**

The relative importance and seasonal trends of various stem borer species predominant in the ecozones under study are in stark contrast to those in West, East and Southern Africa. Based on an in-depth multitrophic study carried out in the present thesis which included soils, vegetation, host plants and natural enemies, various theories were put forward that may partly explain the differences in pest status between season, ecozones, countries and regions. Elucidation of the under-laying mechanisms should enable us to predict how pest populations react as/if one of the key components of the system changes radically. Solutions are put forward to alleviate pest problems in the forest zone and mid-altitudes.

#### **The island character of forest fields as compared to other ecologies in Africa**

Forest fields in Cameroon still represent islands within non-cultivated habitats, and associated pests are strongly affected by edaphic, microclimatic, and biotic factors such as natural enemies and alternative wild host plants, in and in the vicinity of a field (Chapter four-six; Schulthess et al., 1997a; Cardwell et al., 1997). Alternative host plants of stem borers such as grasses and sedges, which buffer maize fields against severe stem borer attacks (Schulthess et al., 1997a; Cardwell et al., 1997; Chapter two), are scarce and most are thin-stemmed and not suitable for stem borers to complete a life cycle. Because maize is probably the most common and most suitable host *E. saccharina*, *S. calamistis* and *M. nigrivenella* populations crash during the dry season whereas *B. fusca* diapauses in the larval stage. Thus in spring and under low host plant density conditions, *B. fusca* has a head start over non-diapausing species and rapidly builds up damaging infestation levels on the first season crop. By contrast, *E. saccharina* reaches critical levels during the second season only, which is similar to its seasonal fluctuations in West Africa. Whereas *E. saccharina* can feed on dry stalks long into the dry season (Chapter three) *S. calamistis* larvae become increasingly

scarce. In addition, *S. calamistis* only oviposits on young plant parts in contrast to *E. saccharina* that prefers old plant parts or debris on the soil. Thus, suitable oviposition substrates are not abundant until the plantation of maize and by that time the *S. calamistis* population is virtually close to zero and the few females are probably of small size and low fecundity.

In contrast to the forest zone in Cameroon, degraded forests common in most West African countries, the forest-savanna transition vegetation and mid-altitudes form a continuum of cultivated and wild host plants which affect population densities as well as borer species compositions (Schulthess et al., 1997a). For example, during a first season survey in Cote d'Ivoire in 1994, *B. fusca* accounted for 67% of all species found in dense forest versus 33% in degraded forest (S. Gounou, IITA, unpubl. data). A similar trend was observed on wild sorghum, *Sorghum arundinaceum*, with 38% and 15%, respectively, in the forest and degraded forest. As mentioned in Chapter four, deforestation and its consequences for natural plant associations could also explain the changes in the distribution of borer species over the past 30 years in the rainforest and transition zone of Nigeria, and especially the relative importance of *B. fusca*. As in Nigeria, human population pressure and concomitant expansion of agricultural areas will finally result in massive deforestation. Changes in the availability and diversity of suitable and non-suitable alternative host plants will have implications for not only the pest species composition and their abundance but also biological control activities in maize systems (see Chapter seven) as well as for host plant resistance, i.e., the main species to be targeted, the genetic diversity of the pest, and the durability of the resistance produced.

The present work did not include inland valleys in the benchmark sites where maize fields may be planted from January onwards. A recent survey in experimental fields showed up to 70% of the plants attacked, with *B. fusca* as the only species (C. Nolte, IITA, Nkolbisson, unpubl. data). It appears that a part of the local *B. fusca* population does not go into diapause. Since most valleys do not have maize fields there must be other suitable plants hosting *B. fusca* during the dry season. If first season fields are close by, pests and beneficials could migrate from inland valley fields or alternative hosts to first season maize upland. Thus,

the vicinity of an inland valley should affect the abundance and composition of pests and natural enemies on first season maize. Further studies are needed to elucidate the population dynamics of pests and natural enemies in this continuum.

### **The existence of different species or geographical races of stem borers**

The difference in distribution and relative importance of a species between zones and regions may also indicate the possibility of differences in geographic races. At IITA in Nigeria, Kaufmann (1983b) fed sorghum to a southern and maize to a northern strain of *B. fusca*. The results for both strains were increased mortality, sterility or changes in sex ratio of offspring. The insular character of forest fields would enhance the formation of strains of both pests and natural enemies, which may vary in host plant preference, fitness and host suitability (ability to encapsulate natural enemies) (See chapter four and seven).

There is also the possibility that there exist more than one *B. fusca* species. As pointed out by Maes (1997) there are still many taxonomic problems in the noctuids and pyralids of Africa which are largely due to historical limitations in systematics and lack of comparative and phylogenetic studies. The latter is largely due to insufficient material. Because of these problems and based on the present findings the Institut de Recherche pour le Developpment (IRD) (former ORSTOM) formed a working group to study the biodiversity and evolution of plant-insect and pest-antagonist complexes with emphasis on *B. fusca* (LeGall, 1999). The main objectives will be the establishment of an inventory and morphological and molecular differentiation of species and strains in the taxon *Busseola*, and the development of tools and molecular markers, as well as physiological (pheromones) and morphometric studies if phenotypical differences between geographic races are apparent.

### **What to do next?**

#### *General sampling methodology*

As shown in chapter three, the maize pests prevalent in Cameroon have highly aggregated spatial distributions. Thus, a high number of samples are required to estimate low to medium densities with a given precision level. One of the reasons for the often weak relationships found among biotic and between biotic and

abiotic components of the system was that the numbers of samples per field were too low. The results of ANOVAs in chapter four-six indicate that the numbers of samples per field as well as the numbers of field per location should be increased. Since blocks don't contribute significantly to the overall variability in the system future work should concentrate on locations close to Yaoundé. This would drastically reduce costs as the crew could return to base every evening. Rather than sticking to the present locations, the fields should be selected in a manner that they form certain gradients such as abundance of alternative hosts in the system, distance from the next inland valley with and without maize during the dry season, soil fertility etc. Within every field five quadrat should be selected at random and observations should be made on each plant. This should result in clearer interactions between the different components and allows for more realistic yield estimates since all plants, irrespective of growth stage, will be sampled.

#### *Management of soil nutrients*

Results from chapter six revealed a positive relationship between soil Mg and *B. fusca* numbers as well as stem damage whereas soil K had a negative effect. Similar results were obtained by Sétamou and Schulthess (1995) for *S. calamistis* and *E. saccharina* from surveys in southern Benin. Subsequent life table studies showed that K negatively affected fecundity of both species (Denké, 1995). For non-diapausing species and in ecologies with a continuum of wild and cultivated host plants the carry-over effect of K on borer fecundity is probably negligible since borer populations crash to close to zero every dry season. For diapausing species under isolated conditions such as forest fields, K may have a long-term effect on population dynamics via reduced fecundity. Probably due to the sampling procedure, time of sampling and soil depth no effect of soil N on plant growth and pests could be shown. This corroborates results by Sétamou and Schulthess (1995) from farmers' fields in southern Benin. Subsequent field trials under controlled conditions and life table studies using N dosages of 0-120 kg/ha showed that N had a positive effect on both survival and fecundity of *S. calamistis* and *E. saccharina* (Sétamou et al., 1993; Sétamou et al., 1995). Percent yield loss, however, decreased linearly with N fertilization indicating that the plant can

overcompensate for increase stem borer damage. One of the main thrusts of IITA in Cameroon is the development of adoptable short fallow systems to maintain or increase soil fertility using leguminous cover crops. In the same context, the effect of ‘slash and burn’ on soil nutrients and plant growth is studied. Following findings of the present study IITA’s soil scientists are now aware that yield data cannot be interpreted without some scoring of insect number or damage. Thus, future on-station and on-farm soil fertility trials will include an insecticide treatment and insect damage will be scored at the vegetative stage (for window damage and dead hearts) and at harvest (stem tunneling and grain damage). In addition, the legumes species will be screened for suitability for *M. nigrivenella* whose wild hosts comprise plants belonging to eleven plant families including legumes and cover crops such as *Mucuna pruriens* DC. *Canavalia ensiformis* (L.) DC (Sétamou et al., submitted). As theorized by Sétamou et al. (submitted), the cover crops species and timing of planting can determine if the cover crop acts as a trap plant or reservoir for pests responsible for attacks on maize.

#### *Host plant resistance: Making field infestations of *B. fusca* more uniform*

The front line defense of choice for most pest and disease control is host plant resistance. The wide genetic variability that exists in most domesticated plant species offers one of the most powerful tools used in agriculture. IITA has identified sources of resistance to both *S. calamistis* and *E. saccharina* while the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), Mexico, and the International Center for Insect Physiology and Ecology (ICIPE), Kenya, have developed genotypes with antibiosis to whorl feeding species such as *C. partellus*, *B. fusca* and the New World genus *Diatrea* spp. Determining levels of cross resistance among the borer species is enhanced through the exchange of germplasm between centers. Consequently, a few genotypes with cross-resistance to different borer species have now been identified.

Mass rearing of *S. calamistis* and *E. saccharina* using artificial diets is a routine activity of the IITA-Ibadan and Benin laboratories. Approximately ten million eggs of *S. calamistis* and *E. saccharina* are produced every year. These are used for field infestations of breeding trials and for biological studies. The major constraint in NARES host plant resistant (HPR) breeding programs is to

achieve uniform field infestations. Since rearing of stem borers on artificial diet is too expensive to be afforded by NARES, other field increase methods have to be sought such as the use of diapausing larvae for egg production (e.g. for *B. fusca*) or the synchronizing of planting time with peak adult flight in areas with reliably high naturally occurring infestations, or planting of spreader rows as proposed in chapter four. Increasing pest populations on several sequentially planted spreader rows, however, may also increase levels of egg parasitism, thereby leading to pest population decline as shown in chapter four and six. It is therefore recommended to do HPR screening for *B. fusca* during the first and for *E. saccharina* and mixed species during the second season. For *B. fusca* the screening should be done in the rainforest, where population densities are reliably high. Also, trials have to be set up to evaluate how inland valleys can be exploited to increase uniformity of field infestations on first season up-land maize.

#### *Host plant resistance x soil nutrient interactions*

Soil nutrients could have an influence on host plant resistance. Host plant resistance is the result of interactions between insect and plant and edaphic factors are known to have considerable effects on the expression of resistance, particularly pseudo-resistance (Painter, 1951; National Academy of sciences, 1969 in Coppel and Mertins, 1977). Thus induced resistance to the pest by the plant could ensue as a result of beneficial alteration of soil nutrients in the plant environment. E.g, the hardening of plant structures induced by K is generally considered to improve mechanical resistance to penetration by pathogens and to feeding by insects (See overview by S. Perrenoud, 1990). Also an insufficient K supply results in the accumulation of soluble low molecular compounds such as soluble N-compounds and carbohydrates and this is often accompanied by increased herbivory (Trolldonier and Zehler, 1976 in Perrenoud, 1990) as shown for *S. calamistis* and *E. saccharina* by Sétamou et al. (1993, 1995). It cannot be suggested that pests could be controlled by the use of fertilizers alone (Perrenoud, 1990). However, improvements in plant resistance or the negative effect of some soil nutrients on herbivore bionomics or development could be regarded as a kind of insurance policy which help to reduce crop damage where the conditions for plant protection are not optimal, as in the small scale agriculture carried out in

Cameroon. Thus it is desirable that when fertilizers are applied according to the dictates of common sense in order to achieve maximum economic returns from crops, the returns in terms of improved plant health should also be optimized. Thus, in late 1999 trials will be set up with maize lines showing various degree of HPR and varying K and N fertilizer dosages to assess the effect of both HPR and fertilizer on pest populations and maize yield.

#### *Intercropping with non-hosts*

In West Africa and especially in the humid zones, most maize is intercropped. Since maize is the only cereal in these zones all other crops are non-hosts which should affect the population dynamics of especially migrating pests. The present results indicate that *B. fusca* infestations on maize decreases with density of cassava in the system. Similar findings were reported by Kaufmann (1983a) for *B. fusca*, *E. saccharina* and *S. calamistis* in Nigerian farmers' fields. Likewise, Ampong-Nyarko et al. (1995) observed a 30% decrease in *C. partellus* oviposition in a maize/sorghum/cowpea intercropping system as compared to pure cowpea and Mahadevan and Chelliah (1986) found that lablab and cowpea reduced oviposition rates on sorghum. By contrast Skovgard and Paets (1996) found that maize/cowpea intercropping did not affect oviposition by *C. partellus*, *C. orichalcociliellus* (Strand) and *S. calamistis* but significantly reduced larva and pupa numbers and increased egg parasitism.

Further research is needed to assess the role of density of other crops and planting arrangement (number of plants per hole and distance between holes) of maize in reducing pest infestations. Special emphasis should be given to peanut, which is an important annual crop in the forest zone of Cameroon.

#### *Biological control and habitat management*

Given the importance of *Telenomus* spp. egg parasitism in the suppression of *B. fusca* during the second season, enhancing the efficiency of these parasitoids could form a strong component of an IPM package against *B. fusca* in the forest zone. Because maize is not always present in the field and because of its high susceptibility to stem borer attack, the pest has to be controlled in wild habitats (Schulthess et al., 1997a). This underlines the importance of the knowledge of the

host plant range and their role in the population dynamics of the pest and beneficials. How to manipulate wild habitats to enhance egg parasitism even before onset of the first season? Schulthess et al. (1997a) reported relatively high levels of *Telenomus* egg parasitism on *S. calamistis* on wild host plants during the off season in Benin. In the Dahomey gap, however, these grasses are an important component of the plant association surrounding crop fields. A recent experiment with *P. purpureum* planted as border rows in farmers' fields in the forest of Cameroon showed that farmers couldn't wait for the researchers to end the experiment and destroy the grasses which they consider weeds (Ndemah, unpubl. data). The results of chapter two also indicate that if not properly managed *P. purpureum* could become an important source of infestations, whereby young larvae may migrate from the tall grass host onto maize thereby aggravating the problem. Probably more suitable trap plants would be *Panicum maximum* or *Andropogon gayanus* on which first larval instar mortality of *S. calamistis* and *E. saccharina* were between 97-100% (Shanower et al., 1993; Sekloka, 1996; Séme-glo, 1997), i.e. much higher than indicated by the results with *B. fusca* in the present study. Unfortunately, the planting of alternative hosts is very likely not an adoptable solution in the peasant farming system. However, with the massive deforestation presently occurring in Cameroon, the proportion of grasses in forest habitats will very likely increase which will have an effect on all trophic levels (Schulthess et al., 1997a; Chapter seven). Thus, a recommendation to the farmers could be not to burn grass habitats during the dry season which should stabilize the efficiency of natural control factors.

In the present work, *Telenomus* spp. egg parasitism appeared to be the only species having an impact on stem borers. However, because of the poor accessibility of borers in the large maize stems parasitization rates on maize are very likely not representative for what's happening in the wild habitat. In addition, the high number of samples to quantify pest-beneficial interactions at low pest densities would make such studies economically questionable. In southern Benin, IITA periodically field exposed *S. calamistis* and *E. saccharina* larvae which were forced to penetrate into the stem during one day; thus a relatively large larvae produced a short tunnel and was therefore easily accessible to natural enemies of

most guilds. Up to 80% parasitism by the tachinid *S. parasitica* and 20% by an East African strain of *C. sesamiae* were obtained, this during a time when pest densities on maize were low (Schulthess, unpubl. data). Typically, parasitism by both species on naturally infested maize are on average below 5%, corroborating observations by Overholt et al. (1997) for *Cotesia* spp. in Kenya. In order to quantify the relative importance of individual natural enemy species and, thus, for identification of promising redistribution candidates similar exposure studies are needed for Cameroon. This requires, however, the continuous availability of lab reared larvae. Since noctuids share most natural enemy species and *B. fusca* is exceedingly difficult to rear it is recommended to use *S. calamistis*.

*C. sesamiae*, the most common natural enemy of noctuid stem borers in East and Southern Africa was exceedingly rare in West Africa including Cameroon. As indicated in chapter seven, the scarcity of thin-stemmed alternative hosts in the forest system may be one of the main reasons for the near absence of this species in the forest. However, *Cotesia* spp. are known to have a high genetic plasticity in terms of host suitability or host plant preference (Mohyuddin et al., 1991; Carl, 1982, Hailemichael et al., 1997). A *C. sesamiae* strain that reproduces on *S. calamistis* but not *B. fusca* collected at the Kenyan coast by ICIPE was introduced into Benin and got established in the southern part of the country. A second strain from Kitale, Kenya, which successfully parasitizes both *S. calamistis* and *B. fusca* was introduced into the IITA-Benin labs in 1998 and is considered for introduction and release in Cameroon. Ideal areas of release would be infested fields in the inland valleys during the dry season from where the natural enemy would gradually spread to upland maize and back. Other redistribution candidates identified in this work was *A. ? antiqua* for *E. saccharina* on sugar cane in South Africa and species of the facultative hyperparasitoid *T. atriclavus* complex for *M. nigrivenella* in West Africa. However, the use of hyperparasitoids in BC remains controversial and politically risky.

Recently IITA-Benin isolated a cytoplasmic polyhedrosis virus (CPV) from *S. calamistis*. CPVs are vertically (i.e. sexually) transmitted and have a long term effect on fitness of an insect population by drastically increasing development time and reducing fecundity (A. Cherry et al., 1999). The insular character of

forest fields allowing for genetically distinct populations and the diapausing behaviour make *B. fusca* an ideal candidate for CPVs. However, Koch's postulate has to be done first to determine if the virus also affects *B. fusca*.

#### *Conclusion: Socio-economic considerations*

As stated earlier in chapter one, an integrated approach that combines several control measures appear to be the best strategy towards solving the stem borer problem. The investigative approach using baseline data from field surveys sought to establish a common analytical base, namely quantifying the effect of diverse factors, biotic and abiotic on *B. fusca* pest problem, in order to assess the significance that each may have for pest management. It is clear, however that a sound technical basis for devising improved technologies is not sufficient to assure their adoption by farmers. Due attention must also be paid to the social and economic constraints that improved technologies will have on farmers adopting these production practices and their perception of the pest problem. For example appropriate habitat management has in principle, great potential as a strategy to reduce pest populations, either directly (acting as trap plants) or indirectly by encouraging the action of natural enemies. Nevertheless in practice, the usefulness of this approach is constrained not just by our lack of knowledge of the host plant range of the pest and the role of individual species, but by the difficulty of bringing the farmers to change the management of field margins and fallow areas, which normally receive little attention, especially in situations where availability of labor is often limited. Therefore, the present work was complemented by a socio-economic study that assessed the farmers perception of the importance of a given pest and disease. (The results will be published elsewhere by Dr. O. Coulibaly, IITA-Benin.) Once the individual components of an IPM strategy are developed and tested a socio-economic assessment will be made on the adoptability and profitability of those control options taking into consideration the different socio-economic conditions presented by the different blocks of the benchmark area.

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