Diversity and abundance of wild host plants of lepidopteran stem borers in two different agroecological zones of Kenya

Nicholas A. Otieno[(1)], Bruno P. Le Rü[(1),*], George O. Ong'amo[(1)], Stéphane Dupas[(2)], Paul-André Calatayud[(1)], Martha Makobe[(3)], John Ochora[(3)] & Jean-François Silvain[(2)]

[(1)] Noctuid Stemborer Biodiversity Project (NSBB). Institut de Recherche pour le Développement / International Centre of Insect Physiology and Ecology (IRD/ICIPE), Nairobi, (Kenya)

[(2)] Institut de Recherche pour le Développement (IRD), CNRS, Laboratoire Evolution, Génomes er Spéciation, Gif-sur-Yvette cedex (France)

[(3)] Jomo Kenyatta University of Agriculture and Technology (JKUAT), Nairobi, (Kenya)

* Corresponding author

Abstract. A survey was carried out between 2004 and 2005 in two ecologically different locations, Kakamega and Muhaka to assess diversity and abundance of wild host plants of lepidopteran stem borers as compared to maize plots during the cropping and non-cropping seasons. Kakamega in Western Kenya is characterized by a Guineo-Congolian rain forest mosaic and Muhaka at the Kenyan coast by a Zanzibar Inhambane mosaic with secondary grassy and woody vegetation. In Kakamega, wild host plants and maize covered 2 and 43% of the surveyed area. No variation in diversity and relative abundance of wild host plants was observed between both the cropping and non-cropping seasons. In Muhaka, the diversity and relative abundance of wild host plant species differed between seasons, with the Shannon Weaver Index (H) of 1.67 and 0.95 for cropping and non-cropping seasons, respectively. Similarly in this location, wild host plant cover varied between cropping (23%) and non-cropping (17.9%). During both seasons, this was higher than the maize cover, with 10.7% and 0% for the cropping and non-cropping seasons, respectively. For both localities, the implication of the differences found in the abundance and diversity between the cropping and non-cropping seasons is discussed.

Résumé. Diversité et abondance des plantes hôtes sauvages des lépidoptères foreurs de graminées dans deux localités écologiquement différentes du Kenya. Une étude a été menée en 2004 et 2005 dans deux localités écologiquement différentes du Kenya, Kakamega à l'Ouest et Muhaka sur la côte afin d'estimer la diversité et l'abondance des plantes hôtes sauvages des lépidoptères foreurs de céréales pendant et en dehors de la saison culturale. Kakamega est caractérisé par une mosaïque de type forêt pluviale Guinéo-Congolaise et Muhaka par une mosaïque de type Zanzibar-Inhambane avec des formations secondaires herbeuses et arborées. A Kakamega, les plantes hôtes sauvages et le maïs occupent respectivement 2 et 43% de la surface étudiée ; la diversité et l'abondance relative des plantes hôtes sauvages ne varient pas avec la saison. Par contre, à Muhaka, la diversité et l'abondance des plantes hôtes sauvages varient selon la saison, l'indice de diversité de Shannon Weaver (H) est de 1,67 et 0,95 respectivement pendant et hors saison culturale. De même, dans cette localité, la surface occupée par les plantes hôtes sauvages varie entre la saison culturale (23%) et hors saison culturale (17,9%) mais reste supérieure à la surface plantée en maïs qui est respectivement de 10,7 et 0%. Pour les deux localités, les implications des différences observées dans l'abondance et la diversité des plantes hôtes sauvages pendant et hors saison culturale sont discutées.

Keywords: Stem Borers, Wild Hosts, Monocotyledons, cropping season, East Africa.

E-mail: notieno@icipe.org, bleru@icipe.org, gongamo@icipe.org, dupas@legs.cnrs-gif.fr, pcalatayud@icipe.org, silvain@legs.cnrs-gif.fr

Accepté le 4 mai 2006

In East Africa, *Busseola fusca* (Fuller, 1901) (Noctuidae) and *Chilo partellus* (Swinhoe, 1884) (Crambidae) are the most important insect pests in the crop fields (Seshu Reddy 1983; Guofa *et al.* 2002). *B. fusca* dominates high altitude areas whereas *C. partellus* is well established in low and mid altitude areas (Seshu Reddy, 1983). Currently, it is assumed that the original hosts of cereal stem borers were wild grasses and sedges, and that the pest species have maintained close association with the wild habitat. In East Africa, the bulk of maize, *Zea mays* L. (Poaceae) and sorghum (*Sorghum bicolor* L. (Moench) (Poaceae) is mainly grown on small plots surrounded by land occupied by vegetation of which the majority are wild host plants of lepidopteran stem borers (Khan *et al.* 1997). During the intercropping period, it is thought that the presence of wild hosts near crop fields favours the survival of stem borers thereby increasing population that colonises crops in subsequent growing season (Ingram 1958; Nye 1960; Seshu Reddy 1989; Randriamananoro 1996; Polaszek & Khan 1998; Haile & Hofsvang 2001). Recent studies done on wild host range of stem borers in East Africa by Le Rü *et al.* (2006a, 2006b) indicate that *B. fusca* and C. *partellus* are oligophagous, contradicting previous report by Polaszek & Khan (1998) characterising these species as polyphagous. Studies done by Kanya *et al.* (2005) in Kitale in Kenya showed that area covered by wild host plants of these pests was below 10% suggesting that wild host plants might not be adequate as refuge of these pests. Until now, little attention has been given to the role of wild host plants in the invasion of crop fields by the stem borer pests. Bowden (1954) argued that the ecology of these pests could only be understood within the context of the wild habitat.

In an attempt to understand the role of wild host plants on pest population dynamics between natural and cultivated habitats, two representative locations, Kakamega and Muhaka, from different agro-ecological zones in Kenya were chosen for their diversity of habitats and farm management practices. Kakamega in Western Kenya is found in moist mid-altitude and is characterized by a Guineo-Congolian rain forest mosaic. Muhaka at the Kenyan coast is found in moist low tropics and is characterized by a Zanzibar Inhambane mosaic with secondary grassy and woody vegetation (Kokwaro 1988). Kakamega is dominated by *B. fusca* while Muhaka by *C. partellus* (Seshu Reddy 1983, Ong'amo 2005). This study was carried out across the natural habitat between the cropping and non-cropping season with a focus on the diversity and abundance of wild host plants of stem borers in the different vegetation associations. This information could be used to assess the possible survival of stem borer pests on wild habitats during the intercropping period and subsequent outbreak or invasion on cereal crops during the cropping season. It would also provide possible explanation whether wild habitat could delay development of resistance of the stem borer main pests to *Bt*-Maize.

Material and Methods

Study localities and sampling design

The Kakamega locality (fig. 1) covers an area of 21.2 km^2 and is located 50 km North of Lake Victoria on the border of transitional rain forest in a depression at the bottom of the Nandi escarpment (Kokwaro 1988). Vegetation species within the forest are typical of planetary Guineo-Congolian rain forests. Parts of the forest (study locality) have been opened to cultivation of maize and sorghum because of the favourable climatic conditions (temperature ranges from 12.7 to 27.1 °C and average rainfall is 1650 mm). The altitude ranges from 1551 to 1730 m above sea level (asl). The location is characterized by a bimodal rainfall distribution that allows two cropping season (CS), the first lasting from March to mid-July and the second from mid-August to November. There is a prolonged dry season from December to the end of February (Kokwaro, 1988) herewith referred to as non-cropping season (NCS).

The Muhaka locality (fig. 1), covering an area of 19.3 km^2, is located on the south of Mombasa in an area with secondary grassy and woody vegetation, on the border of an undifferentiated forest with climatic condition of Inhambane type (minimum temperature, 22 °C; maximum, 30.4 °C; average rainfall, 1212 mm). The altitude ranges from 20 to 67 m above sea level. There is only one cropping season from March to June, the rest of the year too dry spell to grow crops. The locality is characterized by scattered patches of cultivated maize fields (Kokwaro 1988).

In Kakamega, sampling was done in November 2004 for the CS and March 2005 for NCS. In Muhaka, the sampling was carried out in October 2004 for the NCS and in May, 2005 for the CS. The sampling period lasted for three weeks in each session.

Sampling size

High resolution satellite maps of the two locations were used as a basic spatial information to analyse vegetation mosaics in the two locations. Ground actualization was carried to further describe the vegetation formations. The resultant land use map characterized the locations into various homogeneous vegetation structures containing natural and cultivated habitats of stem borers. Sampling was done in the natural habitats inhabited by wild hosts within the vegetation structures described by the satellite land use map of the two locations (Guiheneuf 2004). In Kakamega, four vegetation structures made up of uncultivated habitats were identified while Muhaka had five (tab 1). Geographical Information System (GIS) program, Arc View version 3.2 (ESRI 1992) software was used to generate random sampling points within the vegetation structures. Grid positions of the sampling points were then noted. The sample size (in area occupied by natural vegetation), n, was determined by the equation provided by Webster & Oliver (1990). The number of sampling points in each sampled vegetation structure

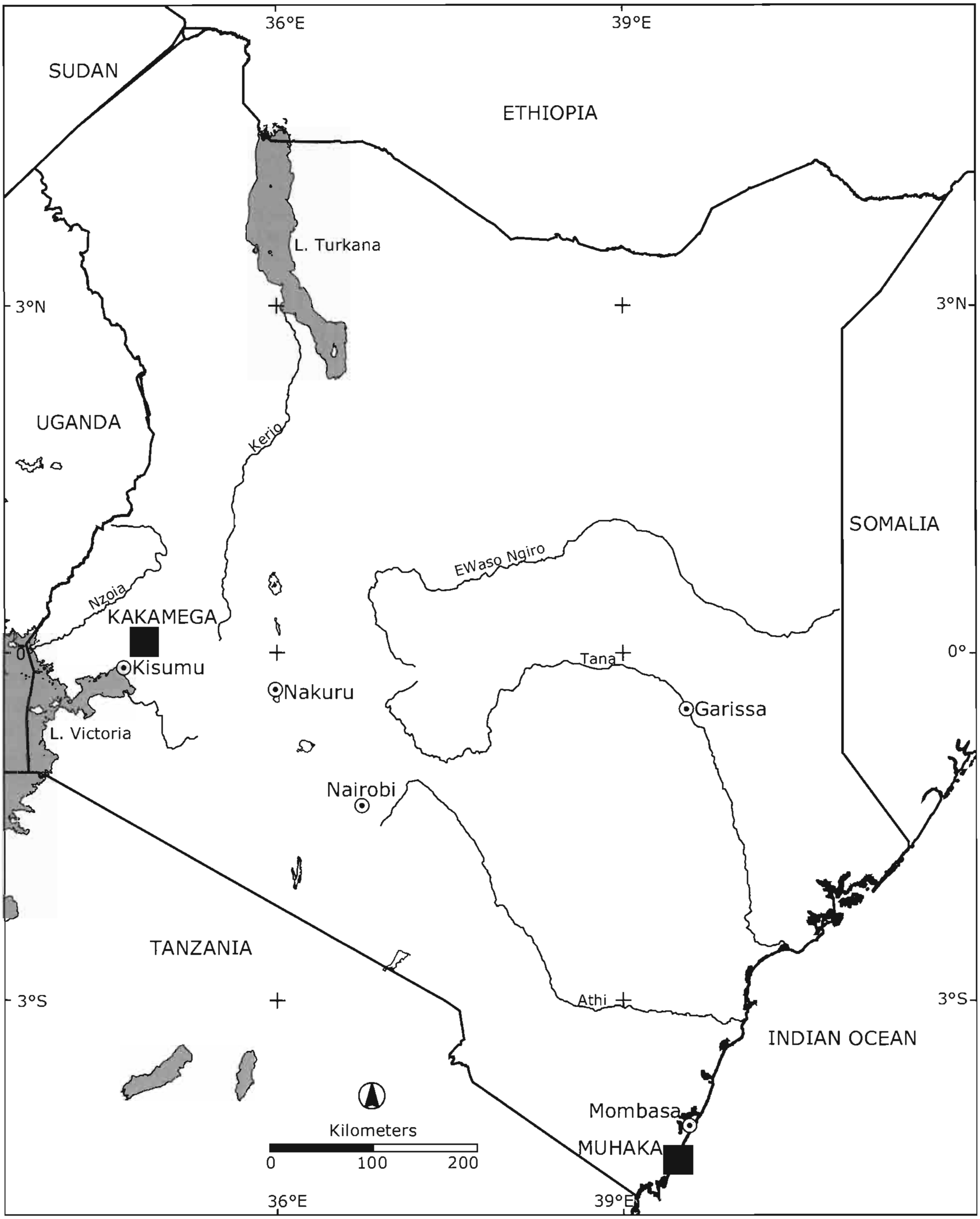

Figure 1
Map of Kenya showing study locations.

was proportional to the relative size of each structure (tab. 1). The sample size equation was as follows;

$$n = (z^2/I^2)pq$$

where n = sample size, I = permitted error (0.1), z = confidence interval (1.64); p = probability of area covered by wild host plants (11.7%) and q = probability of area not covered by wild hosts (maize, tea and natural forest) (88.3) for Kakamega

$$n = (1.64^2/0.1^2) \times 0.117 \times 0.883 = 28$$

For Muhaka; p = 88.7% and q = 11.3% whereby

$$n = (1.64^2/0.1^2) \times 0.887 \times 0.113 = 27$$

Vegetation structures; Forest Glade (FG) and Forest Corridor Vegetation (FCV) in Kakamega had only one sampling point due to their small size. The same was also realised in Roadside Vegetation (RV) in Muhaka. Therefore it became necessary to increase sampling points in such structures to a minimum of three per structure for better statistical analysis. This added to a total of 31 sampling points instead of 28 comprising 93 transect lines in each study location. The noted grid positions of the sampling points were fed into a portable Geographical Positioning System (GPS) kit, Meridian-GPS Magellan, which was used later to identify the points in the field.

Measurement procedure

Transect intercept method of sampling vegetation as described by Grieg-Smith (1983) was employed. At the beginning of each sampling point, a line, referred to as baseline stretching 200 m orienting in a South-North direction was established. The baseline (200 m) was divided into ten equal parts (marks) starting from 0 to the 10th mark (the end of 200 m length). Three sets of numbers from the ten designated marks were randomly generated and then allocated to each baseline. The set of numbers formed the starting points where line transects were established from the baseline. Three line transects (transects 1, 2, 3) of 50 m each were then established starting at the marked points, running perpendicular to the baseline and parallel to one another in a west-east direction (fig. 2). Sampling was done along the line transects and the exercise was repeated in all the sampling points.

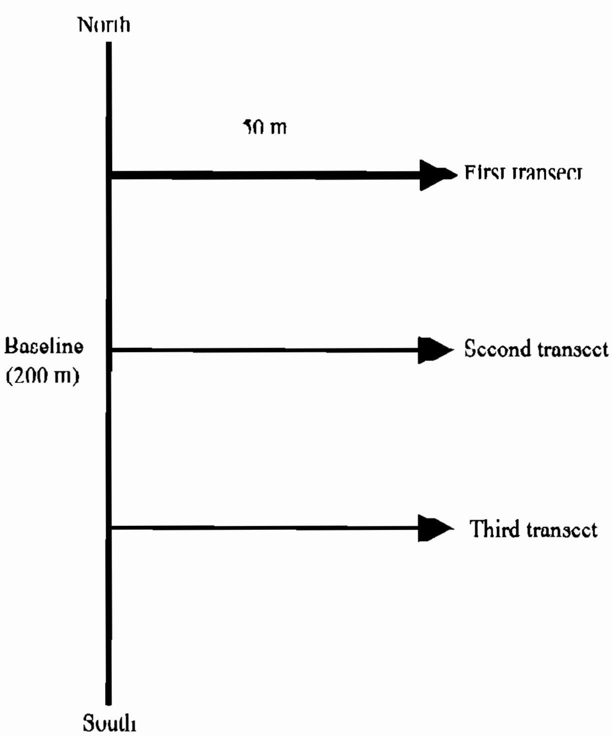

Figure 2
Establishment of baseline and transect lines where sampling took place.

All species belonging to Cyperaceae, Poaceae and Typhaceae intercepting the transects were recorded (Phillips 1995; Frits van Oudtshoorn 2004). Where species identification was not possible in the field, voucher specimen were collected and taken to the herbarium of the University of Nairobi for identification. Crown cover (the proportion of the ground cover occupied by a perpendicular projection of the aerial parts of the individual plant species) of each plant intercepting the transect was recorded (Greig-Smith 1983). The intercept lengths in the whole vegetation structures were summed. This was then divided by the total length of the transect and converted to percentage to give the proportion occupied by each species in that vegetation structure. This gave the percentage cover. Relative abundance was achieved by dividing percentage cover of each plant species by the total percentage cover of all the plant species in a particular vegetation structure. This was used to calculate diversity index. List of wild host plants of stem borer pests was extracted from the list provided by Le Ru *et al.* (2006a, 2006b).

Data Analysis

Diversity and abundance of wild host plants sampled in Kakamega and Muhaka sites were computed using Shannon-Weaver diversity index (H) (Magurran 1988):

$$H = -\sum Pi\,ln\,Pi \text{ where } Pi = Ni/N \text{ (relative abundance)}$$

H: Shannon's diversity index, i : host plant species, *Pi*: proportion of N made up of the *i*th species, N: total crown cover of all wild host plant species in a particular vegetation structure, N*i*: total crown cover of individual wild host plant species, *ln* : natural logarithm. The resulting product was multiplied by –1 to make negative figurers positive.

A t-test was used to compare the diversity indices (Magurran 1988) between vegetation structures within a location and between seasons within the same vegetation structures.

$$t = (H_1 - H_2)/(VarH_1 + VarH_2)^{1/2}$$

where H_l is the diversity in structure 1, Var H_l its variance and N_l total crown cover.

$$\text{Var } H = \{[\Sigma pi(lnpi)^2 - (\Sigma pilnpi)^2]/N\} - [(S-1)/2N^2]$$

The degrees of freedom was calculated using the equation,

$$df = [(VarH_1 + VarH_2)^2]/\{[VarH_1)^2/N_1] + [(VarH_2)^2/N_2]\},$$

where *S*: plant species richness

Results

Diversity and abundance of wild host of stem borers

Kakamega

There were four distinct vegetation structures in this location: Forest and Riverbank Vegetation (FRV), Between Cultivated (BC), Forest Glade (FG) and Forest Corridor Vegetation (FCV) (tab. 1). A total of 20 wild host plant species of stem borers were recorded with cropping season recording 18 while non-cropping season had 16 (tabs. 2 & 3). However, there was no variation in species diversity between the two seasons ($t_{37} = 0.75$; $p > 0.05$). The H values were 2 and 1.8 for cropping season and non-cropping season, respectively. Species richness did not vary significantly between vegetation structures (tab. 4). During the cropping season, the number of host species varied between 6 and 13 (6 species recorded in both FG and FCV and 13 in FRV). The species richness was proportional to the area (size) of the vegetation structure though BC, where cultivation was taking place, and FRV, that had wet-micro-climate, seemed to favour growth of host plant. During the non-cropping season, the vegetation structure, BC, had the highest number of hosts (11 species) followed by FRV (10 species) (tabs. 2 & 3). The variation in host plant distribution between the seasons in the same structure was attributed to their absence along some of the transect lines. The highest indices of 1.95 and 1.5 were recorded in FRV during the cropping and non-cropping season respectively. In contrast, the lowest diversity indices of 0.89 and 0.77 were recorded in FG during cropping season and non-cropping season respectively. The other structures showed intermediate values (tab. 4).

About 43% of the surface area surveyed was under cultivation (mainly maize), which was relatively high compared to total wild host species surface cover during the cropping season (2.2%) and non-cropping season (2.6%) (tab. 3). The relative abundance of wild host plants did not vary with the seasons ($t_{37} = 0.75$; $p > 0.05$) (tab. 4). By contrast, host plants surface cover varied between 0.11 and 0.93% among the vegetation structures during the cropping season and 0.07 and 1.1% during the non-cropping season. The highest cover was observed in the Forest edge and Riverbank Vegetation (FRV) where wild host plants had surface cover 0.7% during the cropping and 1.1% during the non-cropping season. This was a complete opposite with other structures where surface cover was higher during the cropping and lower during the non-cropping season (tab. 3).

Muhaka

There were five vegetation structures: Mixed Vegetation (MV), Open Grassland (OG), Palm Vegetation (PV), Natural Forest and Edge (NF&E) and Roadside Vegetation (RV) in this location (tab. 1). A total of 16 wild hosts species were recorded with a marked difference in species richness between the seasons (16 species during the cropping season and 7 during the non-cropping season) (tabs. 3 & 5). A significant variation in species diversity was recorded between the seasons ($t_{46} = 2.89$; $p < 0.05$), with higher diversity index during the cropping season than the non-cropping season (tab. 4). Wild host species richness varied between 6 and 11 during the cropping season with MV recording the highest (11) among the vegetation structures. The number reduced during the non-cropping season with MV still recording the highest (7) (tab. 3). Palm Vegetation (PV) and RV showed significant variation in species diversity compared to the other structures during the cropping season [MV-PV ($t_{45} = 3.39$; $p < 0.05$), OG-PV ($t_{45} = 2.75$; $p < 0.05$), RV-OG ($t_{43} = 2.17$; $p < 0.05$), RV-PV ($t_{36} = 5.28$; $p < 0.05$), RV-NF&E ($t_{55} = 3.64$; $p < 0.05$)]. During non-cropping season, a significant difference was observed between MV and

Table 1. Area covered (km²) and percentage surface cover by each vegetation structure in Kakamega and Muhaka. In parenthesis is the number of sampling points allocated to the vegetation structures inhabited by wild host plants.

Kakamega	Land cover vegetation structure	Area (km²)	Cover %
	Maize (M)	9.16	43.13
	Tea (T)	0.42	1.96
	Natural Forest (NF)	9.17	43.18
	Between Cultivated (BC)	0.60	2.83 (8)
	Forest edge and Riverbank vegetation (FRV)	1.38	6.48 (15)
	Forest Glade (FG)	0.34	1.62 (4)
	Forest Corridor Vegetation (FCV)	0.17	0.81 (4)
	Total Area	**21.25**	**100 (31)**
Muhaka	Mixed Vegetation (MV)	9.69	44.37 (13)
	Palm Vegetation (PV)	3.13	16.22 (5)
	Open Quary (OQ)	0.05	0.24
	Buildings (B)	0.07	0.36
	Roadside Vegetation (RV)	0.10	0.54 (3)
	Natural Forest and Edge (NF&E)	1.56	8.09 (4)
	Open Grassland (OG)	3.76	19.69 (6)
	Cultivated Vegetation (CV)	2.06	10.69
	Total Area	**19.30**	**100 (31)**

Table 2. Total relative cover (%) and relative cover of each wild host plant species of lepidopteran stem borers in the four different vegetation structures in Kakamega during the cropping and non-cropping seasons.
The wild host plants of *B. fusca* are in bold.

	Plant species	FRV	BC	FG	FCV	Cover %
Cropping season	*Cyperus dives* Delile	0.09	0.15	0	0	0.08
	Cyperus distans L.	0.50	0.25	0	0	0.31
	***Cyperus dichrostachyus* A. Richard**	0	0.13	0	0	0.03
	Scleria racemosa Poiret	0.30	0.90	0	0	0.38
	***Brachiaria brizantha* (A. Richard) Stapf**	1.08	1.47	42.52	1.67	6.60
	Cynodon dactylon (L.) Persoon	4.94	5.65	3.53	0.80	4.41
	***Digitaria milanjiana* (Rendle) Stapf**	0	0	0.07	0	0.01
	***Hyparrhenia diplandra* (Hackel) Stapf**	0.67	0	0	0	0.32
	Hyparrhenia rufa (Nees) Stapf	0.46	1.25	0	0	0.54
	Panicum maximum Jacquin	0.23	0.15	4.62	2.10	1.02
	*Pennisetum macrourum*Trinius	0.64	0	0	0	0.31
	Pennisetum purpureum Schumacher	**0.58**	**2.33**	**0**	**0**	**0.88**
	Pennisetum clandestinum (Chiovenda) Hochstetter	0	0	0.50	0.20	0.09
	***Pennisetum trachyphyllum* Pilger**	0	0	0	2.67	0.34
	Setaria megaphylla (Steudel) T. Durand & Schinz	**0.88**	**3.08**	**0**	**6.30**	**2.04**
	Setaria sphacelata (Schumacher) Moss	0.18	0	0	0	0.09
	Sorghum arundinaceum (Desvaux) Stapf	**0.30**	**0**	**6.43**	**0**	**0.98**
	Typha domingensis Persoon	0	0.67	0	0	0.17
	Average cover in respective structures	10.84	16.03	57.67	13.73	18.60
Non-cropping season	*Cyperus dives* Delile	0	0.09	0	0	0.03
	Cyperus distans L.	0	0.16	0	0	0.06
	Cyperus dichrostachyus A. Richard	0	0.27	0	0	0.10
	Scleria racemosa Poiret	0.07	0.09	0.09	0	0.07
	***Brachiaria brizantha* (A. Richard) Stapf**	0.70	0.17	26.93	0.74	5.427
	Cynodon dactylon (L.) Persoon	7.56	3.25	1.78	0.14	6.57
	Cymbopogon nardus (L.) Rendle	0.41	0.300	3.47	0	1.01
	Digitaria milanjiana (Rendle) Stapf	4.25	6.75	0	1.00	5.36
	Echinochloa pyramidalis (Lamark) Hitchcock & Chase	0.07	0	0	0	0.05
	Panicum maximum Jacquin	0	0	0.79	0.67	0.20
	Pennisetum macrourum Trinius	0.45	0	0	0.17	0.32
	***Pennisetum purpureum* Schumacher**	**0.27**	**0.54**	**0**	**0**	**0.37**
	Setaria megaphylla (Steudel) T. Durand & Schinz	**2.14**	**1.33**	**0**	**1.44**	**2.04**
	Pennisetum trachyphyllum Pilger	0	0	0	4.05	0.36
	***Sorghum arundinaceum* (Desvaux) Stapf**	**0.37**	**0**	**0.85**	**0.73**	**0.47**
	Typha domingensis Persoon	0	0.37	0	0	0.13
	Average cover in respective structures	**16.51**	**13.30**	**33.90**	**8.95**	**22.60**

FRV: Forest and Riverbank Vegetation; BC: Between Cultivation; FG: Forest Glade; FCV: Forest Corridor Vegetation.

NF&E ($t_{32} = 2.07$; $p < 0.05$) and between MV and RV ($t_{30} = 2.38$; $p < 0.05$) (tab. 4).

The relative abundance of wild hosts varied significantly between the two seasons ($t_{46} = 2.89$; $p < 0.05$) (tab. 4). The total wild host species surface cover was two times (23%) higher than maize (10.7%) during the cropping season than during the non-cropping season. Maize plots were mainly found in OG and MV structures where wild host species constituted about 4.9 and 12.1%, respectively, during the cropping season, and 2.7 and 8.2%, respectively, during the non-cropping season (tab. 3).

Wild hosts of *Busseola fusca* and *Chilo partellus*

Three wild hosts plant species [*Sorghum arundinaceum* (Desvaux) Stapf, *Setaria megaphylla* (Steudel) T. Durand & Schinz and *Pennisetum purpureum* Schumacher] of *B. fusca* were recorded in both seasons in Kakamega. In Muhaka 3 wild hosts [*Panicum. maximum* Jacquin, *S. arundinaceum* and

Table 3. Surface cover (%) and species richness of host plants in the different vegetation structures during cropping season (CS) and non-cropping season (NCS) in Kakamega and Muhaka.
In parenthesis is the surface cover (%) and species richness of B. fusca and C. partellus host plants

Vegetation structures	Seasonal variation			
	Surface cover (%)		Species richness	
Kakamega	**CS**	**NCS**	**CS**	**NCS**
Cultivated (maize) habitat	43.3	0		
Uncultivated (wild host) habitat	2.2(0.46)	2.6(0.34)	18(3)	16(3)
FRV	0.7(0.11)	1.1(0.18)	13(3)	10(3)
BC	0.46(0.15)	0.37(0.05)	11(2)	11(2)
FG	0.93(0.10)	0.55(0.01)	6(1)	6(1)
FCV	0.11(0.05)	0.07(0.02)	6(1)	8(2)
Muhaka	**CS**	**NCS**	**CS**	**NCS**
Cultivated (maize) habitat	10.69	0		
Uncultivated (wild host) habitat	23(2.17)	17.9(1)	15(3)	7(1)
MV	12.09(1.3)	8.24(0.46)	11(1)	7(0)
OG	4.9(0.45)	2.7(0.18)	10(0)	4(0)
RV	0.13(0.03)	0.059(0.01)	11(2)	2(0)
PV	3.44(0.02)	5.17(0.22)	6(0)	4(0)
NF&E	2.53(0.16)	2.13(0.02)	8(1)	3(0)

FRV: Forest and Riverbank Vegetation; BC: Between Cultivation; FG: Forest Glade; FCV: Forest Corridor Vegetation; MV: Mixed Vegetation; OG: Open Grassland; PV: Palm Vegetation; NF&E: Natural Forest & Edge; RV: Roadside Vegetation.

Table 4. t-statistics for difference between vegetation structures for within and between seasons in Kakamega and Muhaka study locations.

Kakamega	**Cropping Season (CS)**							**Non-cropping Season (NCS)**							Between seasons	
	BC		FG		FCV			BC		FG		FCV				
	df	t	df	t	df	t	H_{CS}	df	t	df	t	df	t	H_{NCS}	df	t
FRV	19	0.27^{ns}	17	3.63*	18	1.66^{ns}	1.95	28	0.41^{ns}	37	2.83*	24	0.30^{ns}	1.50	23	1.33^{ns}
BC			39	4.65*	30	1.86^{ns}	1.87			27	2.17*	23	0.71^{ns}	1.49	23	1.23^{ns}
FG					36	2.70*	0.89					24	3.32*	0.77	52	0.44^{ns}
FCV							1.45							1.64	18	0.77^{ns}
Total cover							2.00							1.81	37	0.75^{ns}

Muhaka	**Cropping Season (CS)**									**Non-cropping Season (NCS)**									Between seasons	
	OG		PV		NF&E		RV			OG		PV		NF&E		RV				
	df	t	df	t	df	t	df	t	H_{CS}	df	t	df	t	df	t	df	t	H_{NCS}	df	t
MV	52	0.51^{ns}	45	3.39*	55	1.51^{ns}	48	1.67^{ns}	1.66	30	1.05^{ns}	35	1.03^{ns}	32	2.07*	30	2.38*	1.08	43	2.34*
OG			45	2.75*	50	0.89^{ns}	43	2.17*	1.53			25	0.25^{ns}	22	0.68^{ns}	24	1.08^{ns}	0.80	34	2.72*
PV					42	1.19^{ns}	36	5.28*	0.80					58	1.31^{ns}	28	1.73^{ns}	0.86	23	0.29^{ns}
NF&E							55	3.64*	1.33							24	0.61^{ns}	0.65	56	3.82*
RV									2.00									0.54	27	7.89*
Total cover									1.67									0.95	46	2.89*

H: Shannon diversity index; df: degrees of freedom; t: t-test values; ns: Diversity not significantly different; *: Diversity significantly different at $P < 0.05$.
FRV: Forest and Riverbank Vegetation, BC: Between Cultivation, FG: Forest Glade, FCV: Forest Corridor Vegetation.
MV: Mixed Vegetation, OG: Open Grassland, PV: Palm Vegetation, NF&E: Natural Forest & Edge, RV: Roadside Vegetation.

Rottboellia cochinchinensis (Loureiro) Clayton] of *C. partellus* were recorded during the cropping season and only *P. maximum* during the non-cropping season. Hosts of *B. fusca* varied between 1 and 3 among vegetation structures in both cropping and non-cropping seasons, and 1 in FG and 3 in FRV during cropping and non-cropping seasons in Kakamega. In Muhaka, wild host of *C. partellus* varied between 1 and 3 among vegetation structures during the cropping season with RV having the highest (3). During the non-cropping season, only *P. maximum* was present in all structures (tab. 5).

In Kakamega, surface cover of wild host plant species of *B. fusca* was about 0.46 and 0.34% during the cropping and non-cropping seasons respectively while in Muhaka wild hosts of *C. partellus* constituted 2.17 and 1% during the two seasons. However, surface cover of *B. fusca* hosts varied between 0.05 and 0.15% during the cropping and between 0.01 and 0.18% during the non-cropping season among vegetation structures. Hosts of *C. partellus* in OG and MV vegetation structures varied between 0.45 and 1.3% respectively during the cropping season and 0.18 and 0.46% respectively during the non-cropping season (tab. 3).

Discussion

In Kakamega no difference in wild host plant species richness and relative abundance was found between both cropping and non-cropping seasons suggesting continuous presence of host plants throughout the year. This further suggests that the natural habitat could support the population of *Busseola fusca* during the intercropping period in this location. However, *B. fusca* has been reported to enter diapause at the end of cropping season (Kfir 1991). In addition, among the wild plant species identified in this study location only three plants (*Sorghum arundinaceum, Setaria megaphylla* and *Pennisetum purpureum*) were identified as hosts of *B. fusca* (Le Rü *et al.* 2006a, 2006b). Coupled with the limited host range of this pest, dense human population is putting more pressure on the remaining

Table 5. Total relative cover (cover %) and relative cover of each wild host plant species of lepidopteran stem borers in the four different vegetation structures in Muhaka during the cropping and non-cropping seasons.
The wild host plants of *C. partellus* are in bold.

	Plant species	MV	OG	PV	NF&E	RV	cover %
Cropping season	*Cyperus exaltatus* Retz	1.61	1.91	1.87	6.83	0.98	2.32
	Cyperus dives Delile	0.10	0	0	0	0	0.04
	Cyperus prolifer Lamark	0	0.02	0	0	0	0.01
	Brachiaria brizantha (A. Richard) Stapf	1.94	0.22	0.11	0	0.40	0.912
	Cenchrus ciliaris L.	0.05	0	0	0	2.62	0.28
	Cynodon dactylon (L.) Persoon	0	0	0	0	6.67	0.645
	Digitaria milanjiana (Rendle) Stapf	8.94	12.64	15.77	15.47	3.11	11.04
	Echinochloa haploclada (Stapf) Stapf	0	0.56	0	0	0	0.11
	Eriochloa meyeriana (Nees) Pilger Engler & Prantl	0.46	1.69	0	0	0	0.52
	Hyperthelia dissoluta (Steudel) W.D. Clayton	9.95	4.78	3.24	6.03	2.67	6.66
	Panicum maximum **Jacquin**	**2.40**	**2.33**	**0.11**	**1.83**	**4.22**	**2.12**
	Panicum merkeri Mez	0.61	0.09	0	0.50	0.22	0.36
	Pennisetum polystachyon (L.) Schultes	0.66	0.89	0.11	0.33	1.56	0.66
	Rottboellia cochinchinensis **(Loureiro) Clayton**	**0.53**	**0**	**0**	**0.13**	**0.44**	**0.28**
	Setaria sphacelata (Schumacher) Moss	0	0	0	0.13	0	0.02
	Sorghum arundinaceum **(Desvaux) Stapf**	**0**	**0**	**0**	**0**	**0.40**	**0.039**
	Average cover in respective structures	27.25	25.13	21.20	31.27	23.29	26.00
Non-cropping season	*Cyperus exaltatus* Retzius	0.65	0.12	0.48	0	0	0.40
	Cyperus prolifer Lamark	0.05	0	0	0	0	0.02
	Digitaria milanjiana (Rendle) Stapf	10.02	9.76	19.93	18.78	0	12.23
	Hyperthelia dissoluta (Steudel) W.D. Clayton	6.43	2.94	10.08	7.24	8.47	6.37
	Panicum merkeri Mez	0.12	0	0	0	0	0.05
	Panicum maximum **Jacquin**	**1.14**	**0.947**	**1.39**	**0.29**	**2.50**	**1.09**
	Pennisetum polystachion (L.) Schultes	0.17	0	0	0	0	0.08
	Average cover in respective structures	18.57	13.77	31.88	26.31	10.97	20.24

MV: Mixed Vegetation. OG: Open Grassland. PV: Palm Vegetation. NF&E: Natural Forest & Edge. RV: Roadside Vegetation.

land resulting in constant destruction of wild habitat (Otieno *pers obs*). According to Altieri (1991) and Tscharntke & Brandl (2003) destruction of wild habitat may disrupt the plant-herbivore interaction and thus affect the pest population in the wild habitat.

In Muhaka location, there was variation in wild host species richness and relative abundance between the seasons though the results show higher surface cover of wild host plants relative to maize. However, among the hosts recorded, only three (*Panicum maximum, S. arundinaceum* and *Rottboellia cochinchinensis*) were identified as host plants of *Chilo partellus* (Le Rü *et al* this issue). *P. maximum* was the main alternate host of *C. partellus* present in all vegetation structures in both seasons. The other hosts (*S. arundinaceum* and *R. cochinchinensis*) were mainly found at the edge of cultivated fields confirming that farming practice can favour the maintenance of alternative host plants for stem borer pests during the non-cropping season (Rebe & Van den Berg 2001). However, uncontrolled burning of wild habitats during the dry season to clear land in preparation for the cropping season, probably was responsible for the low abundance of wild hosts of the pest in Muhaka location in addition to the long dry season.

A similar study carried out in Kitale in 2003 on the abundance and diversity of alternative hosts plants of stem borers reported 14 wild hosts of cereal pests (*B. fusca* and *C. partellus*) (Kanya *et al*., 2005). This was based on earlier report by Polaszek & Khan (1998) that *B. fusca* and *C. partellus* are polyphagous. The high number of host plants reported earlier was most probably due to misidentification of the stem borers recovered from the wild habitat (Le Rü *et al.* 2006a, 2006b). However, Kanya *et al* (2005) reported wild host abundance of < 10% compared to maize 95%. Interaction between vegetation structure and movement patterns of insects ultimately affects population dynamics in a heterogeneous landscape (Burel *et al.* 2000). Thus, the absence or presence of alternate hosts alone might not account for pest outbreaks in the cultivated fields, and hence, there is need to study the movement patterns of the stem borers as well.

The limited information available on movement of adult moths suggests that most of the population moves relatively short distances (less than 100 m) within the crop or the adjacent vegetation though reports indicate that *B. fusca* is likely to fly long distance under optimum conditions (Fitt *et al.* 2004). However, it is worth noting that *B. fusca* recovered in Kakamega from *S. megaphylla* did not develop to up to adult moths in the artificial diet under laboratory conditions (contrary to *B. fusca* recovered from *S. arundinaceum*) (Le Rü, *pers. obs.*). This could be an indication that the *B. fusca* population belonging to this location might be divided into different compartments with very low exchange between cultivated and non-cultivated habitats. Future prospects need to investigate the structure of *B. fusca* populations in Kakamega and to quantify the exchange between the different habitats.

On these understandings, the importance of wild habitats as reservoir of stem borer pests cannot be estimated until the information on the dispersal potential of stem borers is generated. However, our study and that done by Kanya *et al.* (2005) showed that the area covered by wild host plants was below 10% and therefore inadequate to sustain susceptible stem borers as it is recommended that 20-50% to be non-transgenic plants (Fitt *et al.* 2004).

Contrary to the previous reports (Polaszek & Khan, 1998), this study shows that the host range of *B. fusca* and *C. partellus* is limited both in number and abundance. Nonetheless, it is not clear whether the observed low abundance may facilitate the carry-over of these stem borer pest species between the growing seasons. Probably, these species invading cereal crops come either from other areas or from the maize/sorghum residues present in the crop fields. Attempt should thus be made to study whether traditional farming practices contributes to carry-over of the pests.

Acknowledgements. This work was supported by Institut de Recherche pour le Dévelopment (IRD) through insect-plant interaction unit (R072) in collaboration with International Centre of Insect Physiology and Ecology (ICIPE). The authors gratefully acknowledge the Noctuid Stemborer Biodiversity Project (NSBB) staff especially Leonard Ngala for technical support and Simon Mathenge (Botany Department, University of Nairobi) for identification of plant specimens.

References

Altieri M. A. 1991. Increasing biodiversity to improve insect pest management in agro-ecosystems, p. 165-182 *in*: **Hawksworth. D. L (eds)**, *Biodiversity of microorganisms and invertebrates: Its Role in sustainable agriculture*, Wallingford, UK: CAB International.

Arc View 3.2. 1992. Environmental Systems Research Institute, New York.

Bowden J. 1954. The Stem-borer problem in Tropical crops, p. 104-107 *in: Report 6th Commonwealth Entomological Conference,* Commonwealth Institute of Entomology, London

Burel F., Baudry J., Delettre Y., Petit S., Morvan N. 2000. Relating insects movement to farming systems in dynamic landscapes, p. 5-32 *in*: **Ekbom, B., Irwin, M. E. and Robert, Y. (eds)**, *Interchanges of insects between agricultural and surrounding landscapes.* Kluwer Academic Publishers, Netherlands.

Fitt G. P., Andow D. A., Carrière Y., Moar W.J., Schuler T. H., Omoto C., Kanya J., Okech M. A., Arama P., Maniania N. K. 2004. Resistance risks and management associated with *Bt* Maize in Kenya, p. 209-250 *in*: **Hilbeck A., Andow D. A. (eds.)**, *Environmental risk assessment of genetically modified organisms.* CABI, London, UK.

Frits van Oudtshoorn. 2004. *Guide to grasses of Southern Africa.* Briza, Pretoria, SA, 288 p.

Guofa Z., Overholt W. A., Mochiah M. B. 2002. Changes in the distribution of lepidopteran maize stemborers in Kenya from 1950's to 1990's. *Insect Science and its Application* **21:** 395-402.

Grieg-Smith P. 1983. *Quantitative plant ecology.* 3rd edition, Blackwell Scientific Publication, Oxford, England, 359 p.

Guihéneuf Y. 2004. *Characterisation of wild and cultivated habitat in two ecological areas in Kenya.* Mémoire de D.E.S.S., Université de Paris XII, Paris, 52 p.

Haile A., Hofsvang T. 2001. Survey of lepidopterous stemborer pests of sorghum, maize and pearl millet in Eritrea. *Crop protection* **20***:* 151-157.

Ingram W. R. 1958. The lepidopterous stalk borers associated with graminae in Uganda. *Bulletin of Entomological research* **49***:* 367-383.

Kanya J. I., Ngi-song A. J., Setamou M. F., Overholt W., Ochora J. and Osir E. O. 2005. Diversity of alternative hosts of maize stemborers in Trans-Nzoia district of Kenya. *Environmental Biosafety Research* **3**: 159-168.

Khan Z. R., Lwande W., Ampong-Nyarko K. 1997. *Use of wild habitat in the management of cereal stemborers.* 1995-1997 ICIPE Annual Scientific Report, Nairobi, Kenya.

Kfir R. 1991. Effects of diapause on development and reproduction of the stemborers *Busseola fusca* (Lepidoptera: Noctuidae) and *Chilo partellus* (Lepidoptera: Pyralidae). *Journal of Economic Entomology.* **84**: 1677-1680.

Kokwaro J. O. 1988. Conservation Status of the Kakamega Forest in Kenya: The eastern most relic of the equatorial rain forest. Monograph in systematic botany. *Missouri Botanical Garden* **25**: 471-489.

Le Rü B.P., Ong'amo G.O., Moyal P., Ngala L., Musyoka B., Abdullah Z., Cugala D., Defabachew B., Haile T.A., Kauma Matama T., Lada V.Y., Negassi B., Pallangyo K., Ravololonandrianina J., Sidumo A., Omwega C., Schulthess F., Calatayud P.-A., Silvain J.F. 2006a. Diversity of lepidopteran stem borers on monocotyledonous plants in eastern Africa and the islands of Madagascar and Zanzibar revisited. *Bulletin of Entomological Research* **96**: 1-9.

Le Rü B.P., Ong'amo G.O., Moyal P., Muchugu E., Ngala L., Musyoka B., Abdullah Z., Matama-Kauma T., Lada V.Y., Pallangyo B., Omwega C.O., Schulthess F., Calatayud P.-A., Silvain J.-F. 2006b. Geographic distribution and host plant ranges of East African noctuid stem borers. *Annales de la Société Entomologique de France (N.S.)* **42(3-4)**: 353-361.

Magurran A. E. 1988. *Ecological diversity and its measurement.* Princeton University press, Princeton, 179 p.

Nye I. W. B. 1960. The insect pests of graminaceous crops in East Africa. *Colonial Research Studies* **31**: 1-48.

Ong'amo G. O. 2005. *An assessment of lepidopteran stemborer species distribution in relation to diversity of wild host grasses in maize and sorghum growing zones in Kenya.* MSc thesis, Kenyatta University. Nairobi, Kenya, 79 p.

Phillips S. 1995. *Flora of Ethiopia and Eritrea Volume 7. Poaceae (Gramineae).* **Hedberg I., Edwards S. (eds).** National Herbarium, Addis Ababa University, Addis Ababa, Ethiopia, 398 p.

Polaszek A., Khan Z. R. 1998. Host plants, p. 5-23 *in*: **Polaszek. A (ed)**, *African Cereal stemborers: economic importance, taxonomy, natural enemies and control.* CAB International 1998. University Press, Cambridge, UK.

Randriamananoro J. J. 1996. *Behaviour and Physiological responses of the cereal stalk borer Busseola fusca Fuller (Lepidoptera: Noctuidae) to selected cultivated and wild host plants.* Ph.D. Dissertation, River State University of Science and Technology, Port Harcourt, Nigeria, 141 p.

Rebe M., Van den Berg J. 2001. *Wild host plants of lepidopterous stem borers in Limpopo and Northern Mpumalanga Provinces of South Africa.* Pietermaritzburg, 63 p.

Seshu Reddy K. V. 1983. Sorghum stem borers in East Africa. *Insect Science and its Application* **4:** 33-39.

Seshu Reddy K. V. 1989. Sorghum stem borers in Eastern Africa, p 33-40. *Proceedings of the International Workshop on sorghum stem borers, 17th-20th November, 1987,* ICRISAT, Patancheru, India.

Tscharntke T., Brandl R. 2003. Plant-insect interactions in fragmented landscapes. *Annual Review of Entomology* **49:** 405-430.

Webster R., Oliver M. A. 1990. *Statistical methods in soil and land resource survey.* Oxford University Press. New York, 316 p.