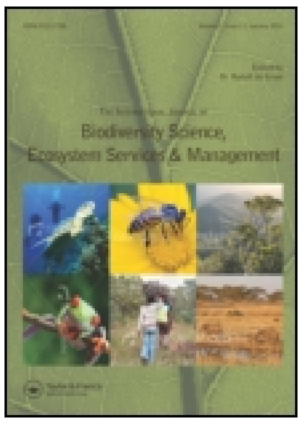

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Diversity and abundance of wild host plants of lepidopteran stem borers in two agro-ecological zones of Kenya

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Key words: Stem borer pest, *Busseola fusca*, *Chilo partellus*, cereal crops, uncultivated habitat, refuge area

SUMMARY

A survey was carried out between 2005 and 2006 in two ecologically different localities, Suam and Mtito Andei, to assess diversity and abundance of wild host plants of lepidopteran stem borers during the cropping and non-cropping seasons. Suam in western Kenya is situated in the moist high tropics and is characterised by an Afromontane vegetation mosaic, while Mtito Andei is located in the dry mid-altitudes characterised by a Somalia Masai vegetation mosaic. In Suam, wild host plants and maize covered 11 and 50%, respectively, of the surveyed area. In Mtito Andei, 27% of the surveyed area was under maize during the cropping season, while wild host plant species covered 13% and 8% during the cropping and non-cropping seasons, respectively. There was no significant variation in the relative abundance and diversity of the wild grasses between the two seasons in either location. The abundance of host plants of *B. fusca* and *C. partellus* is low in natural habitats surrounding cereal crops. The abundance of *C. partellus* was low in its wild host plants and *B. fusca* was absent. Therefore, the role of wild vegetation surrounding cultivated areas in the carry-over of these pests during the non-cropping season is limited.

INTRODUCTION

Cereal crops, particularly maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* L. (Moench)), constitute the most important sources of food in Africa (FAO 2003). In East and Southern Africa, these two crops are grown by both commercial and resource-poor farmers. Major constraints of crop production include several lepidopteran stem borer species whose distribution and pest status varies with region in Africa and ecozones within a region (Schulthess *et al.* 1997; Kfir *et al.* 2002). In eastern Africa, *Busseola fusca* (Fuller) and *Chilo partellus* (Swinhoe) are the major pests, whereas *Chilo orichalcociliellus* Walker and *Sesamia calamistis* Hampson are of minor importance (Seshu Reddy 1983; Guofa *et al.* 2002). Distributions of major species vary with altitude, with *B. fusca* dominating high-altitude areas

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whereas *C. partellus* is well established in low- and mid-altitude areas (Nye 1960; Seshu Reddy 1983; Guofa *et al.* 2002; Kfir *et al.* 2002; Ong'amo *et al.* 2006).

In the tropics, small-scale cereal fields are surrounded by uncultivated habitats that are rich in alternative host plants, which are believed to act as reservoirs for stem borer pests during the non-cropping period. These habitats are considered responsible for pest outbreaks in crops during the subsequent growing season (Ingram 1958; Bowden 1976; Khan *et al.* 1997). However, recent studies in Uganda and Cameroon concluded that wild grasses play a minor role in the seasonal carry-over of stem borer pests (Ndemah *et al.* 2007; Matama-Kauma *et al.* 2008). This is supported by results of surveys carried out in East and Southern Africa since 2002, which suggested that earlier reports of the common occurrence of stem borer pests on wild grasses were due to misidentification of the specimens (Le Ru *et al.* 2006a).

Lepidopteran stem borers have been associated with monocotyledonous host plants belonging to the families Poaceae, Cyperaceae and Typhaceae (Polaszek and Khan 1998; Guofa *et al.* 2002; Le Ru *et al.* 2006a,b) for millions of years (Harris 1962). However, densities of stem borers in wild habitats range between 0.001 and 0.03 per tiller, results that are considerably lower compared to the cultivated habitats (Le Ru *et al.* 2006a, Ndemah *et al.* 2007; Matama-Kauma *et al.* 2008). A study carried out in Kitale, Kenya, that assessed the potential of using wild host plants as a refuge for *Bt*-susceptible pest populations, required in resistance management for *Bt* maize (Kanya *et al.* 2005), showed that the ratio of wild host plants to maize was below 10%. However, another study carried out in Kakamega and Muhaka, representing the moist transitional and lowland tropical zones, showed that the host range of *C. partellus* and *B. fusca* was limited in both number and abundance (Otieno *et al.* 2006), suggesting that Kanya *et al.* (2005) may have been overestimated the populations.

A study was carried out in two locations, Suam and Mtito Andei in Kenya, in an attempt to obtain a wider ecological understanding of the diversity and abundance of wild host plants of the stem borer pests. These locations represent two agro-ecological zones and were chosen for their diversity of habitats and farm management practices. The study was carried out during the cropping and non-cropping seasons to capture 1) the diversity and abundance of wild host plants of stem borers across the natural habitat in the different types of vegetation; and 2) the abundance of stem borer pests in both cultivated and natural habitats.

MATERIALS AND METHODS

Study localities and sampling design

The two study sites, Suam and Mtito Andei, are situated in two different agro-ecological zones in Kenya, dominated by different stem borer pest species; *Busseola fusca* is the dominant borer species in Suam while *C. partellus* dominates in Mtito Andei (Seshu Reddy 1983; Guofa *et al.* 2002; Ong'amo *et al.* 2006).

Suam, in western Kenya, is in the moist transitional zone and is characterised by an Afromontane mosaic with a lightly wooded grassy formation (Figure 1). It covers an area of 25 km^2 and is located on the eastern slopes of Mt. Elgon at 1.17°N to 1.21°N and 34.77°E to 34.34°E, between 1930 to 2150 m above sea level (asl). Approximately 70% of the study area is under maize cultivation, 11% is wild habitats, while the remaining 19% is under other vegetation (Goux 2005). Average annual rainfall is 1350 mm and average temperature is 20.0°C, with a minimum/maximum temperature range of 12.7/26.8°C. The area is characterised by bimodal rainfall that allows only one cropping

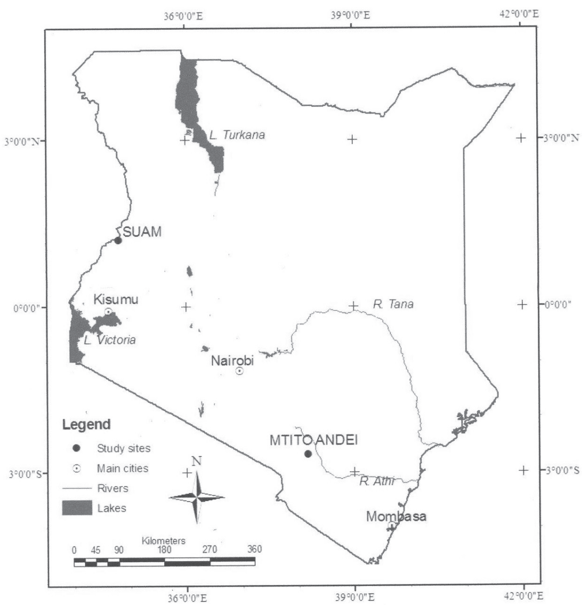

Figure 1 Map of Kenya showing the two study locations, Suam and Mtito Andei

season (CS) per annum, which lasts from April to October. The dry season (hereafter referred to as the non-cropping season, NCS) is between December and March (Corbett and O'Brien 1997).

Mtito Andei is on the western border of the Tsavo Park and is composed of thick deciduous shrubby formations with *Acacia–Commiphora* and other riverine forest species of the Somalia Masaï vegetation mosaic (Figure 1). It covers an area of 25 km^2 and is located on the border of the Tsavo East National Park, between 2.64°E to 2.69°E, and 38.17°N to 38.22°N at 680 to 770 m asl (Goux 2005). Annual rainfall is around 660 mm and mean temperature is 25°C, with minimum/maximum temperatures of 16.8/29.0°C (Corbett and O'Brien 1997). The main cropping season falls between November and January, although maize is grown under irrigation throughout the year. However, the climatic conditions are at times irregular, with some years going without rainfall while others receive rainfall during the known dry period.

In Suam, sampling in the uncultivated habitats was carried out during the non-cropping season (NCS) in March and during the cropping season (CS) in July. In Mtito Andei, there was no rain from November to January and sampling was therefore carried out during the NCS in January 2006, while the CS sampling was carried out in April 2006.

Sampling for diversity and abundance of host plants in the natural habitat

Sample size

Satellite images were used as basic spatial information to describe vegetation types of the study sites (Goux 2005). This enabled translation of the vegetation types to the vegetation physiognomic classification by ground truthing. This resulted in a description of vegetation structural formation classes that was mainly divided into wild and cultivated habitats of stem borers (Goux 2005). Sampling was confined to wild habitats dominated by plant species listed by Le Ru *et al.* (2006a) as host plants of stem borers. Three vegetation structural formation classes made up of wild habitats were identified in

Table 1 Surface area (km^2) and percentage surface area (relative to total surface area of the study site) of each vegetation type in Suam and Mtito Andei. In parenthesis is the number of sampling sites in each vegetation type in the wild habitats

Vegetation type		*Area (km^2)*	*%*
Suam	Forest Woodland (FW)	1.7	6.8 (9)
	Open Grassland (OG)	1	4 (6)
	Savanna Woodland (SW)	4.5	18 (39)
	Agricultural Development Cooperation Maize Farms (ADC)	10	40
	Agricultural Development Cooperation Fallow Farms (ADCF)	1.8	7.2
	Local Community Maize Farms (LCM)	2.5	10
	Wheat Farms (WF)	1	4
	Orange Farms (OF)	0.08	0.32
	Other Cultivated Vegetation (OCV)	0.2	0.8
	Settlement Area and Infrastructure (SAF)	2.25	9
	Total Area	**25.00**	**100 (54)**
Mtito Andei	Savanna Grassland (SG)	0.82	3.22 (3)
	Savanna Woodland (SW)	9.53	37.39 (28)
	Forest Acacia (FA)	7.22	28.32 (20)
	Riverine Vegetation (RV)	0.22	0.86 (3)
	Maize (M)	6.97	27.34
	Sorghum (S)	0.03	0.12
	Green grams (G)	0.51	2
	Beans (B)	0.02	0.08
	Dam (D)	0.01	0.04
	Bare Soil (BS)	0.16	0.63
	Total Area	**25.00**	**100 (54)**

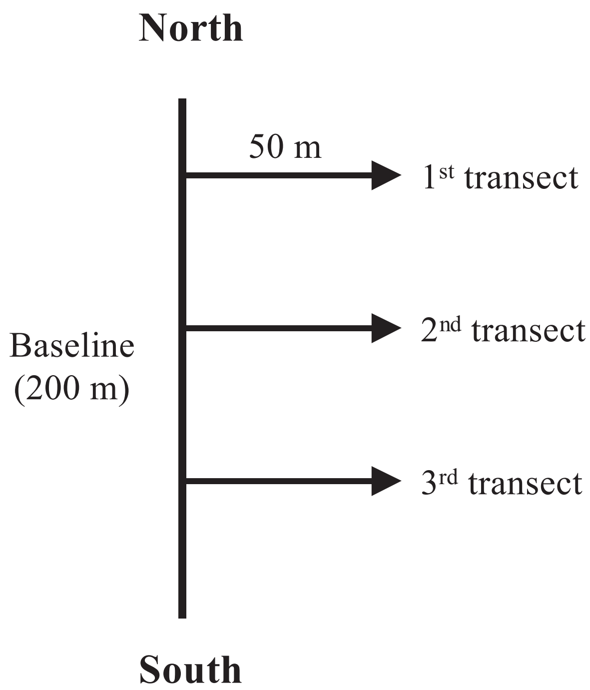

Figure 2 Establishment of baseline and transect lines where sampling took place

Suam and four in Mtito Andei (Table 1). The sample size n (number of sampling points in areas occupied by natural vegetation) was determined from the equation of Webster and Oliver (1990). The Geographical Information System (GIS) program, Arc View 3.2 (ESRI 1992) was then used to generate random sampling points within the vegetation structural formation classes. The number of sampling points in the vegetation structures where sampling was carried out was proportional to the relative area size of each structure (Table 1). The sample size equation was as follows:

$$n = \frac{z^2}{I^2} pq$$

where n = sample size, I = permitted error (0.1), z = confidence interval (1.64), p = probability of area covered by wild host plants, and q = probability of area not covered by wild hosts.

For Suam: p = 28% and q = 72% where

$$n = \frac{1.64^2}{0.1^2}\, 0.28 \times 0.72 = 54$$

For Mtito Andei: p = 69.8% and q = 30.2%, where

$$n = \frac{1.64^2}{0.1^2}\, 0.698 \times 0.302 = 56.$$

Hence, 54 points were sampled at both sites.

Experimental procedure

Baseline study techniques for sampling vegetation were applied (Grieg-Smith 1983). Sampling without replacement was used, where the baseline formed one of the outer boundaries of the sampling unit. The transect intercept method of sampling vegetation as described by Grieg-Smith (1983) was employed. At the beginning of each sampling point, a line (the baseline) stretching 200 m and oriented north– south was established. The baseline (200-m long) was divided into ten equal parts (marks), starting from first mark (0 m) at the beginning to the tenth mark (200 m) at the end of the 200 m transect. Three sets of numbers from the ten designated marks were randomly generated and then allocated to each baseline. The sets of numbers formed the starting points where line transects were established from the baseline. The line transects (transects 1, 2 and 3, each measuring 50 m) were established starting at the marked points, running perpendicular to the baseline and parallel to one another in a west–east direction (Figure 2). The area of a sampling unit was 200 m × 50 m. Sampling was done along the line transects and the exercise was repeated at all the sampling points.

All species in the Cyperaceae, Poaceae and Typhaceae that intercepted the transects were recorded (Phillips 1995; Van Oudtshoorn 2004). However, only plant species listed by Le Ru *et al.* (2006a) as host plants of stem borers are presented (Tables 2 and 5). Voucher specimens were collected and taken to the East African Herbarium in Nairobi, Kenya, when species identification was not possible in the field. Crown cover (the proportion of the ground 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 length of transect intercepted by individual plant species (in centimetres) was recorded. The intercept lengths for each plant species in the whole vegetation structural formation classes were summed. This was then divided by the total length of the transects and converted to a percentage to give percentage plant cover of each species in the vegetation structural formation classes, providing the average cover abundance (%). Relative abundance was achieved by dividing the percentage cover abundance of each plant species by the total percentage cover abundance of all the plant species in the respective vegetation structural formation class. This was then used to calculate the diversity index.

Sampling for abundance of stem borer pests in both cultivated and natural habitats

Cultivated habitat

The total number of maize plants required for each site depends on the area under maize relative to the total area under study. It was determined using Karandinos' (1976) equation:

$$n = \left(\frac{Z_{a/2}}{\delta}\right)^2 q/p \qquad \{\text{Eq } 1\}$$

where n is the number of maize plants required in each site, δ is the reliability level expressed as a fixed proportion of the mean (0.05), $Z_{a/2}$ is the standard normal deviate at 95% (1.96), p is the proportion of land under maize cultivation, and $q = 1 - p$

The total number of maize plants sampled was 942 and 1536 in Suam and Mtito Andei respectively. Then, the number of maize plants inspected for stem borer infestation in each field was determined using the equation described by Zar (1999)

$$n = \frac{Z^2{}_{\alpha(2)}}{4Dd^2} \qquad \{\text{Eq } 2\}$$

where $Z_{a(2)}$ is the standard normal deviate (1.96), d is the permitted error (0.1) resulting in a uniform number plants in all farms, and D is the design effect (1).

$$n = \frac{1.96^2}{4 \times 1 \times 0.1^2} = 96.04 \approx 100 \text{ maize plants per field.}$$

The number of maize fields in the respective localities was determined from the quotient of the total number of plants per site (Eq.1) divided by 100 (Eq 2); 10 and 16 maize fields were sampled in Suam and Mtito Andei, respectively In each field, 100 randomly selected maize plants were inspected for borer infestation symptoms and only infested stems were dissected for larval recovery.

Natural habitat

Since borer densities on wild hosts plants are considerably lower than on cultivated cereals (Nye 1960; Schulthess *et al.* 1997; Ndemah *et al.* 2007; Matama-Kauma *et al.* 2008), selective sampling was adopted to increase the chances of finding borers. In both localities, all potential hosts belonging to the Poaceae, Cyperaceae and Typhaceae found within 200–300m from the border of the sampled maize fields were carefully examined for symptoms of stem borer damage. Damaged plants were cut at the base and dissected for recovery of larvae and pupae. Plants from which the larvae or pupae were collected were identified. In cases where identities of the infested plants were not known, voucher specimens were taken to the East African Herbarium in Nairobi for identification.

Stem borer species

Plants with infestation symptoms were dissected *in situ* for recovery of immature borers (i.e. larvae and pupae). Larvae were reared until pupation on an artificial diet according to the method described by Onyango and Ochieng-Odero (1994). Pupae were removed from the diet media and kept separately in plastic vials until adult emergence. Adults were identified to species level by the ICIPE Biosystematic Unit and voucher specimens were deposited in the ICIPE Museum (Nairobi, Kenya).

Data analysis

Diversity and abundance of wild host plant species at the Suam and Mtito Andei sites were computed using the Shannon–Weaver diversity index (H) (Magurran 1988):

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

H: Shannon diversity index, *i*: host plant 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, *Pi*: proportion of N made up of the i^{th} species, *In*: natural logarithm. The resulting product was multiplied by −1.

A *t*-test was used to compare the diversity indices between vegetation structural formation classes within a location and between seasons within the same vegetation structural formation classes.

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

where H_1 is the diversity in structure 1, Var H_1 its variance and N_1 total crown cover.

$$\text{Var H} = \frac{\sum pi(Inpi)^2 - (\sum piInpi)^2}{N} - \frac{S-1}{2N^2}.$$

The degrees of freedom were calculated using the equation

$$\text{df} = \frac{(VarH_1 + VarH_2)^2}{(VarH_1)^2 / N_1 + (VarH_2)^2 / N_2}$$

where *S*: plant species richness.

RESULTS

Diversity and abundance of wild host plant species of stem borers

Suam

Based on the land-use map described by Goux (2005), three distinct vegetation structural formation classes, namely savanna woodland (SW), forest woodland (FW) and open grassland (OG), were surveyed in the Suam location (Table 1). A total of 31 uncultivated plant species in the Poaceae and Cyperaceae, listed as host plants of lepidopteran stem borers by Le Ru *et al.* (2006a), were recorded. All of them were present during the CS and 28 during the NCS (Table 2). During the CS, the number of host plant species varied between 17 and 28 (17 species recorded in OG and 28 in SW). During the non-cropping season, the highest species richness (22) was recorded in SW and the lowest (16) in OG (Table 2). The species richness in the respective vegetation structural formation class was proportional to the size of the structure. The highest cover abundance of wild host plant species was recorded in OG in both seasons (66.7% and 56.5% during CS and NCS, respectively), while the lowest cover abundance was recorded in SW (30.23% and 33.29% during CS and NCS, respectively) (Table 2). High-cover abundance recorded in OG was attributed to low-woody vegetation present in this vegetation structural formation class as the area was mainly used for pasture.

The cover abundance of the wild host plant species and the Shannon diversity index (*H*) did not vary with season (t_{76} = 0.98, p = 0.3302 and t_{76} = 0.98; p = 0.4151, respectively); *H* varied between 2.46 and 2.31 for the CS and NCS, respectively. The highest *H* of 2.39 and 2.13 were recorded in SW during the CS and NCS, respectively. Although OG recorded the lowest *H* in both seasons, the NCS had a higher *H* (Table 3).

About 50% of the surface area surveyed was under maize cultivation at the time of sampling. This was higher than the surface cover of wild plant species (mostly Poaceae) of 11.18% and 10.92% during the CS and NCS, respectively. In general, the surface cover of wild host plants in the different vegetation structures between the two seasons was similar (Table 4).

Mtito Andei

Four vegetation structures were considered for sampling in this location: savanna woodland (SW), savanna grassland (SG), forest acacia (FA) and riverine vegetation (RV). A total of 22 wild host plant species belonging to the Poaceae and Cyperaceae were recorded, with all of them present during the CS and only 16 during the NCS. Species richness varied between vegetation structural formation classes and season. During the CS, the highest number of species (19) was recorded in RV and the least (6) in SG; while during the NCS, the highest species richness (11) was recorded in FA with the least (3) in SG (Table 5). Due to the wet microclimate favouring vegetation growth throughout the year, RV registered the highest cover abundance of wild host plant species, with 37.3% (CS) and 19.4% (NCS) (Table 5).

No significant variation in the species diversity index (*H*) was recorded between the seasons (t_{23} = 0.83; p = 0.4151), with the CS having an index of 1.73 while the NCS had 1.40. Savanna grassland (SG) showed significant variations in species diversity, with RV during the CS (t_{33} = 2.68; p = 0.01140) and the NCS (t_{19} = 3.00; p = 0.0074). The other vegetation structural formation classes did not show significant differences within and between the seasons. There was no variation in cover abundance of wild host plant species between the seasons (t_{23} = 0.84; p = 0.4151) (Table 3).

During the cropping season, about 27% of the surface area surveyed was under maize cultivation, while wild host plants accounted for 13% versus 3% and 8%, respectively, during the NCS (Table 4). During the NCS, maize was cultivated under irrigation adjacent to RV. However, RV had wild host

Table 2 Percentage (%) cover abundance of each wild host plant species of lepidopteran stem borers in the three different vegetation structural formation classes and total percentage cover of each species in Suam during the cropping and non-cropping seasons; in bold are published wild host plants of *Busseola fusca*

Vegetation Type	*OG*		*FW*		*SW*		*Total %*	
Plant species	*CS*	*NCS*	*CS*	*NCS*	*CS*	*NCS*	*CS*	*NCS*
Cyperus dereilema Steudel	0.67	0.42	–	–	–	–	0.07	0.05
Cyperus dichrostachyus A.Richard	0.33	0.93	–	0.15	0.017	0.06	0.05	0.17
Cyperus distans L.	0.56	0.13	0.28	0.13	0.40	–	0.40	0.04
Cyperus dives Delile	1.78	2.31	4.89	3.25	0.25	1.46	1.20	1.86
Cyperus exaltatus Retz.	–	–	2.60	0.21	0.84	0.12	1.04	0.12
Schoenoplectus corymbosus Roth ex Roem. & Schult.) J.Raynal	1.00	0.84	–	–	0.03	–	0.14	0.09
Brachiaria brizantha (A. Rich.) Stapf.	0.02	0.56	0.22	0.52	0.34	1.47	0.28	1.21
Chloris gayana Kunth.	42.44	22.38	3.97	3.33	6.10	6.62	9.78	7.82
Cymbopogon nardus (L.) Rendle	0.44	0.72	2.52	0.90	8.43	10.92	6.56	8.12
Cynodon dactylon (L.) Pers.	7.28	18.09	22.09	22.30	3.01	2.83	6.66	7.77
Digitaria milanjiana (Rendle) Stapf	–	–	0.57	0.50	0.38	0.45	0.37	0.41
Eleusine jaegeri Pilg.	–	–	0.95	–	0.28	0.05	0.36	0.04
Eriochloa fatmensis (Hochst. & Steud.) Clayton	1.311	–	2.57	–	1.40	–	1.58	–
Hyparrhenia diplandra (Hack.) Stapf	–	0.33	0.22	0.50	1.02	0.26	0.77	0.31
Hyparrhenia papillipes (Hochst. ex A.Rich.) Anderss.	–	0.44	–	–	0.12	2.31	0.09	1.72
Panicum maximum Jacquin	–	–	–	0.85	0.20	0.33	0.14	0.38
Panicum merkeri Mez	–	–	–	–	0.20	0.21	0.15	0.15
Panicum poaeoides Stapf	–	4.22	–	–	0.09	–	0.06	–
Pennisetum clandestinum Chiov.	6.39	0.33	2.59	0.30	2.22	1.88	2.74	1.87
Pennisetum macrourum Trin.	–	–	0.59	–	0.28	–	0.30	0.04
Pennisetum purpureum Schumach.	–	4.44	**0.67**	**3.76**	**0.21**	**0.15**	**0.26**	**0.74**
Pennisetum trachyphyllum Pilg.	0.44	–	3.67	0.96	–	–	0.66	0.65
Pennisetum thunbergii Kunth	–	–	–	–	0.36	0.08	0.26	0.06
Pennisetum unisetum (Nees) Benth.	–	–	0.37	2.10	0.02	0.84	0.07	0.96
Rottboella cochinchinensis (Lour.) Clayton	0.20	–	2.66	–	0.43	–	0.78	–
Setaria incrassata (Hochst.) Hack.	1.87	–	0.73	–	2.23	0.11	1.94	0.08
Setaria megaphylla (Steud.) T.Durand & Schinz	**0.56**	**0.20**	**0.43**	**0.15**	**–**	**–**	**0.13**	**0.05**
Setaria sphacelata (Schum.) Moss	–	–	–	1.06	0.01	2.93	0.01	2.29
Setaria verticillata (L.) P. Beauv.	–	–	1.32	–	0.49	0.02	0.57	0.02
Sorghum arundinaceum (Desv.) Stapf	1.06	–	3.60	4.64	0.72	0.13	1.24	0.87
Typha domingensis Pers.	0.33	–	–	–	0.17	0.05	0.16	0.04
Total % cover abundance in respective of vegetation type	66.68	56.47	57.50	45.62	30.23	33.28	38.82	37.92
Species richness in respective of vegetation type	17	16	21	18	28	22	31	28

OG: Open Grassland, **FW**: Forest Woodland, **SW**: Savanna Woodland, **CS**: Cropping season, **NCS**: Non-cropping season

ground cover of 0.32% during the CS and 0.17% during the NCS (Table 4).

Diversity and abundance of *Busseola fusca* and *Chilo partellus* wild host plant species

Suam

Three *Busseola fusca* host plant species were recorded in both seasons: *Sorghum arundinaceum* (Desv.) Stapf, *Pennisetum purpureum* Schumach. and *Setaria megaphylla* (Steudel) T. Durand & Schinz. During the CS, *S. arundinaceum* was found in all the vegetation structural formation classes, while during the NCS it was not recorded in OG. *Pennisetum purpureum* was missing in OG during both seasons, while *S. megaphylla* was present in FW during both seasons but completely absent in SW and OG (Table 2). *Sorghum arundinaceum* had the highest cover abundance in both seasons; during the CS it varied between 0.72% and 3.6% with vegetation structural formation classes. The highest cover abundance was recorded in forest woodland (FW), while SW had the least cover abundance. The total cover abundance of wild hosts in the whole study area was 1.24% during the CS. In contrast, total cover abundance during the NCS was 0.87%, with FW recording the highest (4.60%) level (Table 2).

Table 3 Student's *t*-test for differences between vegetation types within and between Suam and Mtito Andei

Suam	*Cropping season (CS)*					*Non-cropping season (NCS)*					*Between seasons*	
	FW		*OG*			*FW*		*OG*				
Vegetation type	*df*	*t*	*df*	*t*	H_{CS}	*df*	*t*	*df*	*t*	H_{NCS}	*df*	*t*
SW	70	0.411^{ns}	81	3.980*	2.39	79	1.00^{ns}	79	2.147^{ns}	2.13	62	1.096^{ns}
FW					2.30					1.89	94	1.749^{ns}
OG					1.42					1.67	123	1.101^{ns}
Total cover					2.46					2.31	76	0.978^{ns}

Mtito Andei	*Cropping Season (CS)*							*Non-cropping Season (NCS)*							*Between seasons*	
	FA		*SW*		*SG*			*FA*		*SW*		*SG*				
Vegetation type	*df*	*t*	*df*	*t*	*df*	*t*	H_{CS}	*df*	*t*	*df*	*t*	*df*	*t*	H_{NCS}	*df*	*t*
RV	50	0.64^{ns}	26	1.72^{ns}	33	2.678*	1.86	26	1.20^{ns}	10	1.67^{ns}	19	2.999*	1.45	52	1.66^{ns}
FA			29	1.11^{ns}	35	1.93^{ns}	1.68			14	0.73^{ns}	24	1.50^{ns}	1.08	32	1.80^{ns}
SW					28	0.62^{ns}	1.30					13	0.42^{ns}	0.73	14	1.18^{ns}
SG							1.08							0.53	23	1.58^{ns}
Total cover							1.74							1.40	23	0.84^{ns}

H: Shannon diversity index; df: degrees of freedom; t: *t*-test values; ns: Diversity not significantly different; *: Diversity significantly different at $P < 0;05$. FW: Forest Woodland; OG: Open Grassland; FA: Forest Acacia; SW: Savanna Woodland; SG: Savanna Grassland; RV: Riverine Vegetation

Table 4 Seasonal variation in surface cover of wild host plants of stem borers in various vegetation structural formation classes in Suam and Mtito Andei

Vegetation structures		*% surface cover of wild host plants by stem borers* — *Cropping season (CS)*	*Non-cropping season (NCS)*
Suam	SW	5.44	6
	FW	3.91	3.11
	OG	2.67	2.26
	Total cover	11.18	10.92
	Maize	50	0
Mtito Andei	RV	1.46	0.17
	FA	6.37	4.17
	SW	5.29	2.77
	SG	0.5	0.32
	Total cover	13.03	7.98
	Maize	27.34	3.00

SW: Savanna Woodland; **FW**: Forest Woodland; **OG**: Open Grassland; **RV**: Riverine Vegetation; **FA**: Forest Acacia; **SG**: Savanna Grassland

Mtito Andei

In Mtito Andei, there were four wild hosts of *C. partellus*: *Panicum maximum* Jacquin, *S. arundinaceum*, *Rottboellia cochinchinensis* (Lour.) Clayton and *Pennisetum purpureum*, which were all recorded in both seasons. The number of host species varied between one and four among the different vegetation structures. All four hosts were recorded in RV and FA during GR. During the CS, all four hosts were only recorded in FA, two were recorded in RV, and only *P. maximum* in the other vegetation structural formation classes. The cover abundance of the wild hosts of *C. partellus* varied between 0.01% and 3.56% among different vegetation structural formation classes during the CS. *P. maximum* dominated the host plant community in all four vegetation structural formation classes, with SG recording the highest cover abundance of 3.56% and FA having the least (0.72%). The other hosts, *S. arundinaceum*, *P. purpureum* and *R. cochinchinensis*, were recorded mainly in RV and FA, with the cover abundance varying between 0.12% (*R. cochinchinensis*) and 0.49% (*S. arundinaceum*). During the NCS, *P. maximum* still dominated the wild host cover abundance, with FA recording all four hosts, followed by RV; *Rottboellia cochinchinensis* was the least abundant host at 0.015% (Table 5).

Table 5 Percentage (%) cover abundance of each wild host plant species of the lepidopteran stem borers in the four different vegetation structural formation classes and the total percentage cover of each species in Mtito Andei during the cropping and non-cropping seasons; in bold are the published wild host plants of *Chilo partellus*

Vegetation Type	*SG*		*RV*		*FA*		*SW*		*Total %*	
Plant species	*CS*	*NCS*	*CS*	*NCS*	*CS*	*NCS*	*CS*	*NCS*	*CS*	*NCS*
Cyperus articulatus L.	–	–	0.89	0.67	–	–	–	–	0.15	0.11
Cyperus dichrostachyus A.Richard	–	–	0.19	5.48	–	1.71	–	–	0.03	1.36
Cyperus exaltatus Retz.	–	–	0.16	–	–	–	–	–	0.03	–
Cyperus distans L.	–	–	0.22	–	–	–	–	–	0.04	–
Brachiaria brizantha (A. Rich.) Stapf.	–	8.31	0.19	–	–	0.12	0.01	–	0.04	0.49
Cenchrus ciliaris L.	9.78	–	13.05	8.27	10.16	9.85	8.89	6.21	8.97	7.15
Cynodon aethiopicus Clayton & Harlan	–	–	10.79	3.26	5.26	2.36	0.70	0.04	3.44	1.18
Digitaria milanjiana (Rendle) Stapf	0.40	–	1.13	–	1.70	0.06	0.86	0.07	0.100	0.05
Echinochloa haploclada (Stapf) Stapf	–	–	1.13	–	0.29	–	–	–	0.26	–
Eleusine jaegeri Pilg.	–	–	0.06	0.17	–	–	–	–	0.01	0.03
Eriochloa fatmensis (Hochst. & Steud.) Clayton	0.62	–	0.09	–	0.17	–	0.06	0.16	0.17	0.08
Eriochloa meyerana (Nees) Pilg.	–	–	–	–	0.19	–	0.15	–	0.11	–
Hyparrhenia diplandra (Hack.) Stapf	–	–	–	–	–	0.13	0.16	0.26	0.06	0.17
Leptochloa obtusiflora Hochst.	0.44	–	–	–	0.14	–	–	–	0.06	–
Panicum deustum Thunb.	0.58	0.58	5.19	–	2.13	–	1.80	0.18	2.18	0.13
Panicum maximum Jacquin	**3.56**	**0.93**	**0.80**	**0.36**	**0.72**	**0.14**	**1.22**	**0.32**	**1.02**	**0.31**
Panicum merkeri Mez	–	–	0.07	–	0.32	0.13	0.29	0.16	0.21	0.12
Pennisetum purpureum Trin.	–	–	**0.22**	–	**0.10**	**0.06**	–	–	**0.06**	**0.02**
Rottboellia cochinchinensis (Lour.) Clayton	–	–	0.12	–	0.13	**0.06**	–	–	0.05	**0.02**
Setaria verticillata (L.) P. Beauv.	–	–	1.83	–	1.05	–	–	–	0.58	–
Sorghum arundinaceum (Desv.) Stapf	–	–	**0.49**	**0.22**	**0.14**	**0.10**	–	–	**0.12**	**0.06**
Typha domingensis Pers.	–	–	0.67	0.96	–	–	0.02	–	0.12	0.16
Total % cover abundance in respective vegetation type	**15.38**	**9.82**	**37.28**	**19.39**	**22.50**	**14.72**	**14.15**	**7.40**	**18.66**	**11.43**
Species richness in respective vegetation type	19	8	14	11	11	8	6	3	22	16

SG: Savanna Grassland; **RV**: Riverine Vegetation; **FA**: Forest Acacia; **SW**: Savanna Woodland; **CS**: Cropping Season; **NCS**: Non-Cropping Season

Abundance of stem borer pests in cultivated and natural habitats

Suam

B. fusca was the only stem borer pest recovered from cultivated habitats in both the CS and NCS (Table 6). However, most of the stem borers were recovered during the CS. During the NCS, *B. fusca* was found on old maize stalks remaining in the field after harvest. *B. fusca* was not recovered at all from wild host plants sampled in natural habitats in both the CS and NCS. However, ten infested wild host plants were found in the natural habitat, mostly during the CS, having stem borers belonging to different species of noctuids, pyralids and tortricids. We found that stem borers are rare in both habitats during the NCS.

Mtito Andei

C. partellus was the only stem borer pest recovered from cultivated habitats in both the CS and NCS, with most borers recovered during the CS (Table 6). *C. partellus* was found in the natural habitats in both the CS and NCS on *S. arundinaceum* (both seasons) and on *P. purpureum* (NCS). However, nine (NCS) and eight (CS) wild host plants were found to be infested in the natural habitat, with stem borers of different species of noctuids, pyralids and tortricids.

DISCUSSION

In the two sampled localities, which represent two different agroecosystems, wild host plant species diversity and relative abundance did not vary significantly with season. During this survey, *B. fusca* was not found among the wild host plants recovered in Suam; however, it has been collected once on *S. arundinaceum* during the last 2 years (12 specimens in November 2006) as part of an extensive survey on stem borers carried out in this locality (Ong'amo, personal observation). In Uganda, Matama-Kauma *et al.* (2007) established that *S.*

Table 6 Number of stem borer larvae recovered in Suam and Mtito Andei from various host plants during different seasons. Asterisks indicate the cereal plants found infested

		CS			*NCS*		
	Infested plant species	*B. fusca*	*C. partellus*	*Other borers*	*B. fusca*	*C. partellus*	*Other borers*
Suam	*C. nardus*	–	–	1	–	–	–
	C. dactylon	–	–	3	–	–	–
	C. dives	–	–	2	–	–	–
	P. maximum	–	–	107	–	–	–
	P. macrourum	–	–	6	–	–	–
	P. purpureum	–	–	1	–	–	–
	P. trachyphyllum	–	–	71	–	–	–
	S. corymbosus	–	–	3	–	–	8
	S. arundinaceum	–	–	1	–	–	–
	S. incrassata	–	–	1	–	–	–
	*S. bicolor**	–	–	–	1	–	–
	*Zea mays**	251	–	–	14	–	–
Mtito Andei	*C. aethiopicus*	–	–	4	–	–	16
	C. distans	–	–	10	–	–	–
	C. involucratus	–	–	5	–	–	22
	E. jaegeri	–	–	3	–	–	–
	P. deustum	–	–	1	–	–	1
	P. maximum	–	–	28	–	–	13
	P. purpureum	–	2	8	–	–	–
	R. cochinchinensis	–	–	–	–	–	1
	S. verticillata	–	–	–	–	–	1
	S. arundinaceum	–	46	16	–	11	1
	T. domingensis	–	–	28	–	–	16
	*S. bicolor**	–	63	5	–	–	–
	*Z. mays**	–	148	36	–	22	17

arundinaceum was the principal host of *B. fusca*, while Ingram (1958) hypothesised that grasses occurring next to cultivated fields, may constitute a large reservoir of stem borers. The low-surface cover (0.5%) of *S. arundinaceum*, in either season corroborates results from work done earlier in the same district (Trans-Nzoia) (Kanya *et al.* 2005). This is an indication that natural habitats do not serve as a major reservoir for *B. fusca* during the non-cropping season. Moreover, in Suam, it is a normal practice for maize stalks to be cleared by burning, which normally extends to patches of the wild habitats surrounding the maize field, thereby destroying also the wild host plants of *B. fusca*. Tscharntke and Brandl (2003) noted that destruction of the wild habitat of the insects might disrupt the plant–herbivore interaction, thereby affecting the pest population in the wild habitat. However, diapausing *B. fusca* larvae have been recovered from old maize stalks that survive burning during land preparation (Ong'amo, personal observations), suggesting that the majority of *B. fusca* larvae pass the NCS on maize residues in Suam.

Prior to the present surveys, a prolonged drought of more than 3 years occurred in Mtito Andei (Le Ru, personal observation). Since then, green vegetation has been confined to the riverbanks, leaving the rest of the study area with dry tillers of wild host plants. This explains, in part, why there was no variation in both species richness and relative abundance between the seasons despite the prolonged drought. Although not very abundant, *C. partellus* was found among the wild host plants recovered in Mtito Andei during this survey. According to the surveys done by Le Ru *et al.* (2006b), *C. partellus* was present all year round in this area, but was minimal during the severe drought. This suggests that the wild host plants present along the riverbank could support large *C. partellus* population. In addition, some farmers were able to grow maize under irrigation in fields adjacent to the riverbanks during the dry season (Otieno, personal observation), thus enhancing the survival of the pest.

Recently, *Bt* maize resistant to *C. partellus* has been introduced into Kenya (Mugo *et al.* 2005). In order to prevent development of insect resistance to the *Bt* toxin, it is generally recommended that not less than 20% of the cropping area should be planted with non-transgenic maize (i.e. refuge area strategy, *sensu* Brousseau *et al.* 1999), which would sustain a susceptible pest population (Fitt *et al.* 2004). It was considered that, in Africa, natural hosts of stem borer pests growing in natural habitats may serve as refuges (Khan *et al.* 1997). However, according to the results presented here, less than 5% of the area of both localities is occupied by wild host plants of stem borer pests, and even less during the non-cropping season. Furthermore, our results show that even if *C. partellus* was found in the natural habitat surrounding cereal plots, *B fusca* was absent. Thus, it can be concluded that wild habitats surrounding cereal plots will play little if any role in the resistance management of *Bt* maize targeting either *C. partellus* or *B. fusca*. Additional refuges are needed to complement the wild host plants to delay resistance development in stem borer pests to transgenic crops. However, further research on adult stem borer dispersal is required, since movement of *B. fusca* from distant (up to several km) wild hosts or crops to the maize crop cannot be ruled out.

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REFERENCES

Bowden J. Stem borer ecology and strategy for control. *Annals of Applied Biology* 1976;84:107–11

Brousseau R, Masson L and Hegedus D. Insecticidal transgenic plants: are they irresistible. *AdbiotechNet* 1999;I(July): ABN 022

Corbett JD and O'Brien RF. *The Spatial Characterization Tool – African version 1.0*. Report No. 97–03, CDROM. Texas Agricultural Experiment Station, Texas A & M University, Blackland Research Center, Texas; 1997

FAO (Food and Agriculture Organization of the United Nations). *Production Yearbook for 2002*. Rome, Italy: FAO; 2003

Fitt GP, Andow DA, Carrière Y, Moar WJ, Schuler TH, Omoto C, Kanya J, Okech MA, Arama P and Maniania NK. Resistance risks and management associated with Bt Maize in Kenya. In Hilbeck A and Andow DA (eds), *Environmental risk assessment of genetically modified organisms*. Oxford: CABI; 2004;209–50

Guofa Z, Overholt WA and Mochiah MB. Changes in the distribution of lepidopteran maize stem borers in Kenya from 1950s to 1990s. *Insect Science and its Application* 2002;21:395–402

Goux I. *Characterization of wild and cultivated habitats of insect pests in maize crops (Zea mays L.) in two localities, Mtito Andei and Suam in Kenya*. MSc in Management of Agro-Systems in Tropical Areas, Université de Paris XII, Paris; 2005

Grieg-Smith P. *Quantitative Plant Ecology*. 3rd ed. Oxford: Blackwell; 1983

Harris KM. Lepidopteran stem borers of cereals in Nigeria. *Bulletin of Entomological Research* 1962;53: 139–71

Ingram WR. The lepidopterous stalk borers associated with Gramineae in Uganda. *Bulletin of Entomological Research* 1958;49:367–83

Kanya JI, Ngi-song AJ, Setamou MF, Overholt W, Ochora J and Osir EO. Diversity of alternative hosts of maize stem borers in Trans-Nzoia district of Kenya. *Environmental Biosafety Research* 2005;3: 159–68

Karandinos MG. Optimum sample size and comments on some published formulae. *Bulletin of the Entomological Society of America* 1976;22:417–21

Kfir R, Overholt WA, Khan ZR and Polaszek A. Biology and management of economically important lepidopteran cereal stem borers in Africa. *Annual Review of Entomology* 2002;47:701–31

Khan ZR, Chiliswa P, Ampong-Nyarko K, Smart LE, Polaszek A, Wandera J and Mulaa MA. Utilisation of wild gramineous plants for management of cereal stem borers in Africa. *Insect Science and its Application* 1997;17:143–50

Le Ru, BP, Ong'amo GO, Moyal P, Ngala L, Musyoka B, Abdullah Z, Cugala D, Defabachew B, Haile TA, Kauma Matama T, Lada VY, Negassi B, Pallangyo K, Ravolonandrianina J, Sidumo A, Omwega C, Schulthess F, Calatayud P-A and Silvain JF. Diversity of lepidopteran stem borers on monocotyledonous plants in eastern Africa and the islands of Madagascar and Zanzibar revisited. *Bulletin of Entomological Research* 2006a;96:555–63

Le Ru BP, Ong'amo GO, Moyal S, Muchungu E, Ngala L, Musyoka B, Abdulla Z, Matama-Kauma T, Lada VY, Pallangyo B, Omwega CO, Schulthess F, Calatayud P-A and Silvain JF. Geographic distribution and host plant ranges of East Africa noctuid stem borers. *Annales de la Société Entomologique de France* 2006b;42:353–61

Magurran AE. *Ecological diversity and its measurement.* Princeton: Princeton University Press; 1988

Matama-Kauma T, Schulthess F, Le Ru BP, Mueke JM, Ogwang JA and Omwega CO. Abundance and diversity of lepidopteran stem borers and their parasitoids on selected wild grasses in Uganda. *Crop Protection* 2008;27:505–13

Mugo S, De Groote H, Bergvinson D, Mulaa M, Songa J and Gichuki S. Developing Bt maize for resource-poor farmers – Recent advances in the IRMA project. *African Journal of Biotechnology* 2005;4: 1490–504

Ndemah R, Schulthess F, Le Ru B and Bame I. Lepidopteran cereal stem borers and associated natural enemies in maize and wild grass hosts in Cameroon. *Journal of Applied Entomology* 2007; 131(9–10):658–68

Nye IWR. The insect pests of graminaceous crops in East Africa. *Colonial Research Studies* 1960;31: 1–48

Ong'amo GO, Le Ru B, Dupas S, Moyal P, Calatayud P-A and Silvain JF. Distribution, pest status and agroclimatic preferences of lepidopteran stem borers of maize and sorghum in Kenya. *Annales de la Société Entomologique de la France* 2006;42:171–7

Onyango FO and Ochieng'Odero JPR. Continuous rearing of the maize stem borer *Busseola fusca* on an artificial diet. *Entomologia experimentalis et Applicata* 1994;73:139–44

Otieno NA, Le Ru BP, Ong'amo GO, Dupas S, Calatayud P-A, Makobe M, Ochora J and Silvain JF. Diversity and abundance of wild host plants of lepidopteran stem borers in two different agro-ecological zones of Kenya. *Annales de la Société Entomologique de France* 2006;42:371–80

Phillips S. *Flora of Ethiopia and Eritrea Volume 7. Poaceae (Gramineae).* Addis Ababa, Ethiopia; Uppsala, Sweden; 1995

Polaszek A and Khan ZR. Host plants. In Polaszek A (ed.), *African cereal stem borers: economic importance, taxonomy, natural enemies and control.* Cambridge: CAB International, University Press; 1998:5–23

Schulthess F, Bosque-Pérez NA, Chabi-Olaye A, Gounou S, Ndemah R and Goergen G. Exchange of natural enemies of lepidopteran cereal stem borers between African regions. *Insect Science and its Application* 1997;17:97–108

Seshu Reddy KV. Study of the stem borer complex of sorghum in Kenya. *Insect Science and its Application* 1983;4:3–10

Tscharntke T and Brandl R. Plant–insect interactions in fragmented landscapes. *Annual Review of Entomology* 2003;49:405–30

Van Oudtshoorn F. *Guide to Grasses of Southern Africa.* 2nd edition. Pretoria, SA: Briza; 2004

Webster R and Oliver MA. *Statistical methods in soil and land resource survey.* New York: Oxford University Press; 1990

Zar JH. *Biostatistical Analysis.* 4th edition. New Jersey: Prentice Hall; 1999:40–44