C·A·B INTERNATIONAL INSTITUTE OF BIOLOGICAL CONTROL

Report

THE POPULATION ECOLOGY OF *HELICOVERPA ARMIGERA* IN SMALLHOLDER CROPS IN KENYA WITH EMPHASIS ON ITS NATURAL ENEMIES.
FINAL REPORT, PHASE II:
APRIL 1988-MARCH 1991

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NRI EMC X044

ODA-NRE Project R4365B

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Kenya Station, Box 30148, Nairobi, Kenya

May 1991

April 1991

Title of project:
The population ecology of *Helicoverpa armigera* in smallholder crops in Kenya, with emphasis on its natural enemies.

Organisation:
International Institute of Biological Control - Kenya Station.

Reporting Period:
Phase II. 1 April 1988 to 31 March 1991

Objectives of the project:
The basic objective is a better understanding of the role of natural enemies in the population dynamics of *H. armigera* in small holder food and cash crops in Kenya, with a view to developing IPM strategies for its control in Africa. Specific questions posed include:

(1) How does the incidence of parasitoids, predators and pathogens vary with season and crop?

(2) What determines the specificity of natural enemies to *H. armigera* on particular crops?

(3) What is the relative importance of the parasitoids, predators and pathogens and what role, if any, do they play in the regulation of the population of *H. armigera*?

(4) To what extent do natural enemies move around, within and between crops, and how important is this to *H. armigera* population dynamics?

(5) How is the contribution of natural enemies to *H. armigera* mortality influenced by the application of *Bacillus thuringiensis* (BT) and other insecticides?

Work carried out in this period:

A sampling programme for incidence and phenology of *H. armigera* and its natural enemies was set up at seven different sites throughout the country, more or less representing the major agricultural areas in different ecological zones of Kenya. They extended from the wet and high altitudes of Kakamega and Kisii through the Lake Victoria Basin site at Kibos (near Kisumu), the dry central sites of Mwea Tebere and Makueni to the coastal sites of Msabaha and Mtwapa.

Each site consisted of replicated plots with three to five of the following crops: cotton, sorghum, maize and sunflower, bean, pigeon pea.

The sampling sites were divided into intensive sites and minor sites. Trials at the intensive sites were relatively large, with three or four crops grown in four replicates and sampled every week. Trials at the minor sites were smaller, crops were grown in three replicates and intervals between sampling occasions were about three weeks.

Kakamega and Kibos were intensive sites from the first season, when all other sites were minor sites. Subsequently, Mwea Tebere (from the second season) Makueni and Msabaha (from the third season) were upgraded to intensive sites. At the other minor sites, trials were stopped after the second season.

In addition, a series of field experiments were run to demonstrate the role of the different predator groups. Barrier experiments, using insect glue around the base of the plants to exclude ants, were run on sunflower at Mwea Tebere, Kakamega and in farmer's fields at Lugari, near Kakamega. To

separate the role of ants and predatory bugs, field plots treated either with barriers, or with barriers and a weak pesticide application to selectively kill natural enemies were set up on cotton at Kibos and Mwea Tebere, and on sunflower at Kakamega. Experiments on cohorts of *H. armigera* using cages and glue barriers to exclude predators were carried out on cotton at Kibos. Egg exposure studies were run on cotton at Kibos and Mwea Tebere, and on sunflower at Kakamega.

Together, these studies show how the incidence of *H. armigera* and its natural enemies vary with season and crop in several parts of Kenya. There are no substantial indications of specificity of important natural enemy groups to particular crops. We have shown that at the population levels found at our sites, parasitoids and pathogens do not play an important role in the population dynamics of *H. armigera* and the damage it causes to the crops, with the likely exception of trichogrammatid egg parasitoids. Predators clearly do have an impact, but this is variable and can be masked by background mortality. The timing of movement of predators onto the crops is critical for their effectiveness; often they arrive too late to have useful impact.

Collaborative trials between IIBC, the University of Wales College Cardiff, and KARI on the use of a selected strain of *Bacillus thuringiensis*, commercially available *Bt*, and cypermethrin to control *H. armigera* are reported by UWCC under their ODA funded project; population levels of natural enemies were monitored along with *H. armigera*, but the levels of *H. armigera* were too low to obtain useful results.

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1. Introduction

1.1. Organisation

This is the final report of the second phase of an ODA funded project to research the role of natural enemies in the population dynamics of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) in Kenyan small-holder crops. The first, preparatory phase ran from April 1987 - March 1989 (Cock *et al.* 1988). During Phase I, the following progress was achieved:

- potential field sites were visited and collaboration with KARI planned and co-ordinated,
- a laboratory culture of *H. armigera* was set up, for studies on natural enemies and field experiments,
- preliminary surveys were made for *H. armigera* and its parasitoids and pathogens,
- a catalogue and review of the natural enemies of *H. armigera* in Africa was compiled and published (Van den Berg *et al.* 1988),
- taxonomic work was started to sort out some of the problems associated with the natural enemies *H. armigera*.

Because parasitoids and pathogens were not common during the present phase, attention was focused on predators. A summary of the natural enemies is presented in Section 3.1. As part of the project, taxonomic research was carried out on some of the problem groups of natural enemies; results are presented in Annex 2. One of the objectives of the project was to produce a field guide to the natural enemies encountered which will soon be printed.

Initially, field plots were established at six KARI research stations (Section 2.1). These sites are:

Kakamega Regional Research Centre
Kibos Cotton Research Sub-Centre
Kisii Regional Research Centre
Mwea Tebere National Fibre Research Centre
Makueni Sub-Centre of Machakos National Dryland Farming Research Centre
Mtwapa Regional Research Centre
Msabaha Regional Research Sub-Centre of Mtwapa Regional Research Centre

The project has been carried out in collaboration with KARI staff at the co-operating research stations, and a complete list of staff involved is given as Annex 1. Dr Cock co-ordinated activities from the IIBC Kenya Station at NARC Muguga, where the bulk of the culture was also maintained. Mr Van den Berg was based at Kakamega during the four seasons, and carried out the intensive studies in Western Kenya, from where he supervised Mr Onsongo (who joined the project late in the first year) based at Kibos during the long rains of 1989 and 1990. During the long rains 1990, Mr Onsongo and Mr Van den Berg were actively involved in collaborative trials with the University of Wales College Cardiff on the effectivity of *Bacillus thuringiensis* in controlling *H. armigera* on cotton and sunflower. Mr Oduor was based at the IIBC Station and co-ordinated the setting up and sampling of the two central sites at Mwea Tebere and Makueni, and the two coastal sites at Mtwapa and Msabaha. During the third season (short rains 1989/90) he concentrated his activities on the former two sites, and during the fourth season (long rains 1990) focused on Mwea Tebere only. At most sites, a KARI Research Officer was allocated by the Centre Director to provide on the spot management of activities, and a technical assistant to manage the plots on a day to day basis, and assist in the sampling with the entomologist and technicians from IIBC at Muguga.

The project was visited by IIBC's Chief Research Officer, Dr J K Waage (now Deputy Director), January 28 to February 6, 1989. During this visit progress was reviewed, field sites inspected, and future plans discussed. His report on this visit (dated 20 February 1989) has been circulated separately.

1.2. Background

The African Bollworm, *Helicoverpa armigera*, better known under its earlier name *Heliothis armigera*, is a major constraint to food and cash-crop production in East Africa, attacking various crops including cotton, legumes, maize, sorghum, sunflower, tobacco and tomato. Damage is frequently localized on the reproductive parts of crops, i.e. those parts which are harvested. Nearly all the detailed studies on the biology and control of this pest have been made in cotton.

Generally, *H. armigera* larvae live hidden within the fruiting parts of the plant during most of their development. Thus, large amounts of insecticide are needed if larvae are to ingest a lethal dose during their short period of contact with the foliage between hatching and entering the host-plant. Moreover, *H. armigera* has a strong ability to develop resistance to insecticides (Joyce 1982), and cases of resistance of *H. armigera* to organochlorines and pyrethroids in the field have been reported in several parts of the world. Therefore, more sustainable and ecologically sound management systems are required.

Biological control is a major component of integrated pest management which seeks to maximize the contribution of naturally occurring parasitoids, predators and pathogens to depression of pest populations.

In eastern and southern Africa, limited studies exist on the importance of natural enemies of *H. armigera* (e.g. Coaker 1959; Nyambo 1986, 1990; Parsons 1940a; Reed 1965). However, these studies mostly focused on (larval) parasitoids (Van den Berg *et al.* 1990). In a few cases, predators have been mentioned as potentially important control agents, but no detailed studies exist on their impact on *H. armigera*. Moreover, there are no lifetable studies of *H. armigera* from Africa, which studied the impact of natural enemies in relation to other mortality factors acting on *H. armigera* (ICRISAT 1982; King & Jackson 1989).

In Kenya, *H. armigera* is a major pest on cotton and sunflower (Khaemba & Mutinga 1982; Muthamia 1971; Rens 1977), but only a minor pest on maize and sorghum. In this report, we present the ecology and generational mortality factors of *H. armigera* in several smallholder crops.

2. General materials and methods

2.1. Field sites

The phenology sampling programme was set up at seven different sites throughout the country, more or less representing the major agricultural areas in different ecological zones of Kenya. They extended from the wet and high altitudes of Kakamega and Kisii, through the Lake Victoria Basin site at Kibos (near Kisumu), the dry central sites of Mwea Tebere and Makueni, to the coastal sites of Msabaha and Mtwapa (Figures 9.1-9.4). Details of the KARI research stations and the agriculture in their areas are given in Annex 1.

Each field plot comprised replicated plots with three to five of the following crops: cotton, sorghum, maize and sunflower, bean, pigeon pea. Tables of crops, planting spaces, plot sizes, planting dates, fertilisers, weeding dates, etc. are given in Annex 5. At each site, additional plots were planted with *Helicoverpa* hosts such as cleome, finger millet, legumes and tomatoes, for the purpose of casual observations, rather than regular sampling. Towards the end of the season it was necessary to employ bird scarers to keep away the mixed flocks of small birds which would otherwise have have destroyed much of the crops.

The sampling sites were divided into intensive sites intended to produce good population data for analysis and minor sites to monitor pest and natural enemy incidence and phenology. Trials at the intensive sites were relatively large (0.4-0.5 ha), with three or four crops grown in four replicates (individual plot size approx. 14x 20 m). Weekly, 30 plants were sampled per crop. Trials at the minor sites were smaller (0.12-0.2 ha), crops were grown in three replicates and intervals between sampling occasions were longer than a week. Twenty plants were sampled per occasion.

Field sites were used for up to four seasons (short rains 1988-89 to long rains 1990). Kakamega was run as an intensive site for all four seasons; Kibos for both long rains only. Kisii, Mwea Tebere, Makueni, Mtwapa and Msabaha were minor sites for the first two seasons; thereafter Mwea Tebere was run as an intensive site for the next two seasons, while Makueni and Msabaha were for the next season (short rains 1989-90) only.

2.2. Sampling protocol

A standard sampling protocol was set up for comparable sampling between the six field sites. Plants for sampling were selected using random number tables. For the intensive sites 30 plants were sampled for each crop, split evenly between the four replicates, whereas for the minor sites 20 plants split evenly between the three replicates were sampled.

First, the time of the day, plant height and plant stage were recorded. Then, without touching the plant, all plant parts were briefly checked for any fast-moving predators, such as crickets, thereafter all plant parts were thoroughly checked for any arthropod stages, taking apart leaves, leaf-sheaths (of maize and sorghum) and flowering/fruiting parts of the plant. Most time was spent on the latter plant parts, such as the panicle of sorghum (all individual grains were checked), the flower head of sunflower (bracts and individual florets were removed), and the tassel and cob of maize. This was to ensure accurate sampling of small stages such as *H. armigera* eggs and anthocorids. All data (type of pest/predator, their stages numbers, and position on the plant) were directly scored on detailed data-sheets for each crop (see Cock *et al.* 1989).

H. armigera eggs could be identified in the field using a hand-lens. The instar of larvae could be estimated in the field from head-capsule widths (see Section 2.5), but was regularly confirmed under the microscope afterwards. All eggs and larvae were taken to the laboratory for rearing of parasitoids, and assessment of percentage parasitism (based on host-stage specificity of parasitoids [van den Berg *et al.* 1988]). Eggs were reared through singly in labelled tubes, with a minimum of attached plant material to avoid condensation inside the tube. Larval instars were

reared through singly in labelled diet containers (see Cock *et al.* 1988). Details of the stages at collection and the outcome (death, moth emerged, parasitoid emerged or pathogen) were recorded on separate data sheets.

2.3. Culture

A culture of *H. armigera* was established at Muguga. The sources were adult moths from light traps run at Muguga, and adults reared from field collected larvae.

The adults are held in a plastic oviposition cage 20cm high, 15cm diameter, lined with grease-proof paper and covered with muslin cloth on which is placed a pad of damp cotton wool. Honey diluted with water (50%) is provided, smeared on grease-proof paper.

The eggs are removed daily and kept for emergence. The larvae are reared on an semi-synthetic diet used at IIBC Kenya Station for rearing graminaceous stem borers (*Chilo* spp.). The ingredients are:

1.	Rose coco beans powder	109.6 g
2.	Maize/sorghum leaves powder	40.0 g
3.	Brewers yeast	8.0 g
4.	Ascorbic acid	2.6 g
5.	Sorbic acid	1.0 g
6.	Methyl para-hydroxy-benzoate (dissolved in 100% ethanol)	1.6 g
7.	Agar No. 3 (Technical)	10.2 g
8.	Vitamin E (one capsule)	147.0 mg
9.	40% Formalin solution	2.0 ml
10.	Distilled water	900 ml

Note that these were given incorrectly in Cock *et al.* (1988). Ingredients 1-6 are mixed in a commercial blender with 500 ml hot boiled distilled water. The agar is dissolved in 400 ml boiled distilled water, and the vitamin E capsule and formalin solution added. These ingredients are then blended together until homogenised before being poured into the sterilised rearing containers under a lamina flow cabinet.

The rearing containers are 1 fluid oz. clear plastic cups, 2.5cm diameter at the base, 4cm diameter at the top and 4.5cm high with push-in cardboard or ventilated-plastic lids.

The jars are surface-sterilised with diluted domestic bleach (10%) for 24 hours and the lids heat sterilised in a drying oven. They are filled approximately half full with diet.

Neonate larvae are kept five per container until the fourth instar, when they are transferred to individual containers, to prevent cannibalism which is otherwise prevalent. At this stage obviously backward larvae are discarded. The larvae pupate within the diet and pupae are separated out for emergence.

2.4. Light trap and pheromone trap monitoring

The use of light traps provides, potentially, an effective monitoring system for *H. armigera*. KARI runs an "armyworm unit" which monitors *Spodoptera exempta* on a national basis by means of a network of light traps and pheromone traps.

One of the light traps is at the IIBC compound at Muguga, near Nairobi. At this site *H. armigera* has already been recorded since 1971. Figure 2.1 shows (a) the annual total trap catches of *H. armigera*

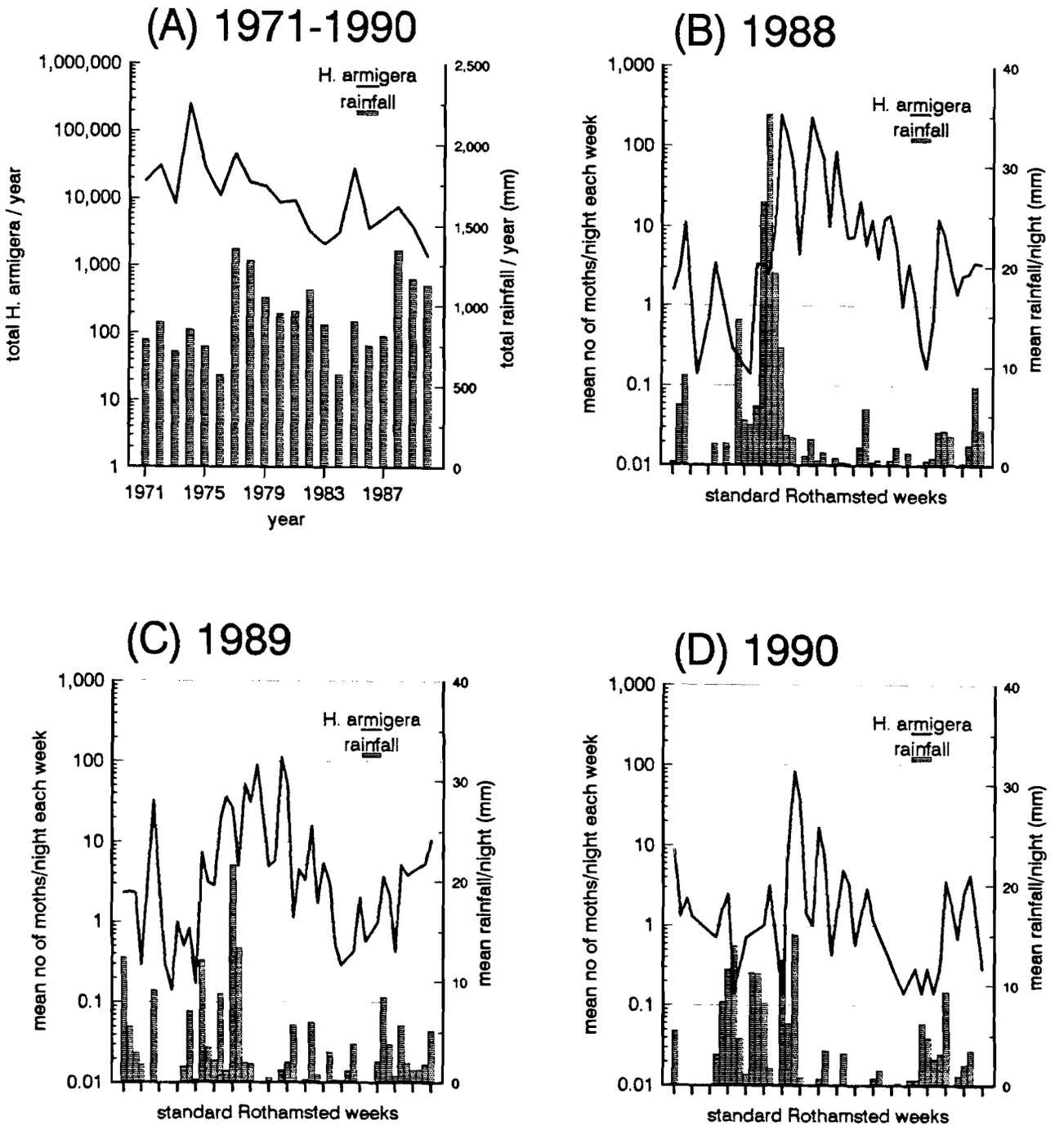

Figure 2.1. Mercury vapour light trap catches of *H. armigera* and rainfall at IIBC Kenya Station, Muguga, Kiambu District. (a) annual total trap catches and annual total rainfall for 1971-1990 (by courtesy of KARI armyworm unit); (b) Weekly average nightly catches of *H. armigera* and weekly average daily rainfall for 1988; (c) as (b) for 1989; (d) as (b) for 1990.

and total annual rainfall for the full set of data from KARI armyworm, and (b) the weekly totals of *H. armigera* from the project light trap at Muguga for 1988-90.

At Muguga there is a single principal peak (overlaid by a lunar cycle) during the long rains. Annual catches have fluctuated greatly over the last 20 years, but the last three years during which the project has run do seem to be at the minimum end of the range. Since the incidence of *H. armigera* at our field sites was also considerably lower than we had been led to expect, this could well have been a widespread phenomenon.

Light trap and pheromone trap catches from other sites were too low to be useful for analysis of patterns.

2.5. Head-capsule widths

In a field-sampling programme where stage-specific mortality is measured, it is crucial to accurately identify the six instars of *H. armigera*. For this purpose, the head-capsule widths of the individuals of a cohort of *H. armigera* were measured in the laboratory during their development, and cast head-capsules were recorded to indicate a new instar. Thus, the head-capsule width distribution could be established for each instar. A 40x binocular microscope with graticule ocular was used. Figure 2.2 shows that there is little overlap between the instars, indicating that head-capsule width is a good characteristic for identifying the instar of a larva. However, *H. armigera* in the field are exposed to more diverse conditions (e.g. different nutrition/climate), and may thus show more overlap between instars.

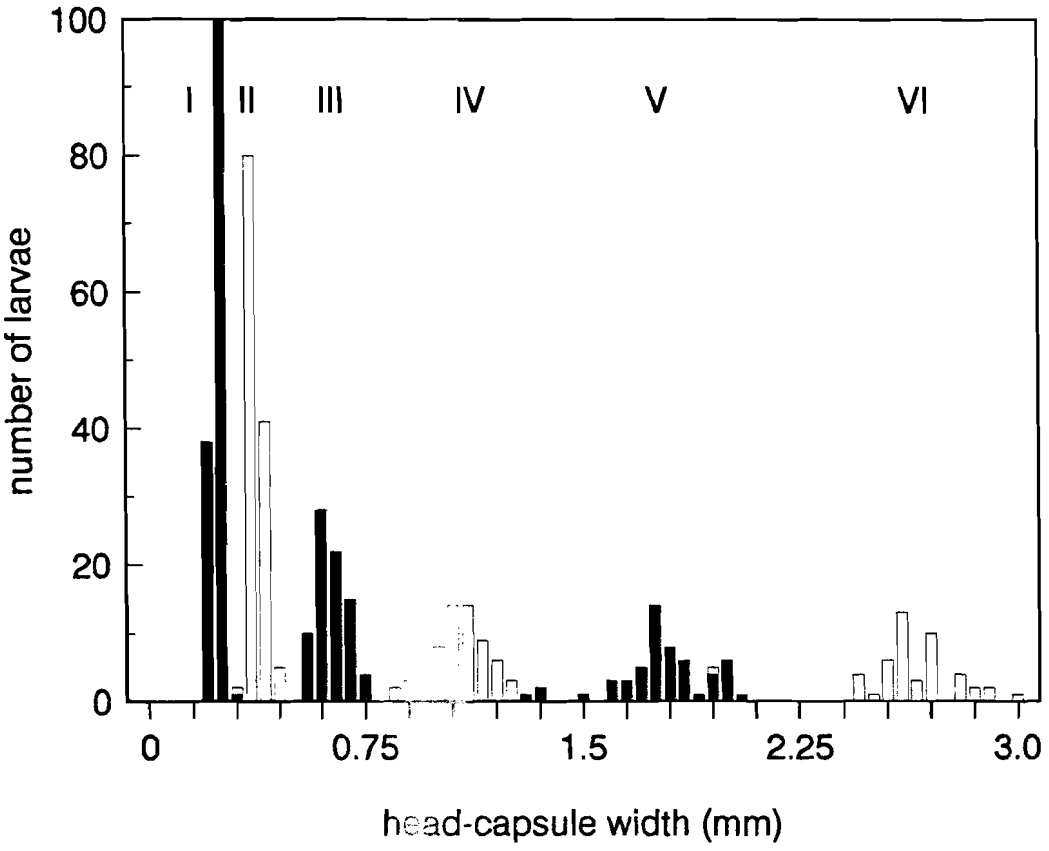

Figure 2.2. Head-capsule width distribution of larval instars of *H. armigera* in a laboratory population followed during development. Black and white bars differentiate consecutive instars.

3. The natural enemies

3.1. Summary of groups and importance

In the sampling programme, all potentially important invertebrate natural enemies, including predators, parasitoids and pathogens, were recorded. Parasitoids and pathogens were usually uncommon in every field site, but predators occurred in moderate, sometimes high, densities. From early in Phase II, we had decided to concentrate on predators in our sampling programme and in additional experiments, because other groups were scarce, and the impact of predators had not been studied before, but was likely to be important in controlling pests such as *H. armigera*.

Table 3.1 lists the (potential) natural enemies of *H. armigera* found in our sites. Specimens were identified by the International Institute of Entomology (IIE) and the Natural History Museum (NHM).

Parasitism was generally low or absent at our sites, but highest levels of parasitism were found in Kakamega and Kibos. Here, *Trichogrammatoidea* spp., *Telenomus ullyetti* and *Linnaemya longirostris* were the dominant egg- and larval-parasitoids.

Our data, and data from Ukiriguru, a comparable site in western Tanzania, suggest that the occurrence of parasitoids can vary greatly between seasons and between sites. In general however, the level of parasitism was lower, and the species composition was poorer, at our sites in Kenya than in western Tanzania (Nyambo 1990; van den Berg *et al.* 1990).

Generally, the most common and most promising predators in the field sites were anthocorids and various types of ants. These predators can contribute considerably to natural mortality (see Sections 11-16).

There is a diverse ant fauna within Kenya which is local and irregular in occurrence.

Paederus spp. (Staphylinidae) were sometimes frequent at several sites, but their role as predator is unknown. Various widespread species of Coccinellidae, several of which were confirmed as predators of *H. armigera* in the laboratory, were occasionally common, particularly at Makueni. Spiders were not common.

Birds were abundant on sunflower and sorghum towards the ripening stage of the crops. These were a variety of weaver birds, which are mainly seed eaters (causing more damage than *H. armigera*) although they may contribute to *H. armigera* larval mortality. This mortality would come too late in the crop cycle to prevent much damage by *H. armigera*.

Pathogens were almost never encountered in the field. Larvae reared through in the laboratory were sometimes diseased, although even this is suspect because it could be stress induced disease or possibly secondary infection in the laboratory.

3.2. Taxonomic research

The state of knowledge of the taxonomy, and hence our ability to identify the natural enemies with which we have been working is summarised in the previous section and Table 3.1. Identifications were paid for by the project and made by taxonomists of IIE and NHM.

Research was initiated during Phase I of the project to clarify two aspects of taxonomic confusion regarding the natural enemies of *H. armigera* in Africa, as pin-pointed by our review in Phase I (van den Berg *et al.* 1988).

Firstly, the NHM collection of "*Palexorista laxa*" (Tachinidae) was reviewed critically, and it has now been established that all reared specimens of *P. laxa* are from *Helicoverpa* spp. and *P. laxa* has not reliably been reared from any other host. Details on this work are presented in Annex 2.1.

The second area of research tackled the complex of *Cardiochiles* (Braconidae), several species of which have been reared from *H. armigera* in East Africa. Although much progress has been made sorting out the *Cardiochiles* spp. of Africa (Huddlestone & Walker 1988), mostly using complimentary funds from FAO for the Sahel region, progress has been slower for East Africa due to a shortage of material. However, a reference collection of 17 species of *Cardiochiles* from East Africa has now been compiled at the NHM; 10 of these are undescribed species. We borrowed additional material from Tanzania to supplement that available in the NHM. Contrary to our expectations, *Cardiochiles* spp. have not been a feature of the natural enemy complex of *H. armigera* in Kenya during the four sample seasons.

Little information exists on egg parasitoids of *H. armigera*. In our studies, egg parasitoids were usually the most important group of parasitoids of *H. armigera*, and a complex of species was found. Therefore, numerous specimens were studied at IIE, and it appeared that most of the egg parasitoids (i.e. *Trichogrammatoidea* spp.) in our samples were new records for Africa. A detailed report is given in Annex 2.2.

During the course of the project, our attention was directed to the predators, especially ants and anthocorids, which are known to be important predators of pests in many situations (Goodenough *et al.* 1986) The most problematic of these are the anthocorids, as little information exists on African *Orius* spp. and many different types were encountered in the field, with different morphological characters or colour patterns. Hence, this group was studied at IIE, to establish the species found and their relative abundance in samples from Kenya. The majority of samples came from western Kenya, where anthocorids are more common than in the other areas (Section 9). A detailed report is given in Annex 2.3.

There is considerable interest among scientists in the Kenya National Programme in an illustrated field guide to the natural enemies of *H. armigera* in Kenya. They rightly pointed out that they are handicapped by the lack of such aids. To this end we have prepared a guide (van den Berg & Cock 1991, in prep.) based on 70 selected colour pictures from the field and the laboratory, covering *H. armigera*, other pests which might be confused with it, and the range of natural enemies which attack it in farmers' fields. This will be published during 1991.

Table 3.1. List of natural enemies of *H. armigera* at the sample sites.

Species	Site[a]
Parasitoids	
Tachinidae	
Linnaemya longirostris (Macquart)	Ka,Mw
Palexorista laxa (Curran)	Ka
Palexorista quadrizonula (Thomson)	Mw
Ichneumonidae	
Charops ater (Szepligeti)	Ka
Charops sp. (= *?ater*)	Ka,Mw
Netelia sp. or spp.	Ka
Braconidae	
Apanteles sp.	Ka,Ma
Apanteles sp. (*ultor*-group of Nixon)	Ka
Meteorus laphygmarum Brues	Ka
Eulophidae	
Euplectrus laphygmae Ferrière	Mw
Scelionidae	
Telenomus ullyetti Nixon	Ka,Ma
Trichogrammatidae	
Trichogrammatoidea armigera Nagaraja	Ma,Ka
Trichogrammatoidea eldanae Viggiani	Kb,Ki
Trichogrammatoidea lutea Girault	Kb,Ka
Trichogrammatoidea simmondsi Nagaraja	Kb,Ka
Trichogrammatoidea sp. nr. *bournieri* Pintureau & Babault	Ma
Trichogramma sp.	Ka,Ma
(Potential) Predators	
Anthocoridae	
Blaptostethus sp.	Kb
Cardiastethus exiguus (Poppius)	Kb
Cardiastethus sp.	Kb
Orius albidipennis (Reuter)	Kb,Ka
Orius tantillus (Motschulsky)	Kb,Ka
Orius thripoborus (Hesse)	Kb,Ka
Orius sp. A nr. *thripoborus* (Hesse)	Mw,Kb
Orius sp. B	Mu
Orius sp. C	Lu
Nabidae	
Tropiconabis capsiformis (Germar)	Ka
Lygaeidae	
Geocoris amabilis Stål	Kb
Reduviidae	
Pirates ?nitidicollis (Reuter)	Ka
Polytoxus flavescens Villiers	Kb
Chrysopidae	
Brinckochrysa sp.	Mw
Chrysoperla spp.	Ka,Ki
Mallada sp.	Mw

Hemerobiidae	
Micromus sjostedti Weele	Ka,Ma,Mw
Micromus timidus Hagen	Mw
Carabidae	
Apristus latipennis Chaudoir	Ka
Calleida fasciata Dejean	Kb
Elaphropus optimus (Peringuey)	Ka
Hexagonia sp. nr. *punctatostriata* (Laferte Senectere)	Ka
Stenidia sp.	Ka
Staphylinidae	
Astenus tricolor Cameron	Ka
Paederus riftensis Fauvel	Ka
Paederus eximius Reiche	Mw,Na
Paederus sabaeus Erichson	Ka
Coccinellidae	
Cheilomenes propinqua (Mulsant)	Ki,Ka,Ma,Ms
Cheilomenes sulphurea (Olivier)	Ka,Ma,Mw
Cheilomenes lunata (Fabricius)	Ka,Ki,Ma,Mw
Cheilomenes aurora (Gerstaecker)	Na
Declivitata ?olivieri (Gerstaecker)	Ma
Exochomus ventralis Gerstaecker	Ms,Mt
Platynaspis capicola Crotch	Ma
Scymnus sp. *?morelleti* Mulsant	Ka
Vespidae	
Belonogaster sp.	Mu
Polistes sp.	Ka
Formicidae	
Acantholepis sp.	Mw
Camponotus flavomarginatus Mayr	Kb,Na
Camponotus nr. *flavomarginatus* Mayr	Kb
Camponotus sp. 1 *maculatus*-group	Ka
Camponotus sp. 2 *acvapimensis*-group	Ka
Camponotus sp. 3 *rufoglaucus*-group	Ms
Monomorium opacum Forel	Mw
Myrmicaria sp. or spp.	Ka,Ki
Myrmicaria opaciventris Emery	Kb
Odontomachus troglodytes Santschi	Ka
Oligomyrmex sp.	Kb
Pachycondyla sennaarensis (Mayr)	Ms
Pheidole sp. 1	Kb,Mw
Pheidole sp. 2	Ka,Ms
Serrastruma ?maynei (Forel)	Kb
Tetramorium sericeiventre Emery	Mw
Tetramorium zonacaciae (Weber)	Ka
Syrphidae	
Allograpta nasuta (Macquart)	Ma
Melanostoma annulipes (Macquart)	Ka
Pathogens	
Nuclear Polyhedrosis Virus	Ka

[a] Ka, Kakamega; Ki, Kisii; Ma, Makueni; Ms, Msabaha; Mt, Mtwapa; Mw, Mwea Tebere; Na, Nairobi; Mu, Muguga

4. Microhabitat selection and spatial distribution of *Helicoverpa armigera* and its predators in smallholder crops in Kenya.

Introduction

Helicoverpa armigera attacks a wide variety of crops, including cotton, sunflower, maize and sorghum. Larvae generally feed on the flowering and fruiting parts of those crops. The distribution of *H. armigera* eggs and larvae within the plant is important for evaluating its natural mortality factors. The impact of abiotic factors (e.g. rain) and biotic factors (e.g. natural enemies) on *H. armigera* will depend on the location of a stage on the plant.

The objective of this section is to study the intra-plant and inter-plant distribution of *H. armigera* stages on different crops, and how this corresponds with that of their major predators.

Materials and Methods

Experimental field site
The study is reported for four sites: Kakamega, Mwea Tebere, Kibos and Makueni, although similar data is also available for Kisii, Mtwapa and Msabaha. Sampling started from the short rains 1988/89 and continued for four seasons until the long rains 1990. At Kibos, crops were planted during the long rains seasons only (seasons 2 and 4), whereas at Makueni, sampling ended after the third season.

At Kakamega Regional Research Centre, KARI, crops were grown in four replicates. Individual plot sizes were 19x20 m for sunflower, 17x20 m for maize and 12x20 m for sorghum. Varieties and spacings used were as given in Annex 5.

A similar trial was set up at Kibos, Cotton Research Sub-centre, KARI, with the crops cotton, maize and sorghum, but the data for maize and sorghum at Kibos were not used because of low *H. armigera* densities. Cotton was grown in 19x20 m plots replicated four times.

At Mwea Tebere National Fibre Research Centre, KARI, crops were grown in three replicates. Individual plot sizes were 13.5x11 m for cotton, 8x11 m for sunflower, 7x11 m for maize, and 3.5x11 m for bean. Varieties and spacings used were as in Annex 5.

At Makueni, crops were grown in three replicates. Individual plot sizes were 12.5x10 m for cotton, 8.5x10 m for maize, 6.5x10 m for sorghum, and 11x10 m for pigeon pea. Varieties and spacings used were as given in Annex 5.

Sampling methods
Sampling was conducted weekly from monday to friday, starting from pre-flowering, continuing until harvest (see Sections 5-8). All plant parts were checked and all relevant arthropods recorded, as described in Section 2.2. Every week, 20 plants (at Mwea Tebere and Makueni) or 30 plants (at Kakamega and Kibos) were sampled, and the results pooled for the week.

Results and discussion

I. Microhabitat selection

Kakamega and Kibos
Figures 4.1-4.4 show the results from western Kenya for sunflower, maize, sorghum and cotton, respectively. The data are averaged over 4 seasons, with standard deviations between seasons, except for the data for cotton (from Kibos) which were based on one season.

The degree of microhabitat-association (or microhabitat-overlap) between *H. armigera* stages and their predators was calculated as:

$$y = 1 - \tfrac{1}{2} \sum_{i=1}^{i=I} (\sqrt{(p_i - q_i)^2})$$

where y is coefficient of association, p is relative occurrence of *H. armigera* on plant part i, and q the relative occurrence of the predator on plant part i. $0 <= y <= 1$; if $y = 0$, none of the *H. armigera* and predators occur in the same microhabitat, if $y = 1$, all of the *H. armigera* and predators occur in the same microhabitat.

Table 4.1 shows the association coefficients, pooled for the different seasons. (A complete table for the separate seasons is available). There are strong differences between the crops, which means that a predator may be effective on one crop but not on another.

On sorghum, anthocorid adults and nymphs are strongly associated with the microhabitats of *H. armigera* eggs. On sunflower and maize, the association of anthocorids with eggs is much lower, although the association with young larvae is relatively high (anthocorids can only attack eggs and L1). This is because eggs are mostly laid on the periphery of the flower head, whereas the larvae move to the flowers and seeds.

Table 4.1. Degree of microhabitat association between stages of *H. armigera* and their predators in western Kenya (see text). Results pooled for all seasons; sunflower, maize and sorghum from Kakamega, seasons 1-4; cotton from Kibos, seasons 2 and 4.

		Egg	L1-3	L4-6
SUNFLOWER				
	Myrmicaria sp.	0.411	0.575	0.403
	Pheidole sp.	0.337	0.315	0.267
	Orius nymphs	0.152	0.350	
	Orius adults	0.254	0.458	
MAIZE				
	Myrmicaria sp.	0.460	0.163	0.201
	Pheidole sp.	0.303	0.269	0.127
	Orius nymphs	0.170	0.559	
	Orius adults	0.265	0.595	
SORGHUM				
	Myrmicaria sp.	0.009	0.063	0.000
	Pheidole sp.	0.116	0.065	0.082
	Orius nymphs	0.906	0.947	
	Orius adults	0.931	0.943	
COTTON				
	Myrmicaria sp.	0.809	0.238	0.224
	Camponotus sp.	0.774	0.159	0.164
	Pheidole sp.	0.753	0.199	0.593
	Orius nymphs	0.740	0.437	
	Orius adults	0.479	0.670	

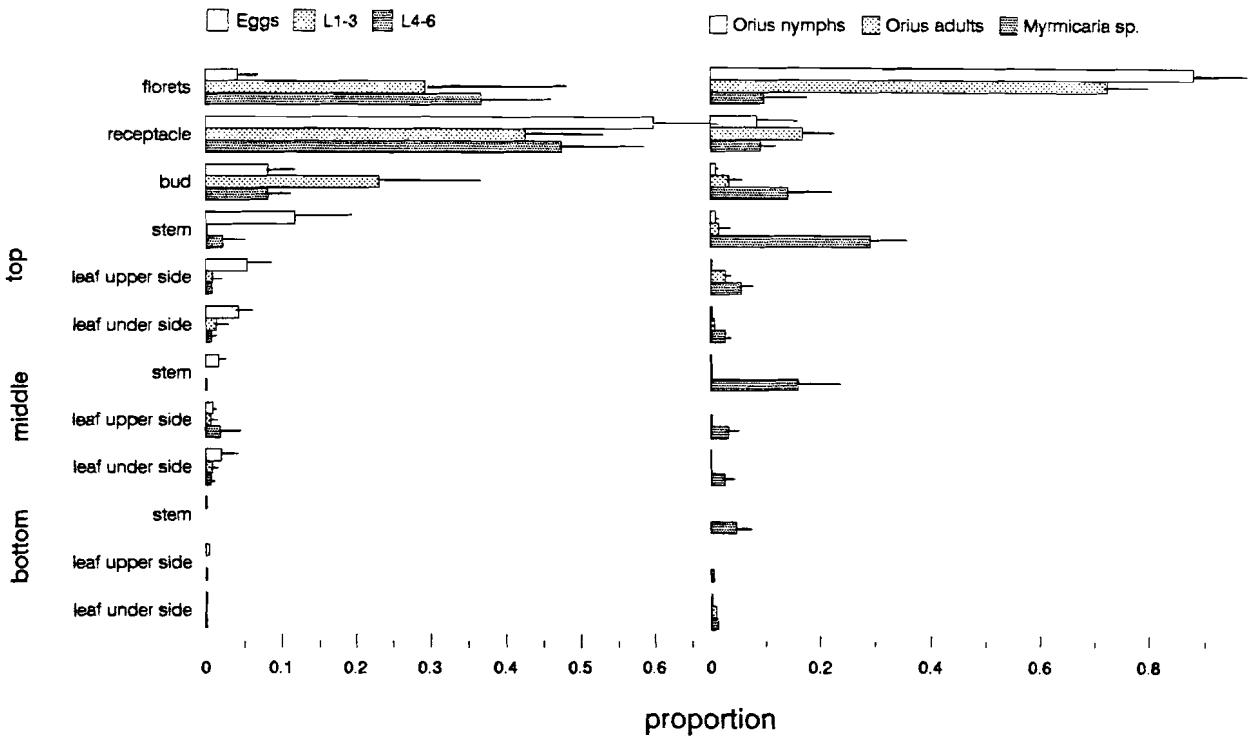

Figure 4.1. Relative distribution (4-seasons' average with standard deviations) of *H. armigera* stages and predators over individual plant parts of sunflower. Kakamega 1988-90.

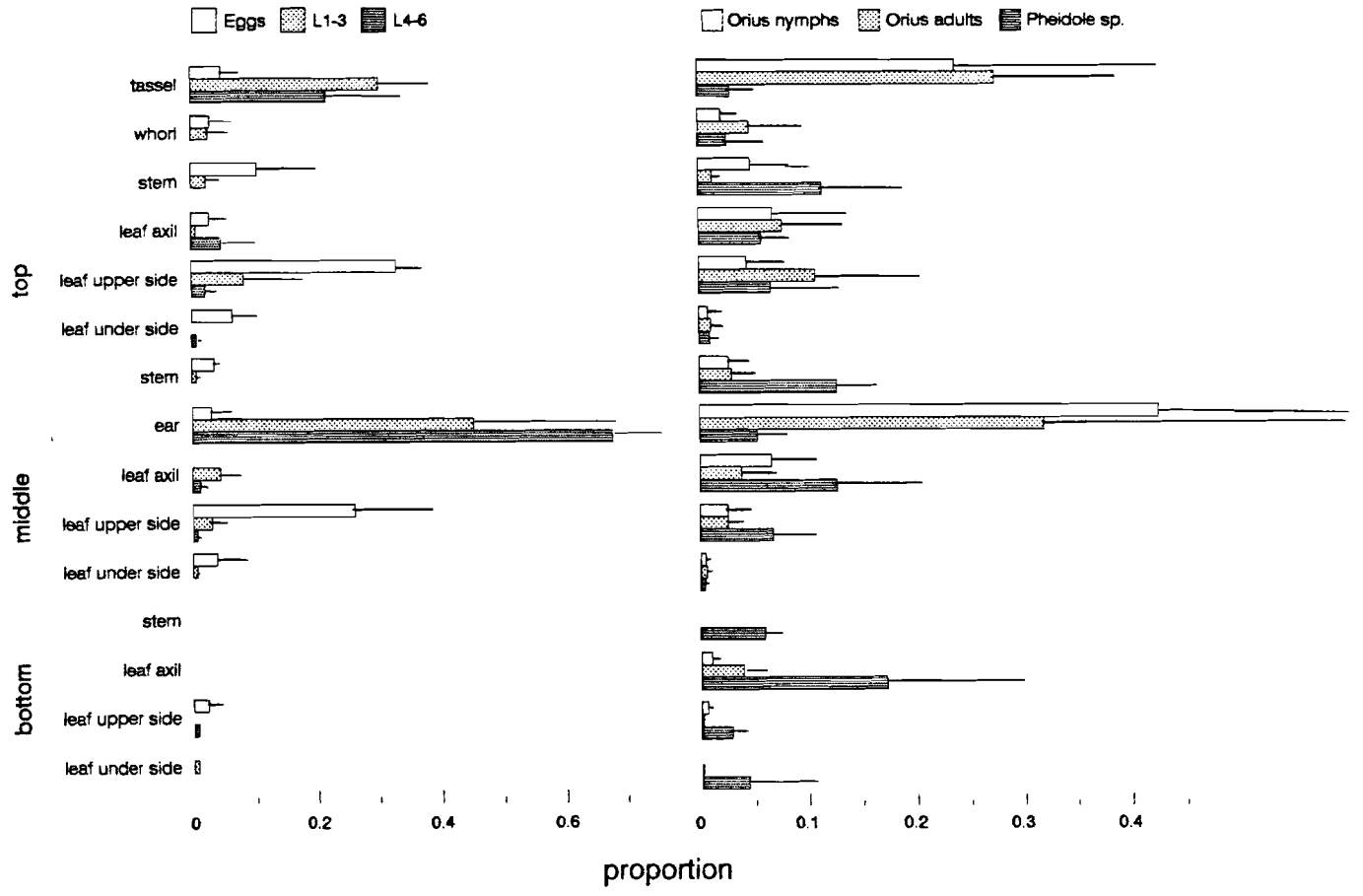

Figure 4.2. Relative distribution (4-seasons' averages with standard deviations) of *H. armigera* stages and predators over individual plant parts of maize. Kakamega 1988-90.

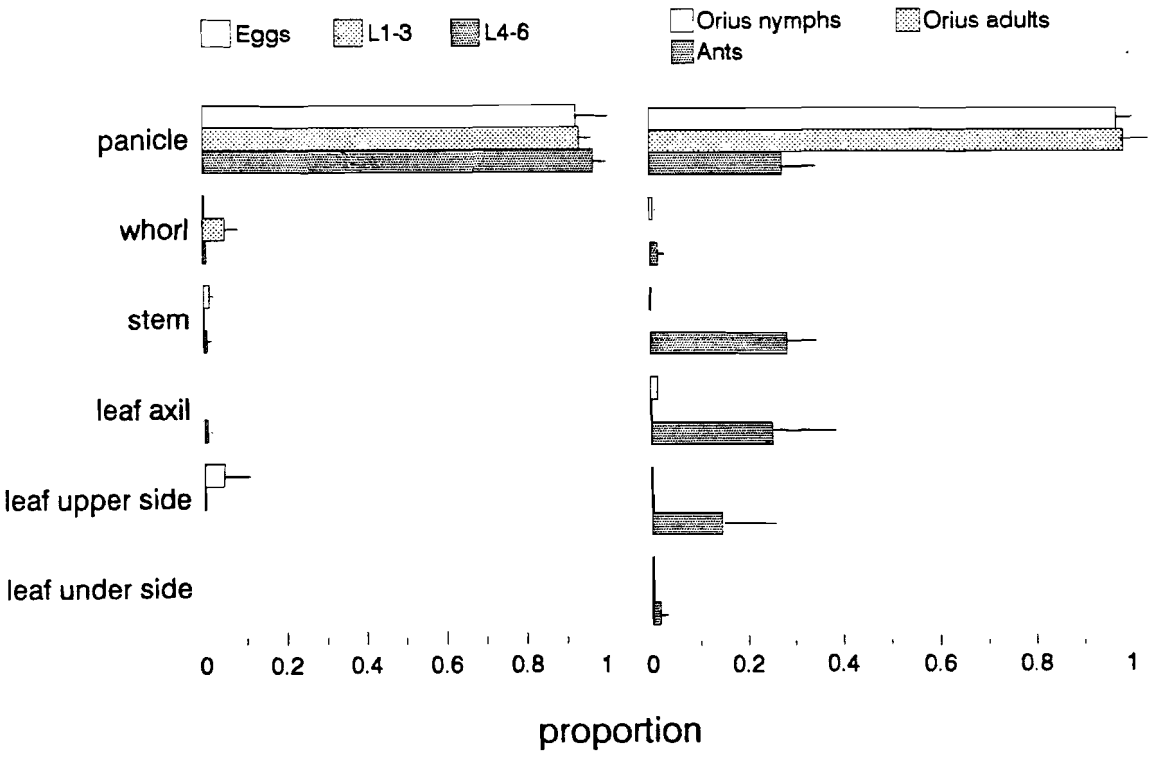

Figure 4.3. Relative distribution (4-seasons' averages with standard deviations) of *H. armigera* stages and predators over individual plant parts of sorghum. Kakamega 1988-90

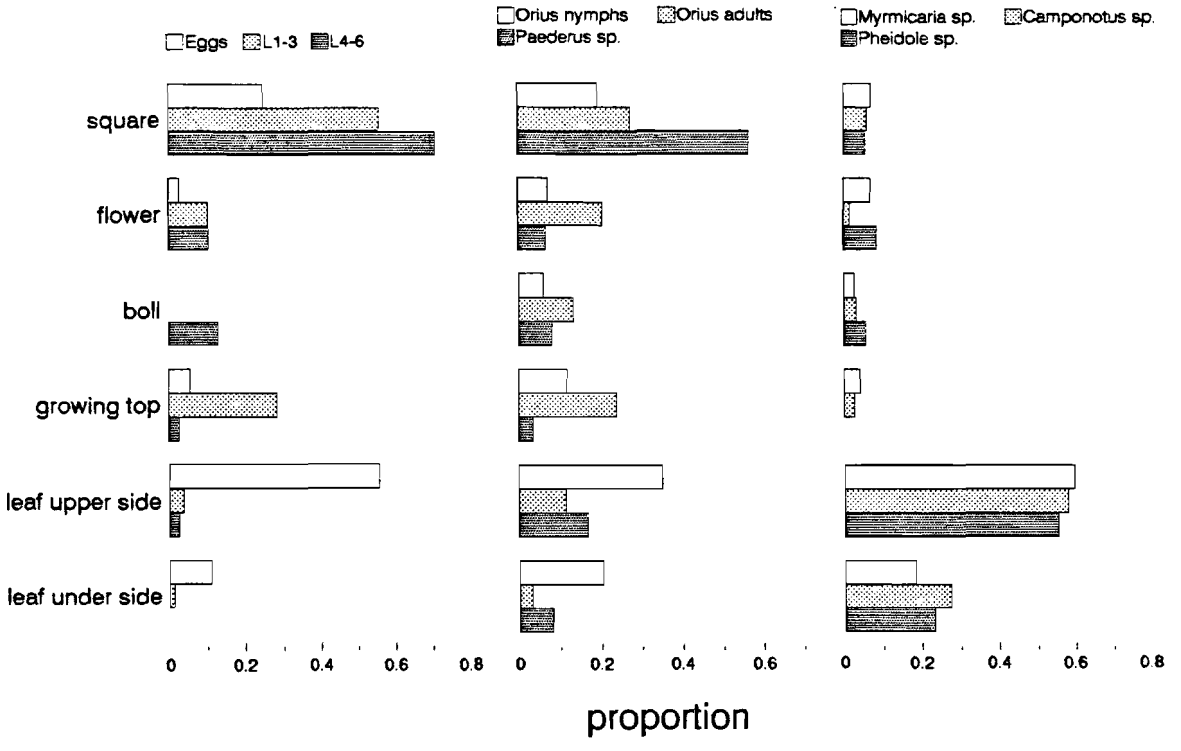

Figure 4.4. Relative distribution of *H. armigera* stages and predators over individual plant parts of cotton. Kibos, long rains, 1989.

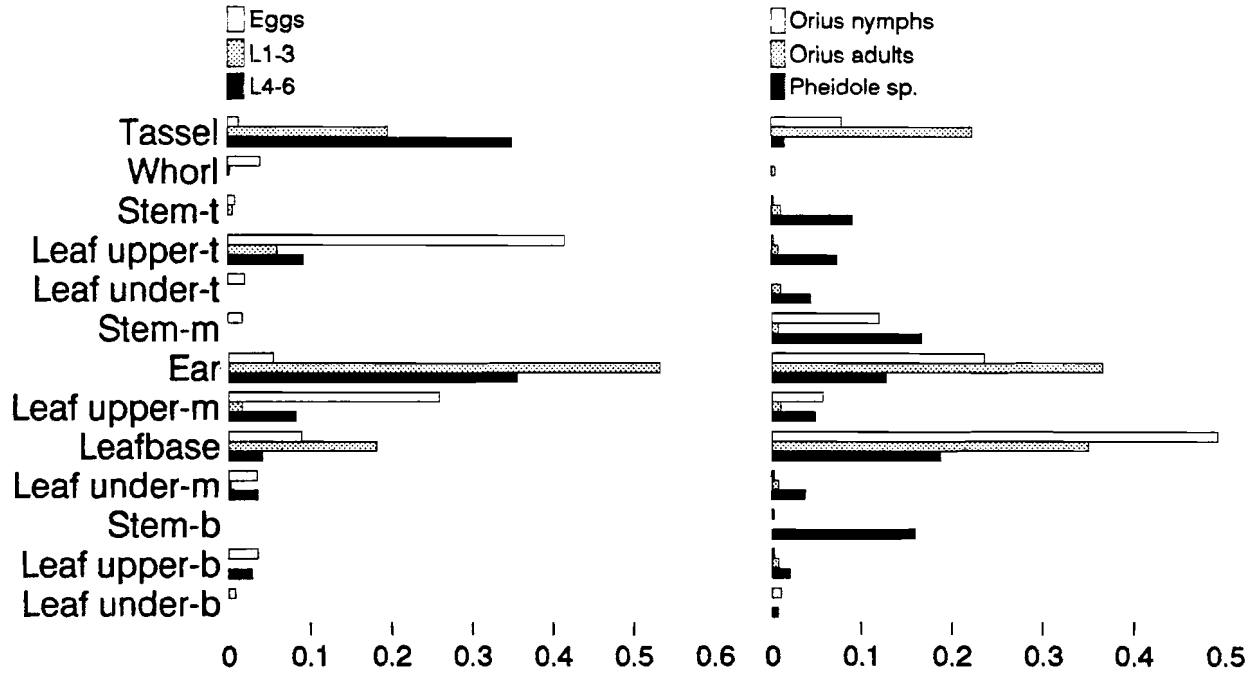

Figure 4.5. Relative distribution (4-seasons' averages) of *H. armigera* stages and predators over individual plant parts on maize. Mwea Tebere 1988-90; t, m, and b in the labels refer to the top, middle and bottom of the plants.

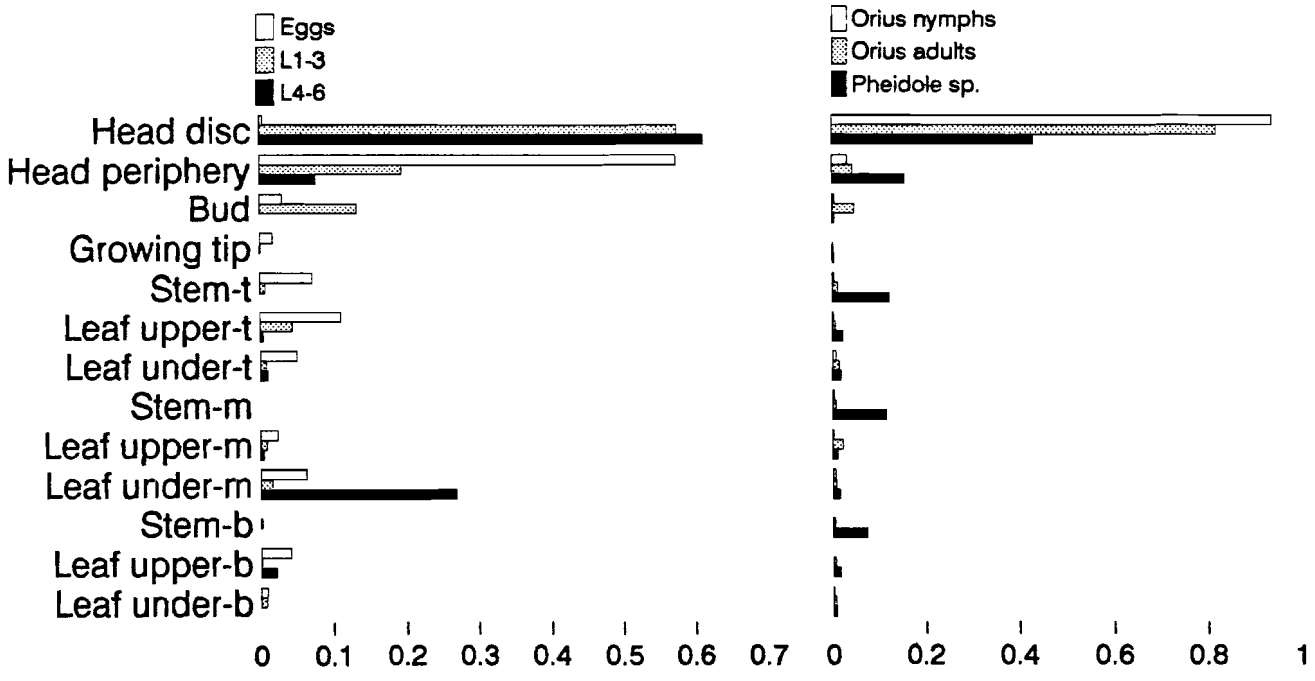

Figure 4.6. Relative distribution (4-seasons' averages) of *H. armigera* stages and predators over individual plant parts on sunflower. Mwea Tebere 1988-90; t, m, and b in the labels refer to the top, middle and bottom of the plants.

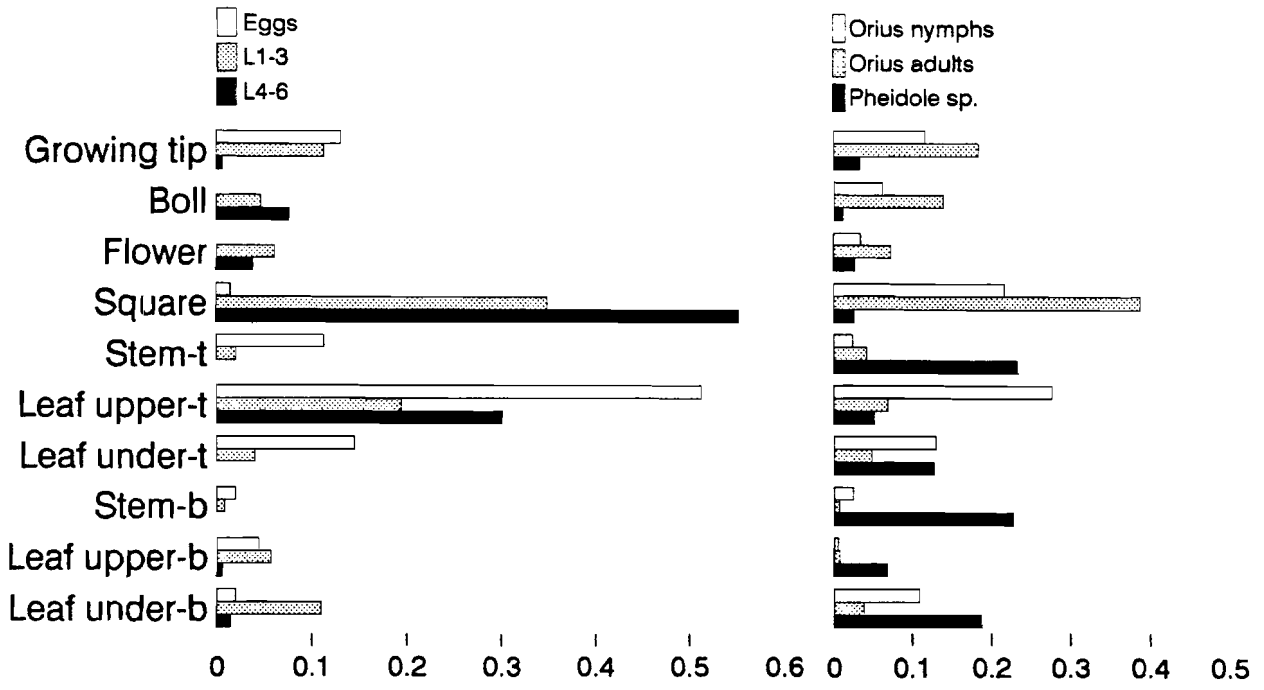

Figure 4.7. Relative distribution (4-seasons' averages) of *H. armigera* and predators over individual plant parts on cotton. Mwea Tebere, 1988-90; t, m, and b in the labels refer to the top, middle and bottom of the plants.

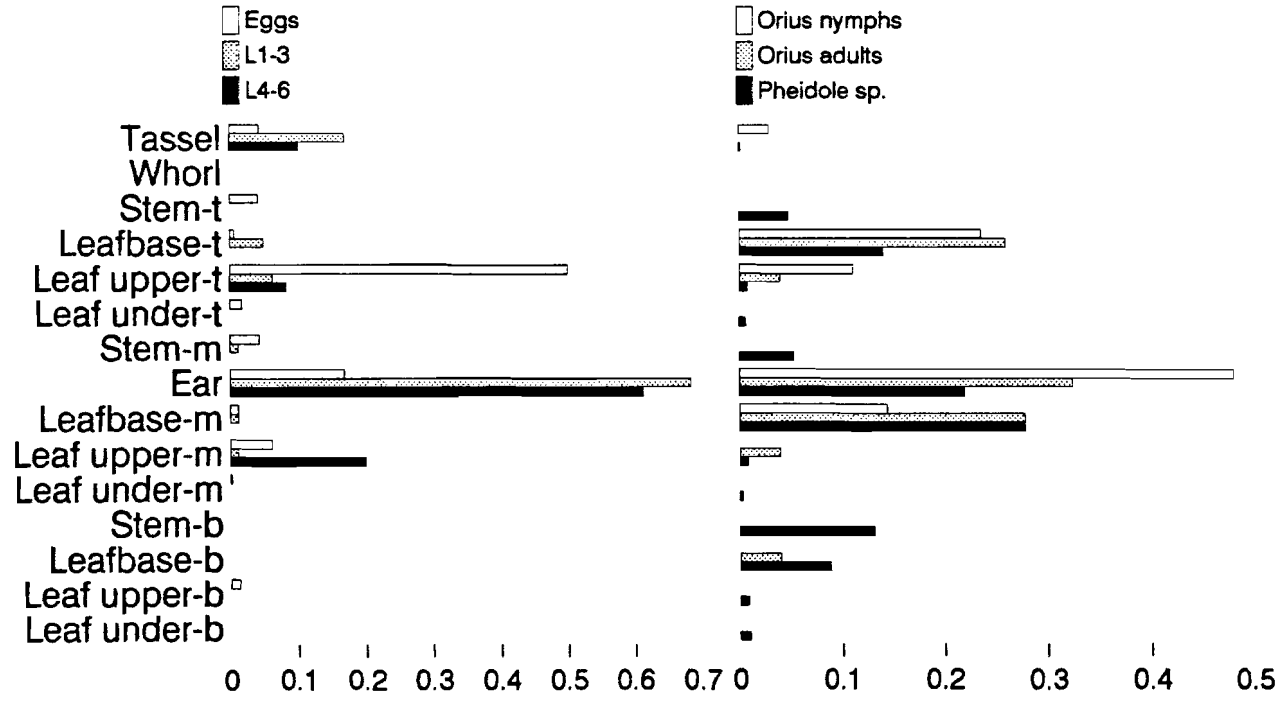

Figure 4.8. Relative distribution (3-seasons' averages) of *H. armigera* and predators over individual plant parts on maize. Makueni, 1988-89; t, m, and b in the labels refer to the top, middle and bottom of the plants.

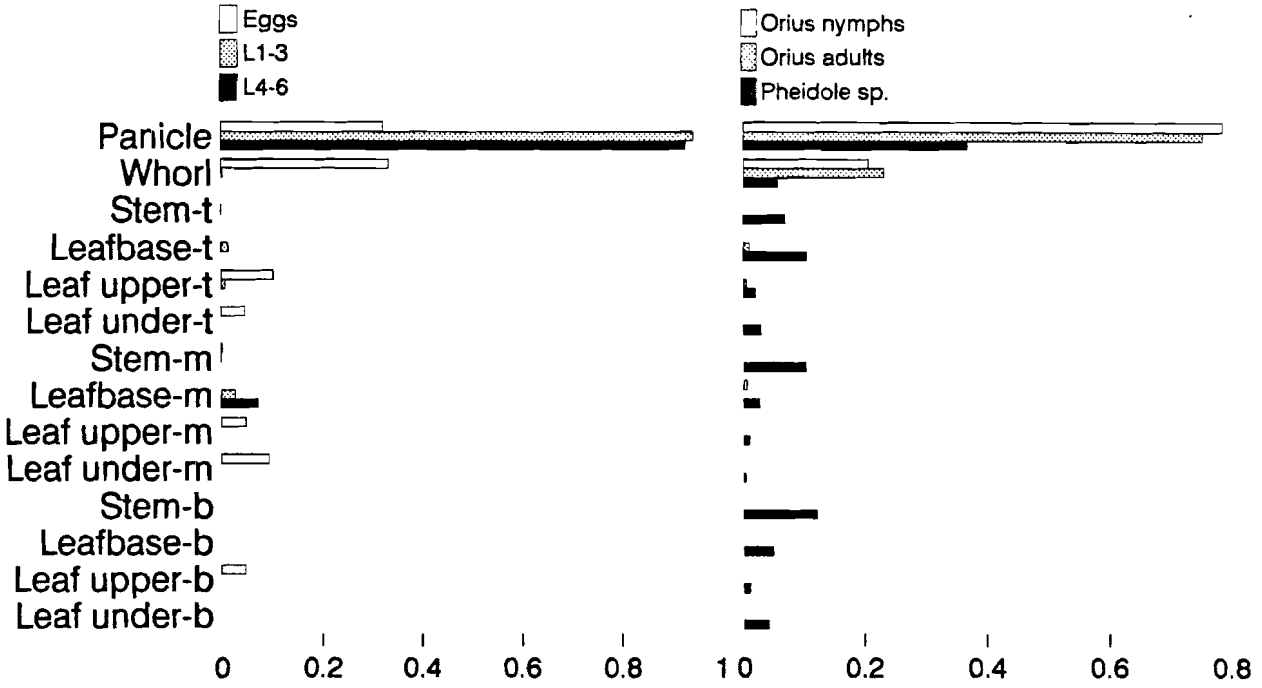

Figure 4.9. Relative distribution (3-seasons' averages) of *H. armigera* and predators over individual plant parts on sorghum. Makueni, 1988-89; t, m, and b in the labels refer to the top, middle and bottom of the plants.

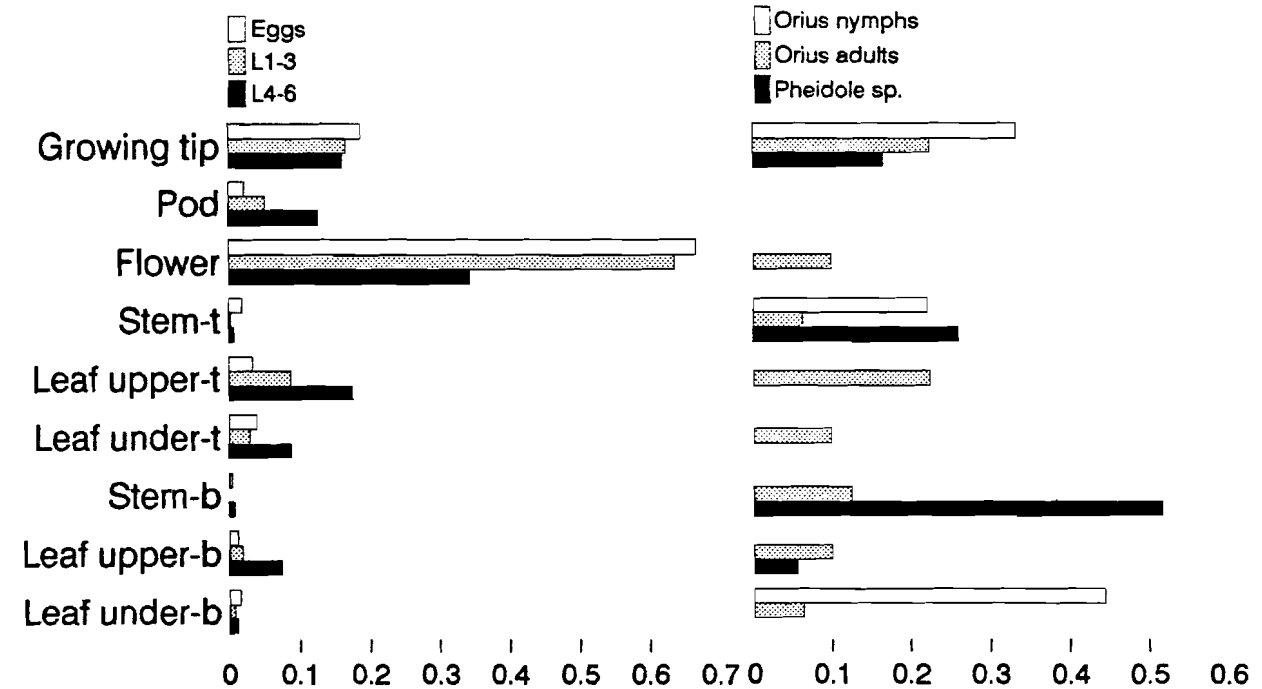

Figure 4.10. Relative distribution (3-seasons' averages) of *H. armigera* and predators over individual plant parts on pigeon pea. Makueni, 1988-89; t and b in the labels refer to the top and bottom of the plants.

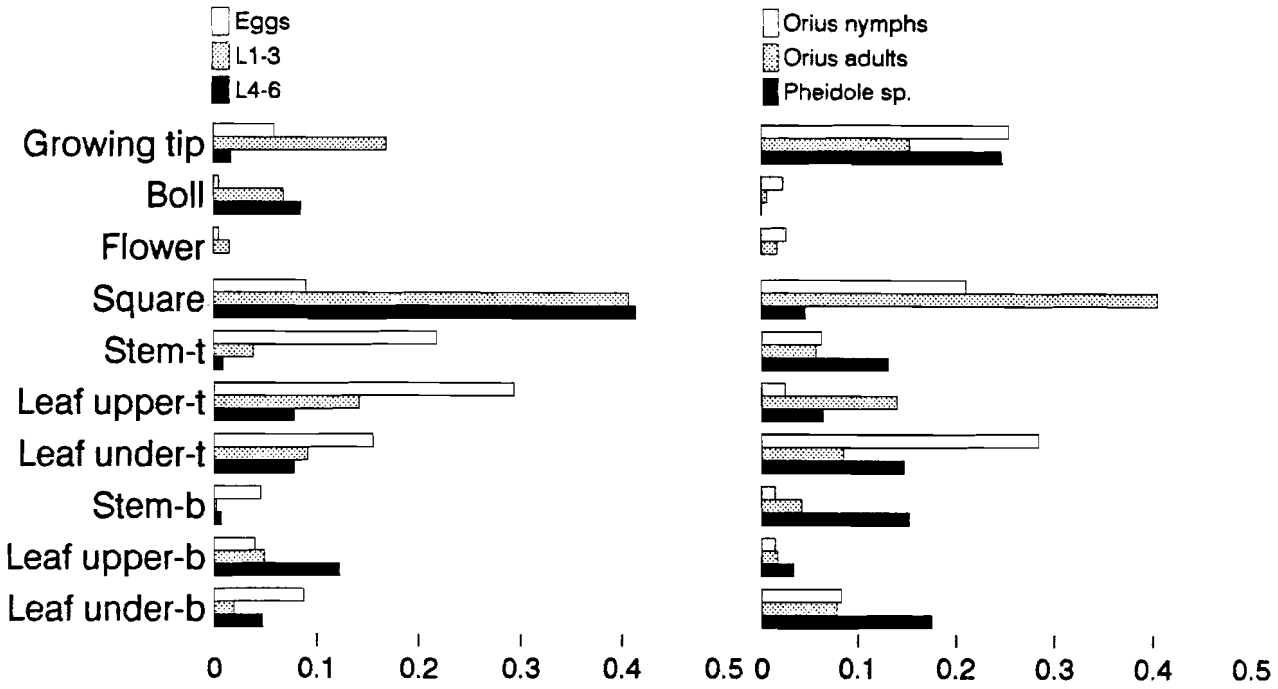

Figure 4.11. Relative distribution (3-seasons' averages) of *H. armigera* and predators over individual plant parts on cotton. Makueni, 1988-89; t and b in the labels refer to the top and bottom of the plants.

Ants were usually quite closely associated with all *H. armigera* stages on sunflower and maize, but on sorghum there was little overlap because ants where rarely found in the panicle.

On cotton, ants were more closely associated with eggs than with larvae, mainly because they are found mostly on the leaves, where a large proportion of the eggs are laid (Figure 4.4). Microhabitat association between anthocorids and eggs was high.

Table 4.2 shows how the intra-plant distribution of predators on maize changes as the crop develops (data are pooled over all seasons). During the vegetative stage, anthocorids are mostly found on the leaves and in the whorl. At pollen shed, they move to the tassels and leaf-axils, where shed pollen accumulates. During ripening, many are found on the ear. *Myrmicaria* and *Pheidole* ants show less seasonal changes.

Mwea Tebere and Makueni

Results of the intra-plant distribution of *H. armigera* and its natural enemies on maize, sunflower, and cotton, pooled over the four seasons are shown in Figures 4.5-4.7 (Mwea Tebere) and 4.8-4.11 (Makueni).

On maize (Figures 4.5, 4.8) most of the eggs of *H. armigera* were found on the upper leaf surface of the plants, while most of the young and old larvae were on the ear (cob) and tassel. *Orius* spp. nymphs and adults were recorded mainly from the leaf-base and ear. These parts were used by *Pheidole* sp., which was also often found walking on the stem.

Table 4.2. Relative distribution of predator stages on maize during different plant development stages; Kakamega, seasons 1-4, 1988-90.

	whorl	leaf axil	ear	tassel	leaf	stem	n
Orius ADULTS							
vegetative	44.7	5.3	3.0	9.1	35.6	2.3	132
tasseling	9.6	35.5	3.0	44.7	5.1	2.0	197
ripening	0.0	34.4	46.9	13.7	4.1	0.8	241
Orius NYMPHS							
vegetative	59.3	15.3	15.3	3.4	6.8	0.0	59
tasseling	2.8	37.3	24.4	23.3	7.3	4.9	287
ripening	0.0	25.4	61.9	7.9	3.8	1.0	291
Myrmicaria SP.							
vegetative	0.0	4.2	0.0	0.0	91.7	4.2	24
tasseling	14.3	7.1	2.0	18.4	22.4	35.7	98
ripening	6.9	3.4	12.6	3.4	26.4	47.1	87
Pheidole SP.							
vegetative	2.4	42.5	1.1	0.0	12.6	41.4	717
tasseling	0.0	55.7	2.7	0.8	6.8	34.0	589
ripening	0.1	51.4	9.4	0.1	23.6	15.3	1600

On sorghum, most of the *H. armigera* eggs, larvae, *Orius* spp. and *Pheidole* sp. were found in the panicle (Figure 4.9).

On sunflower (Figure 4.6) most of the eggs were recorded on the head periphery (bracts and receptacle) and the larvae fed on the head disc (florets and developing seeds). The head disc also harboured most of the *Orius* spp. *and Pheidole* sp.

The upper leaf surface was preferred for oviposition on cotton (Figures 4.7, 4.11) while the larvae were mainly found feeding on the squares. *Orius* spp. were mainly observed on the squares and *Pheidole* sp. on the stem.

On pigeon pea, most of the eggs and larvae of *H. armigera* were found on the buds and flowers, although some were also found on the growing tip where most *Orius* spp. were also found (Figure 4.10). *Pheidole* sp. occurred mostly on the stem.

Oviposition occurred mostly on upper leaf surfaces of maize and cotton, bracts and buds of sunflower etc., which are rough and hairy. This may explain the absence of the *H. armigera* eggs on the upper leaf surfaces of sorghum which are relatively glabrous. From the oviposition sites, larvae have to move to their feeding sites. This is a short distance in sunflower (from bracts to florets), but a longer one in cotton (upper leaf surface to squares) and maize (upper leaf surfaces to ears and tassels), so neonate larvae may be more susceptible to predation and other mortality factors on these crops.

Although coefficients of association have yet to be calculated, the above results show that predators are often found in the same microhabitat as their prey stages, on these crops.

II. Spatial distribution

Further analysis on spatial distribution of the stages of *H. armigera* and its predators was carried out on the data from Kakamega and Kibos.

Using Taylor's Power Law (Taylor 1961), regression of log*(mean)* versus log*(variance)* of data points gives a slope b which is a measure of aggregation (b = 1, random; b > 1, aggregation). Taylor states that b is species specific.

Individual data points used in the regression are samples of 30 plants of one sampling occasion (1 week). Separate regressions were made for each crop for each season. To test Taylor's theory that b is species-specific, statistical analysis could show whether b is larger than 1, and whether b differs per season. Further advice will be taken regarding this analysis.

In Table 4.3, the data are pooled over all seasons. On sunflower, maize and sorghum, eggs are slightly aggregated, but this is less so for L1-3, and even less for L4-6, indicating a dispersion or density-dependent mortality of larvae. Aggregation of anthocorids is similar to or a little higher than that of eggs. Aggregation of ants is similar to that of aphids, but higher than that of *H. armigera* stages.

Table 4.3. Parameter estimates of log*variance* x log*mean* regressions (Taylor's Power Law, [Taylor 1961]), to determine the spatial distribution pattern of *H. armigera* stages and its predators.

		b	a	r^2	n[a]
SUNFLOWER					
	Eggs	1.233	0.310	0.955	49
	L1-3	1.110	0.129	0.953	61
	L4-6	1.088	0.136	0.974	51
	Pheidole sp.	1.632	0.849	0.873	44
	Orius nymphs	1.387	0.533	0.939	57
	Orius adults	1.428	0.497	0.938	61
MAIZE					
	Eggs	1.215	0.334	0.960	18
	L1-3	1.119	0.171	0.983	21
	L4-6	1.063	0.089	0.929	20
	Pheidole sp.	1.580	0.865	0.935	26
	Orius nymphs	1.258	0.392	0.973	23
	Orius adults	1.221	0.356	0.942	30
	Aphids	1.776	0.860	0.903	37
SORGHUM					
	Eggs	1.324	0.481	0.928	21
	L1-3	1.204	0.310	0.967	21
	L4-6	1.103	0.100	0.947	19
	Pheidole sp.	1.754	1.083	0.926	20
	Orius nymphs	1.398	0.688	0.955	23
	Orius adults	1.450	0.577	0.919	24
	Aphids	1.898	0.698	0.889	30
COTTON					
	Eggs	1.064	0.182	0.872	20
	L1-3	1.129	0.181	0.953	19
	L4-6	1.312	0.391	0.900	13
	Myrmicaria sp.	1.284	0.424	0.934	10
	Camponotus sp.	1.522	0.311	0.642	15
	Pheidole sp.	1.808	0.631	0.816	15
	Orius nymphs	1.307	0.582	0.910	28
	Orius adults	1.366	0.504	0.929	29
	Aphids	1.374	1.168	0.824	30

[a] number of mean-variance pairs in the linear regression, with each pair representing 30 plants sampled.

5. Seasonal dynamics of *Helicoverpa armigera* and its natural enemies in Kakamega, Western Province: life-table construction for a system consisting of three crops.

Introduction

Helicoverpa armigera and other *Helicoverpa* and *Heliothis* spp. are a group of polyphagous pests of major economic importance. Therefore, it seems surprising that only few detailed life-table studies exist on this group (Hogg & Nordheim 1983; Titmarch 1985; Vargas & Nishida 1960). One reason might be that this group is a relatively low-density pest, which lays its eggs singly and dispersed on plant structures, making it a difficult object for absolute population sampling. Furthermore, studies always concentrated on single-crop situations. For Africa, where *H. armigera* is widespread and causes substantial damage to a number of crops, no life-table studies exist.

It is generally believed that natural enemies play a substantial role in population suppression of *Helicoverpa* spp. in unsprayed fields, but a recent workshop on biological control of *Heliothis* (King & Jackson 1989) emphasised the lack of sound data on this subject.

In East Africa, *H. armigera* feeds on a variety of crops but is only a problem on some of these. Sunflower, maize and sorghum are commonly grown in Western Kenya, predominantly at smallholder farms where they are found in small adjacent plots, or as mixed cultures. In Kenya, *H. armigera* can be a problem in sunflower (Khaemba & Mutinga 1982), sometimes in sorghum, but rarely in maize, although moths readily oviposit on maize. Maize has been suggested as a trap crop for *H. armigera* (Abate 1988).

In this context, it is important to study the population dynamics and to construct life-tables of *H. armigera* in a smallholder system consisting of more than one crop, to interpret the dynamic population processes.

The present study covers the dynamics of *H. armigera* and its natural enemies in sunflower, maize and sorghum, over four seasons, in Kakamega.

Materials and methods

Experimental field site
The study site was at KARI's Regional Research Centre, Kakamega, Western Province, located in an area which receives among the highest and most reliable rainfall (1950 mm per year) in Kenya. Annual crops can be grown two seasons per year. The study started from the short rains 1988/89 and continued for four seasons until the long rains 1990. Mono-crop plots of sunflower, maize and sorghum were grown in 4 replicates within a 0.4 ha field plot. Individual plot sizes were calculated such that at most 10% of the plants would be sampled (i.e. destructively) by the end of the season (for sunflower 19x20 m, maize 17x20 m, sorghum 12x 20 m). After the first season, during the 1988/89 short rains, the experimental site was moved to a similar site 300 m away. Thus, some factors, like ant communities, changed after the first season. Varieties and spacings are given in Annex 5.

Meteorological data were obtained at the Research Centre in the immediate vicinity of the experimental field plots. Mean daily temperature was calculated from data obtained every hour.

Sampling methods
Sampling was conducted weekly from monday to friday, during the morning hours (7.30-11.00 a.m.), to avoid the hottest time of the day, except during the first season when sampling was also done late afternoon (4.30-7.00 p.m.). For sampling, plants were first checked without touching the plant for any fast-moving insects, then all plant parts were checked and all relevant arthropods recorded. Fruiting plant parts (flower head of sunflower, cob and tassel of maize, panicle of sorghum) were dissected for any small arthropod stages. *H. armigera* eggs could be distinguished

from the very similar *Plusia* spp. (see field guide in preparation). Instars were estimated based on head-capsule width (Section 2.4) and were regularly verified against known instars. Every week, 30 plants were randomly selected of each crop. The average time spend sampling per plant was approx. 25 minutes. Data were pooled per week. Larvae and eggs were taken to the laboratory for emergence of parasitoids.

Development period of parasitised eggs
In a test tube in the laboratory, half-day old *H. armigera* eggs laid on tissue paper were exposed for three hours to *Trichogrammatoidea* spp. adults, and were kept at 18-23°C. The adult parasitoids were newly emerged from field-collected *H. armigera* eggs, and had mated and fed on honey solution prior to the exposure. Half of the eggs were kept in a separate test tube without parasitoids under the same conditions. The eggs were checked regularly, depending on the rate of emergence (as often as every 15 minutes during peak emergence), first for eclosion of larvae, then for emergence of parasitoids. Development period of unparasitised eggs was 4.86 d (s.e. 0.02 d; n=95), and the development period of eggs parasitised by *Trichogrammatoidea* spp. (including the half day prior to parasitisation) was 12.52 d (s.e. 0.04 d; n=89). This means that parasitised eggs remain in the field 2.58 times longer than unparasitised eggs, and will thus be over-represented in samples by that factor, assuming they are sampled with the same accuracy. Therefore, observed percentage egg parasitism in samples was divided by 2.58.

Estimation of recruitment
For larvae, total recruitment of the generation was estimated with Southwood's method (Southwood & Jepson 1963; Southwood 1978). This method divides the graphical area under the curve of a stage by the residence time in that stage (the development period). This method was chosen because it is simple to calculate, and is not restricted by conditions set by other methods (e.g. survival rates are allowed to be different for each stage). Development periods depend on the temperature. Based on the mean weekly temperature values (Figure 5.1), temperature-driven development rates were calculated for every week as below, and recruitment estimates were derived accordingly.

For L2-3: $Y = 0.02088X - 0.24143$

For L4-6: $Y = 0.00683X - 0.07210$

where Y is the rate of development (1/day) and X is the temperature (degrees Celcius). Here, L1 was excluded form recruitment estimates, because of under-sampling of this small stage. Data were derived from Twine (1977) (see Section 15).

Sections 11 and 15 show that Southwood's method largely underestimates the recruitment of eggs. This may be (1) due to mortality that occurs during the egg stage, or (2) due to sampling errors.

Regarding egg mortality, recruitment estimates (N_s) of Southwood's method are, correctly speaking, not the number that enter a stage, but the number somewhere at the median of a stage, which is the resultant of the actual recruitment (N_r), minus the mortality that has already acted on the stage. Consequently, N_s will be lower than N_r. The same applies to larvae.

Regarding sampling errors, Southwood's method is only accurate if young eggs are sampled with the same accuracy as older eggs, which is not true for *H. armigera*. Eggs of *H. armigera* younger than 1 day are yellow/white in colour, but after one day they become brown in colour, and are therefore difficult to detect against the dark leaf background. Indeed, the majority of eggs encountered during sampling (with 20 minutes spent sampling per plant) were usually the light-coloured young eggs. Therefore, what was measured as egg density does not include all eggs but only the newly-recruited, young, eggs. This assumes that eggs do not all disappear after one day. Indeed, in the egg exposure experiments (Section 14), where eggs were marked and checked, most

eggs were still present after two days, but it would have been difficult to detect them without the markings.

If this measure would be divided by the full developmental period of eggs, as in Southwood's method, the resulting recruitment estimate would largely under-estimate egg recruitment. Instead, the above measure should be divided by the age up to which eggs are recovered, which would be less than the development period, something like 1 day.

This new measure of recruitment, which we will call N_d, provides a more accurate estimate of true recruitment (N_r) than N_s, as shown in Table 5.1. N_d is the graphical area of a stage divided by 1 day, the age after which eggs become difficult to find. Unless egg recruitment N_r was measured directly, as in Sections 11 and 15, we will always use the estimate of recruitment N_d instead of Southwood's estimate N_s.

Table 5.1. A new estimate for egg recruitment[a] N_d, compared with the actual recruitment (N_r) and the estimate with Southwood's method (N_s). Data from Sections 11 and 15.

	control	barrier	sprayed
SUNFLOWER, KAKAMEGA			
N_d	5.9	6.8	10.2
N_r	9.7	9.7	9.7
N_s	1.4	1.6	2.4
COTTON, KIBOS			
N_d	13.0	20.1	15.6
N_r	22.5	22.5	22.5
N_s	3.1	4.8	3.7

[a] per plant over one crop season.

Results and discussion

Figure 5.1 shows the climatic data at the field site during the four sample seasons.

The levels of parasitism and pathogens on the three crops is presented in Table 5.2. Their total impact was generally low. Only on sunflower, a tachinid, *Linnaemya longirostris*, caused moderate mortality, however this parasitoid kills the larva just before pupation after damage has already occurred, so that it does not prevent crop damage.

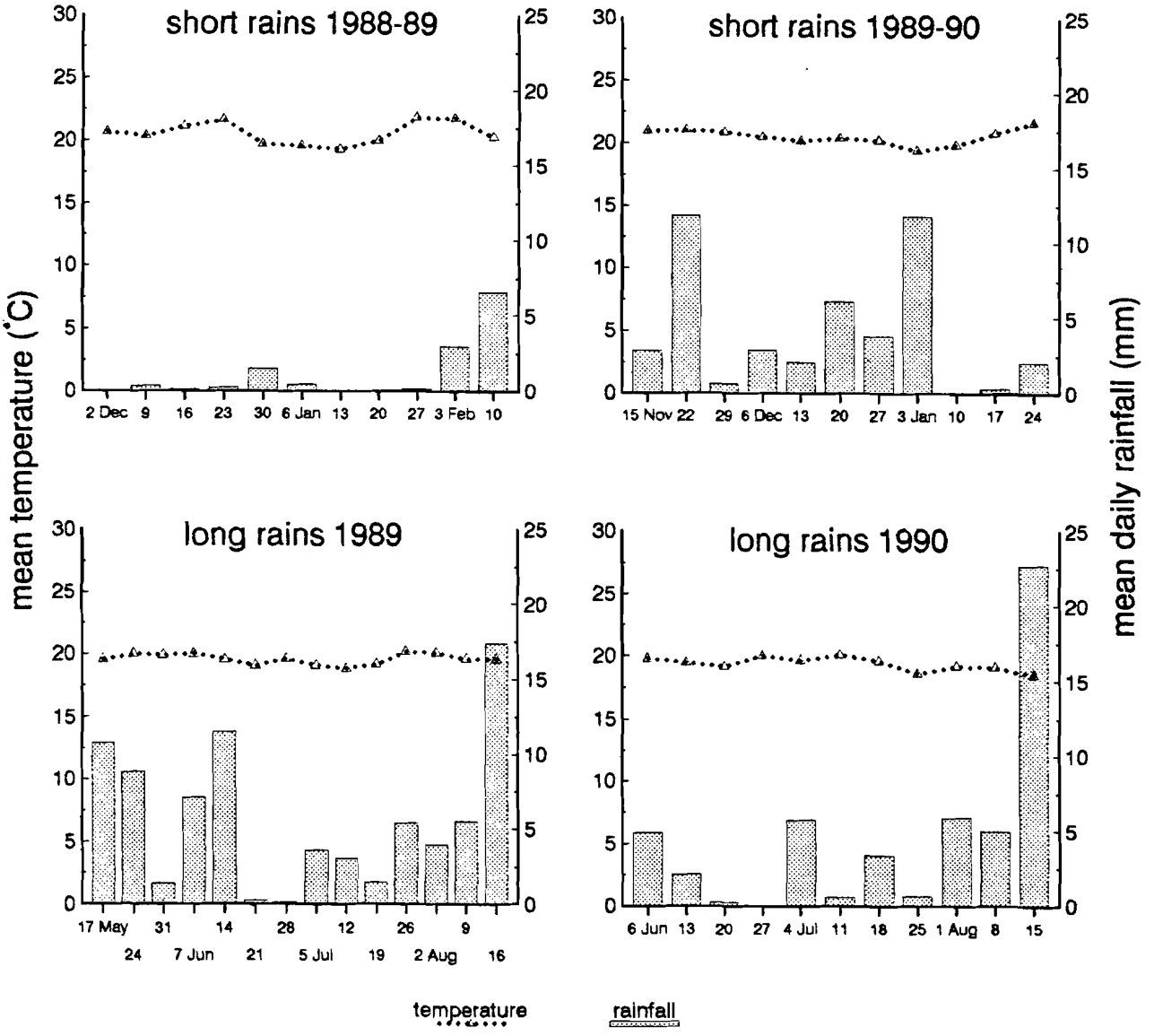

Figure 5.1. Mean temperature and mean daily rainfall during the four sample seasons, Kakamega.

Table 5.2. Mortality of H. armigera eggs and larvae caused by parasitoids and pathogens. Data are average percent generational parasitism values over (3 or) 4 seasons, with host stages selected for calculations of percent parasitism.

	host stages[a]	sunflower	maize	sorghum
Linnaemya longirostris	L5-6	23.5	0.0	5.8
Charops ater	L1-3	2.2	0.0	0.0
Apanteles sp.	L1-3	0.0	8.7	4.0
Meteorus laphygmarum	L3-4	0.9	0.0	2.8
Trichogrammatoidea spp.	E	4.0	8.9	6.5
Telenomus ullyetti	E	2.4	0.0	1.0
Mermithidae	L2-5	0.2	2.4	1.0
Nuclear Polyhedrosis Virus	L1-3	0.5	0.0	0.0

[a] E, egg; L1-6, instars.

I. Sunflower

Figures 5.2-5.5 show populations of *H. armigera* and dominant predators on sunflower, during four seasons. Table 5.3 shows the partial life-tables of *H. armigera* eggs and larvae. One generation of *H. armigera* develops per crop season.

Stage mortality varies largely from season to season, sometimes an egg peak gives rise to a considerable (damaging) level of larvae (Figure 5.3), and sometimes it gives rise to virtually no larvae at all (Figure 5.2). There is also a large variation in the densities of predators. The relationship between the average densities of predators during the season, and the stage-specific mortality during the season is discussed in Section 17.

II. Maize

Figures 5.6-5.8 show populations of *H. armigera* and dominant predators on maize, during three seasons. Table 5.4 shows the partial life-tables of *H. armigera* eggs and larvae.

Single generations of *H. armigera* develop on maize during the crop season. A distinct oviposition peak was usually observed at the onset of pollen shed. Thereafter, eggs were rarely found. Mortality was very high (on average 94.9 %) during the young larval instars, considerably higher than on sunflower and sorghum. The previous section showed that eggs are mostly laid on the leaf blades, whereas larvae feed almost exclusively on the ear and tassels. Hence, neonate larvae would have to migrate for a considerable distance to reach soft plant parts, and this would reduce their chance of survival because of starvation or increased exposure to natural enemies. Having reached soft plant parts, mortality of older larvae is much lower.

Mortality of young stages was especially high during the long rains of 1990, although predator densities were low. This indicates the role of mortality factors other than natural enemies (possibly related to plant quality), but requires further study (see Priority Tasks for Follow-up). The relationship between the average densities of predators during the season, and the stage-specific mortality during the season is shown in Section 17.

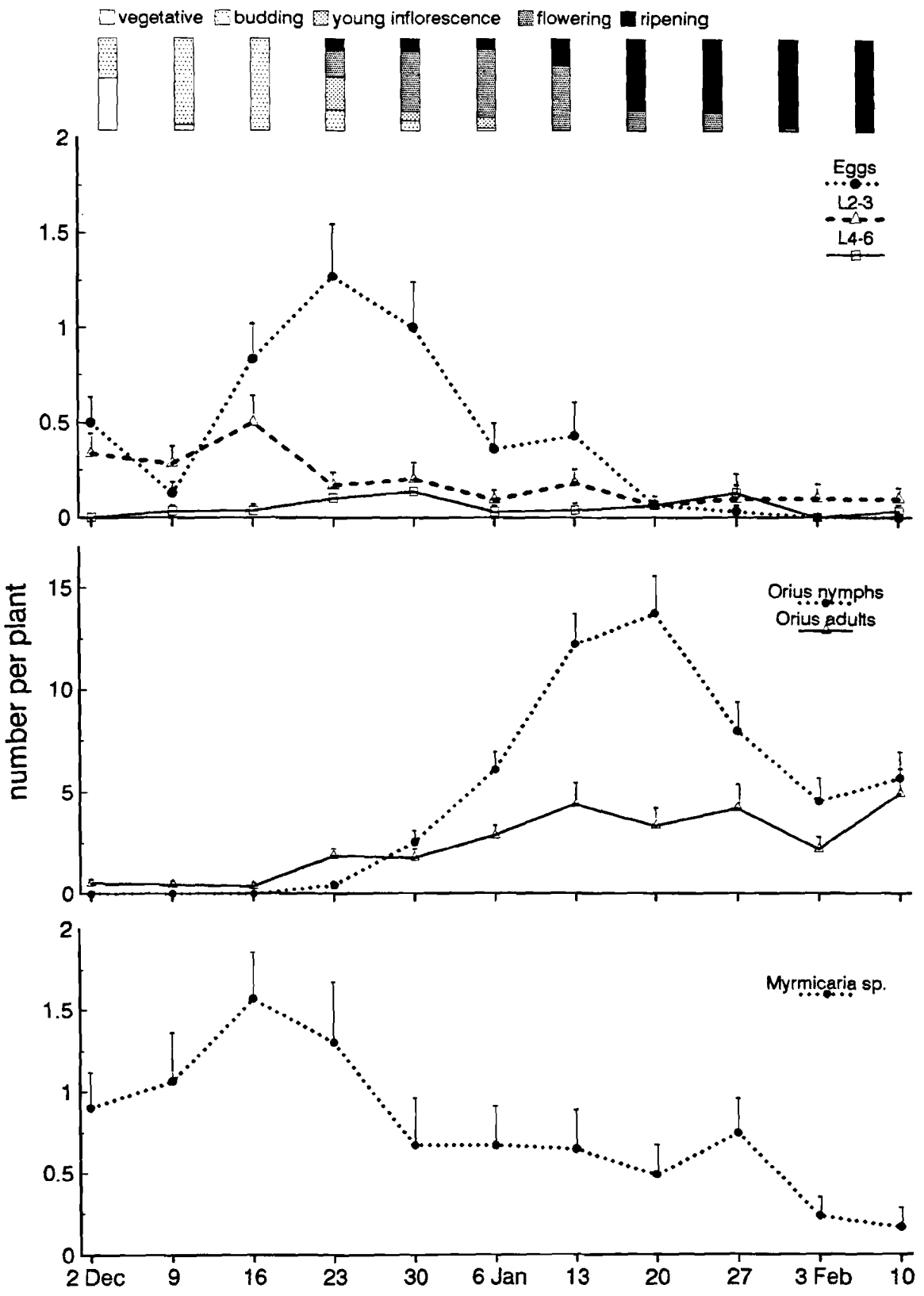

Figure 5.2. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Kakamega. I. Sunflower, short rains 1988-89.

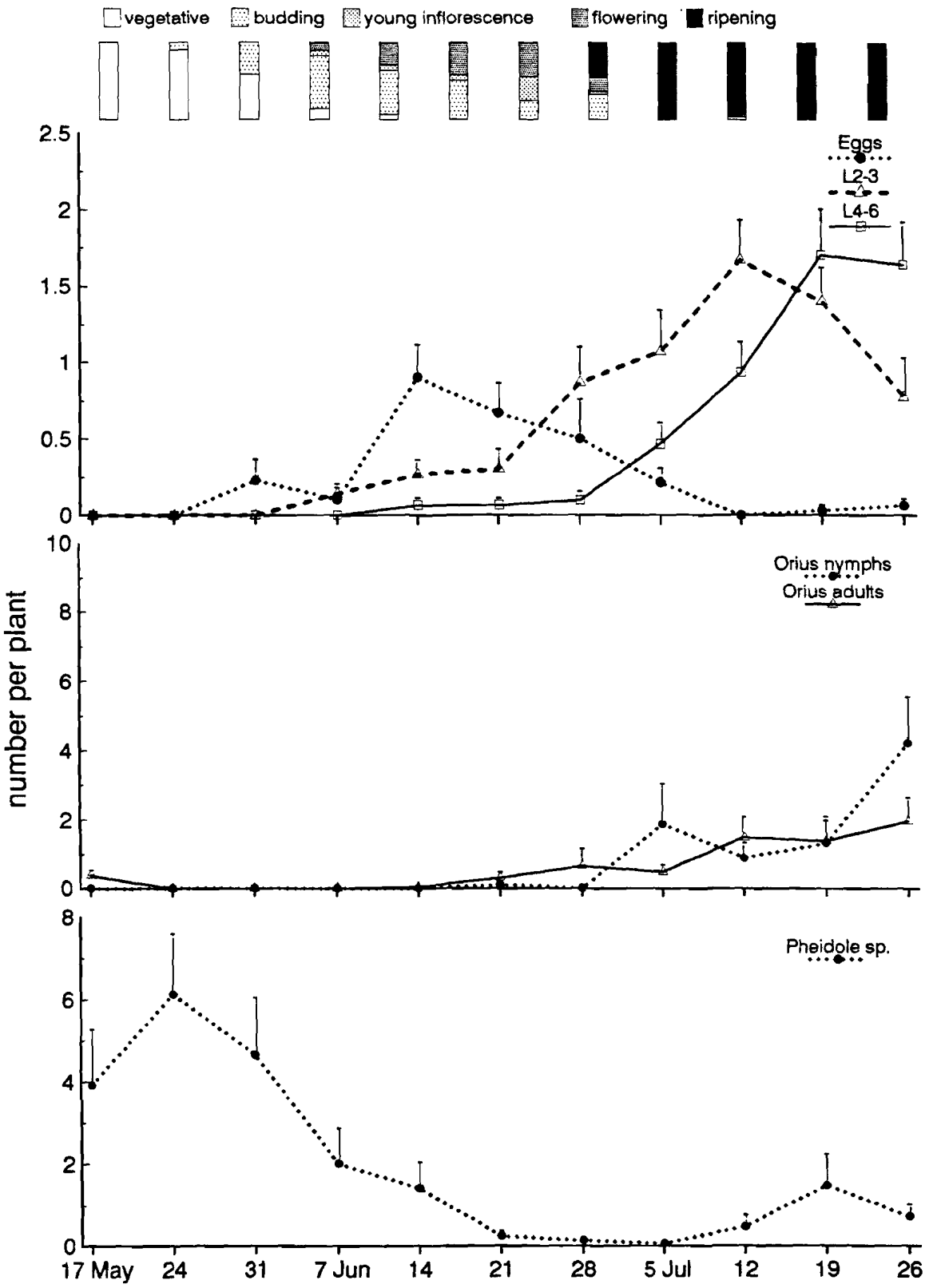

Figure 5.3. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Kakamega. II. Sunflower, long rains 1989.

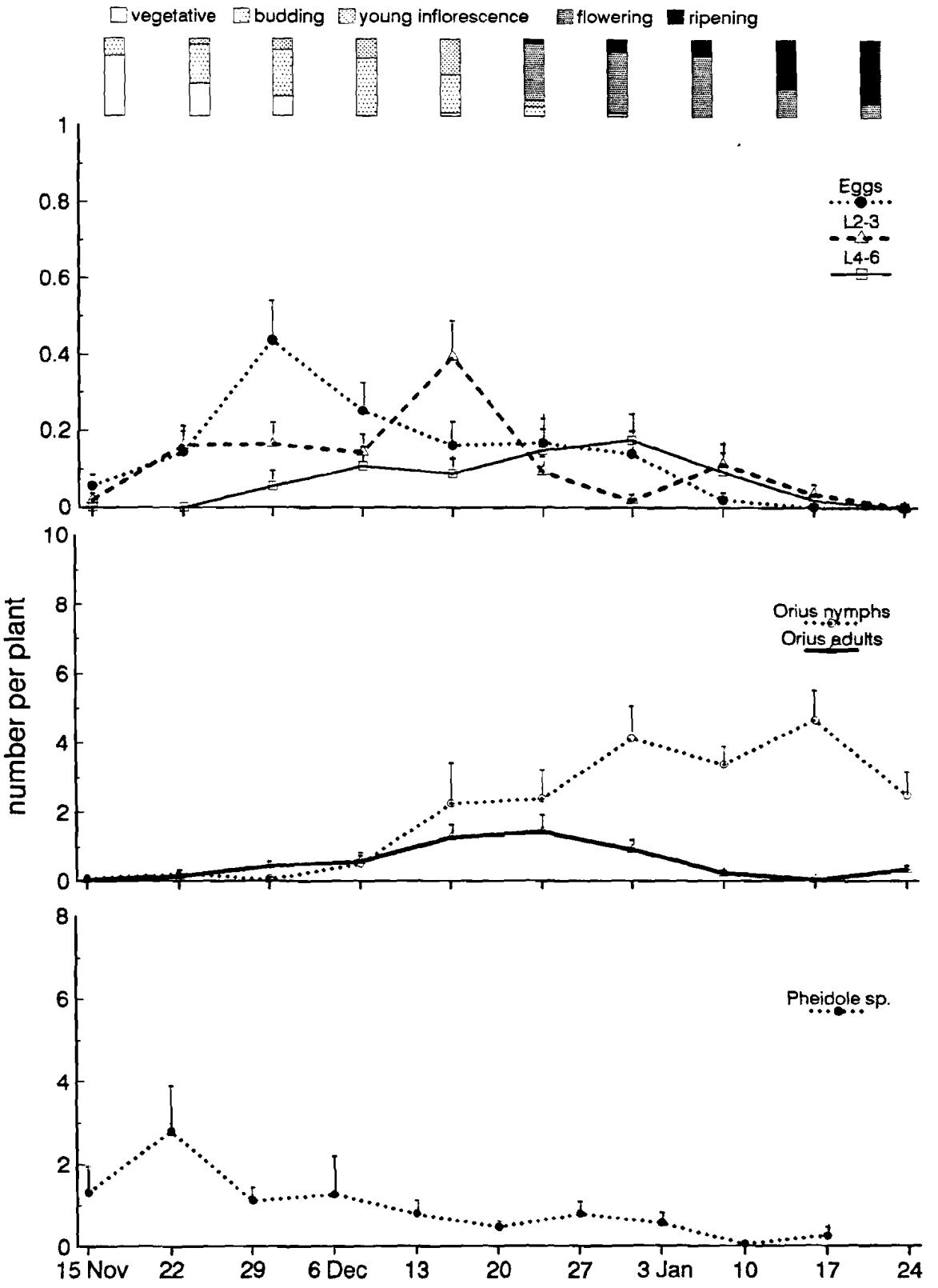

Figure 5.4. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Kakamega. III. Sunflower, short rains 1989-90.

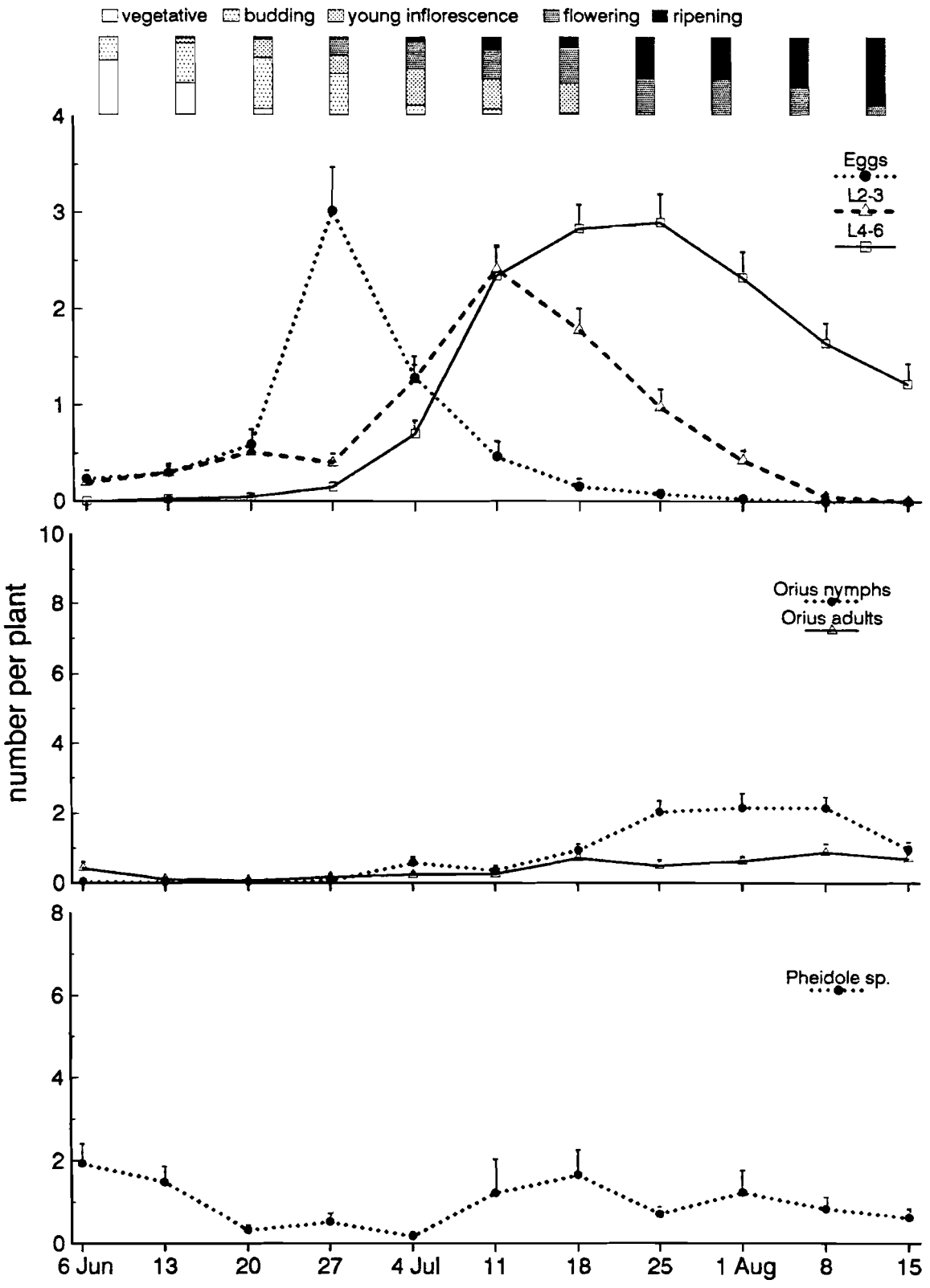

Figure 5.5. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Kakamega. IV. Sunflower, long rains 1990.

Table 5.3. Partial lifetables for *H. armigera* eggs and larvae on sunflower, Kakamega.

short rains 1988/89

x	d_xF	l_x	d_x	$100\,q_x$
Eggs[1]		30.56		
	failed to hatch		0.00	0.0
	parasitism		2.90	9.5
	unknown		25.14	82.3
L2-3		2.52		
	parasitism/pathogens		0.00	0.0
	unknown		2.24	89.0
L4-6		0.28		
	parasitism		0.07	27.0
	total mortality			99.3

long rains 1989

x	d_xF	l_x	d_x	$100\,q_x$
Eggs[1]		18.73		
	failed to hatch		1.24	6.6
	parasitism		0.00	0.0
	unknown		11.87	63.4
L2-3		6.86		
	parasitism/pathogens		0.34	5.2
	unknown		4.76	69.5
L4-6		1.74		
	parasitism		0.00	
	total mortality			90.7

short rains 1989/90

x	d_xF	l_x	d_x	$100\,q_x$
Eggs[1]		7.88		
	failed to hatch		0.92	11.7
	parasitism		0.18	2.3
	unknown		6.11	77.6
L2-3		1.58		
	parasitism/pathogens		0.09	6.0
	unknown		1.15	72.5
L4-6		0.34		
	parasitism		0.18	54.1
	total mortality			98.0

long rains 1990

x	d_xF	l_x	d_x	$100\,q_x$
Eggs[1]		42.08		
	failed to hatch		2.82	6.7
	parasitism		2.40	5.7
	unknown		30.07	71.5
L2-3		9.61		
	parasitism/pathogens		0.89	9.3
	unknown		3.05	31.7
L4-6		5.67		
	parasitism		0.73	12.9
	total mortality			88.3

[1] Corrected recruitment estimate Nd (see text).

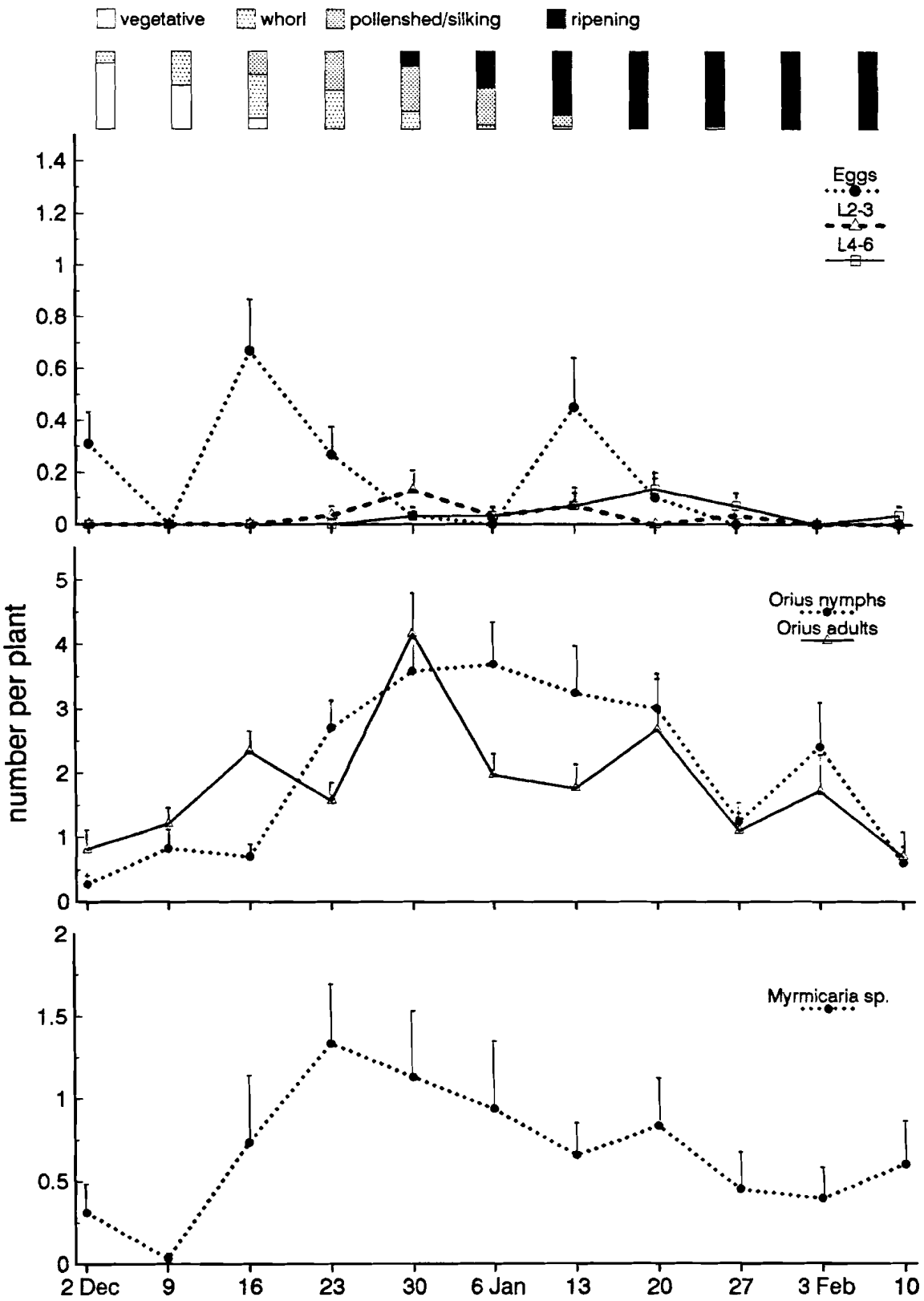

Figure 5.6. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Kakamega. V. Maize, short rains 1988-89.

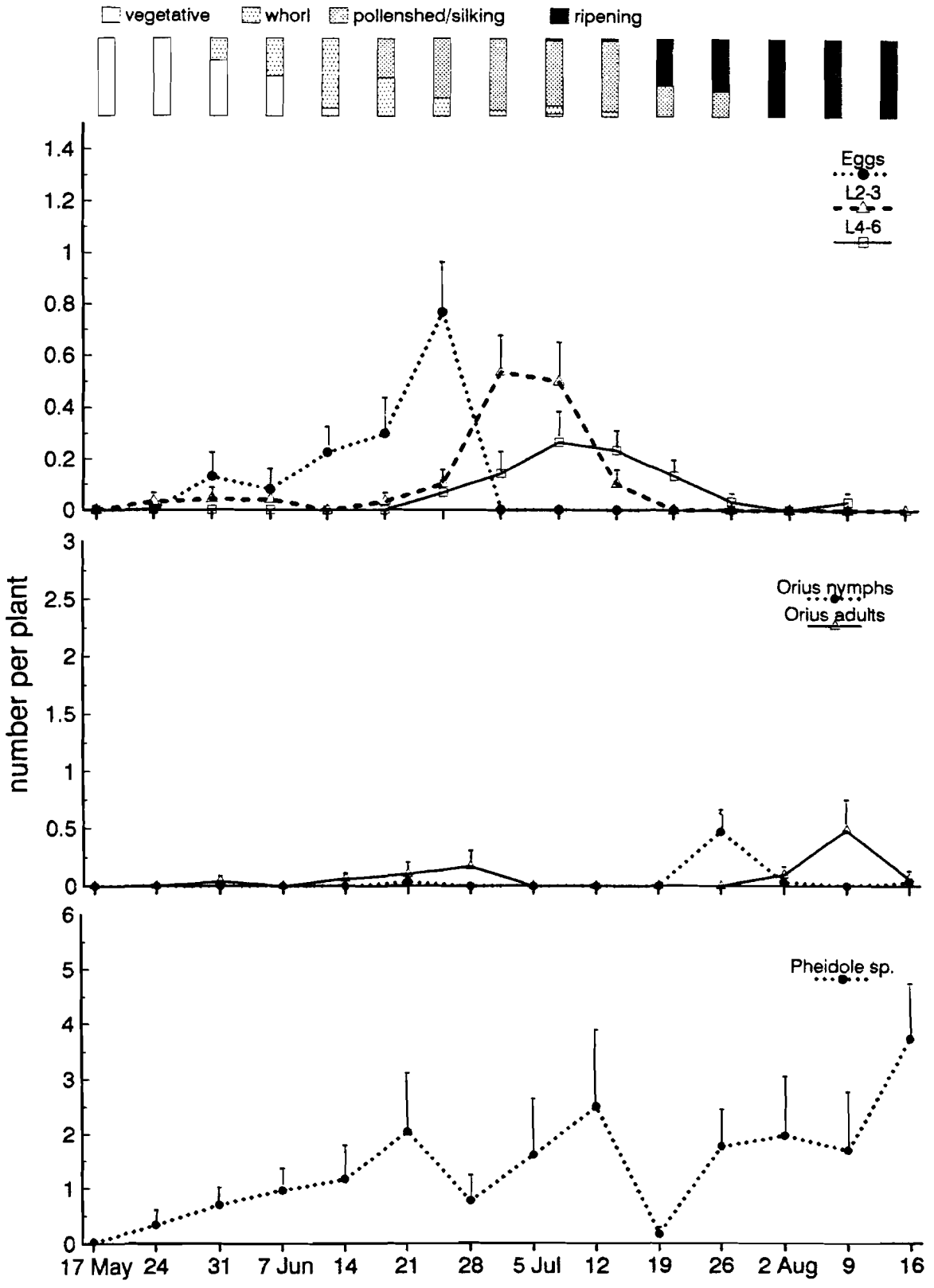

Figure 5.7. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Kakamega. VI. Maize, long rains 1989.

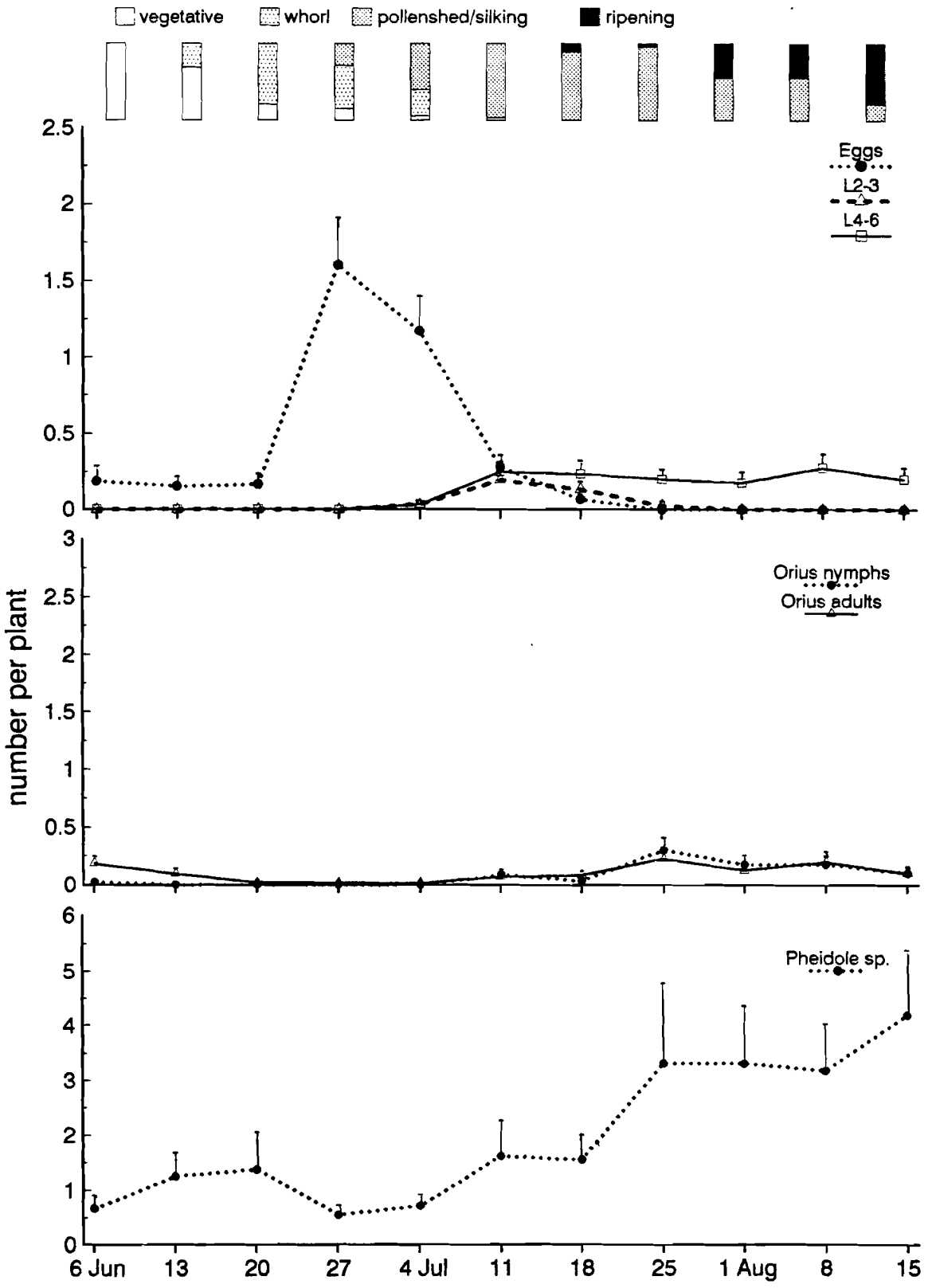

Figure 5.8. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Kakamega. VII. Maize, long rains 1990.

Table 5.4. Partial lifetables for *H. armigera* eggs and larvae on maize, Kakamega.

short rains 1988/89

x	d_xF	l_x	d_x	$100\,q_x$
Eggs[1]		11.68		
	failed to hatch		0.00	0.0
	parasitism		0.00	0.0
	unknown		11.30	96.8
L2-3		0.38		
	parasitism/pathogens		0.00	0.0
	unknown		0.21	56.4
L4-6		0.16		
	parasitism		0.00	0.0
	total mortality			98.6

short rains 1989/90

x	d_xF	l_x	d_x	$100\,q_x$
Eggs[1]		0.0		
L2-3		0.0		
L4-6		0.0		

long rains 1989

x	d_xF	l_x	d_x	$100\,q_x$
Eggs[1]		10.52		
	failed to hatch		0.79	7.5
	parasitism		1.04	9.9
	unknown		7.93	75.4
L2-3		1.55		
	parasitism/pathogens		0.17	11.0
	unknown		1.00	64.9
L4-6		0.37		
	parasitism		0.00	0.0
	total mortality			96.5

long rains 1990

x	d_xF	l_x	d_x	$100\,q_x$
Eggs[1]		24.69		
	failed to hatch		0.22	0.9
	parasitism		4.15	16.8
	unknown		20.09	81.4
L2-3		0.46		
	parasitism/pathogens		0.07	15.1
	unknown		-0.14	-30.4
L4-6		0.52		
	parasitism		0.00	0.0
	total mortality			97.9

[1] Corrected recruitment estimate Nd (see text).

III. Sorghum
Figures 5.9-5.11 show populations of *H. armigera* and dominant predators on sorghum, during three seasons. Table 5.5 shows the partial life-tables of *H. armigera* eggs and larvae.

As for the previous two crops, only one generation developed on sorghum. The oviposition peak was usually distinct, starting immediately after the whorl had opened, and ending as the production of pollen ceased. There is a large variation in stage-specific mortality between the seasons, which is most obvious in the first two seasons; during the short rains of 1988/89, mortality of young stages was very high (98.4 %), while negligible mortality was observed during the long rains of 1989. This difference may be due to anthocorid predators which were abundant in the first case, but rare in the second case. The relationship between the average densities of predators during the season, and the stage-specific mortality during the season is shown in Section 17. Further, on sorghum, anthocorid adults and nymphs are found mostly in the same microhabitat as *H. armigera* eggs and larvae, as shown in the previous section, which makes them potentially important predators.

Conclusion

This study has shown that the life-tables of *H. armigera* depend on the crop it is feeding on. In Table 5.6, recruitment and mortality estimates of *H. armigera* stages are averaged over the four seasons. Clearly, egg recruitment is highest on sunflower, although the egg recruitment on sorghum might be underestimated relative to that of the other crops, because of difficulties spotting the eggs in the complex panicle structure.

Table 5.6 shows that total survival is lowest on maize, where only 2.2 % of the eggs survive until the L4-6 stage, and survival is highest on sunflower with 8.1 %. The stage-specific survival levels are also very different from one crop to the other. Most obvious is the low survival of young stages of *H. armigera* on maize, as discussed above. Survival of older stages is lowest on sorghum.

Anthocorids and ants are the most prominent predator groups. Their role in reducing *H. armigera* densities may be considerable, and the data presented in this section indicate links between the occurrence of predators and mortality. The impact of these predator groups on *H. armigera* was assessed in separate studies presented in later sections.

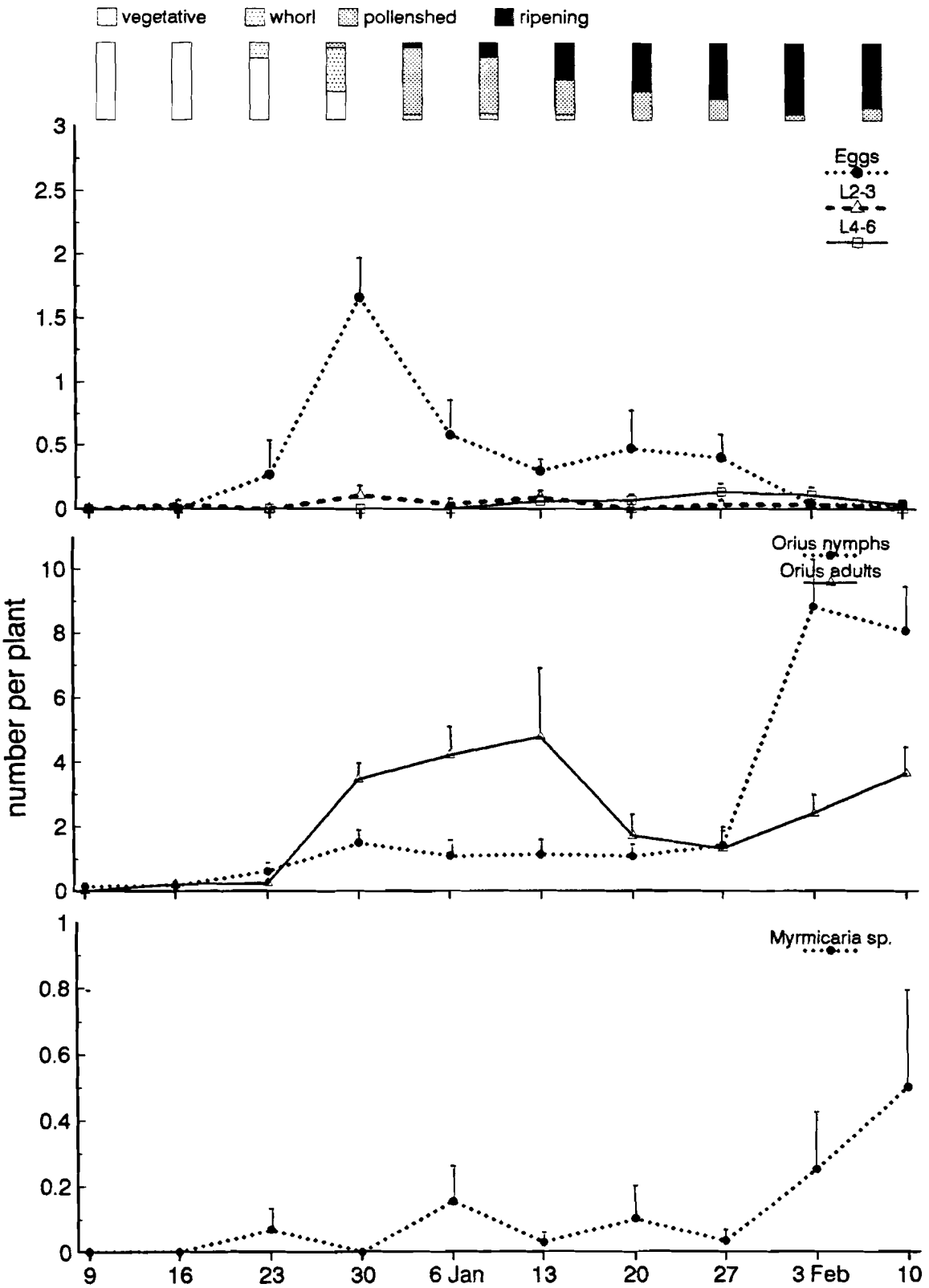

Figure 5.9. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Kakamega. VIII. Sorghum, short rains 1988-89.

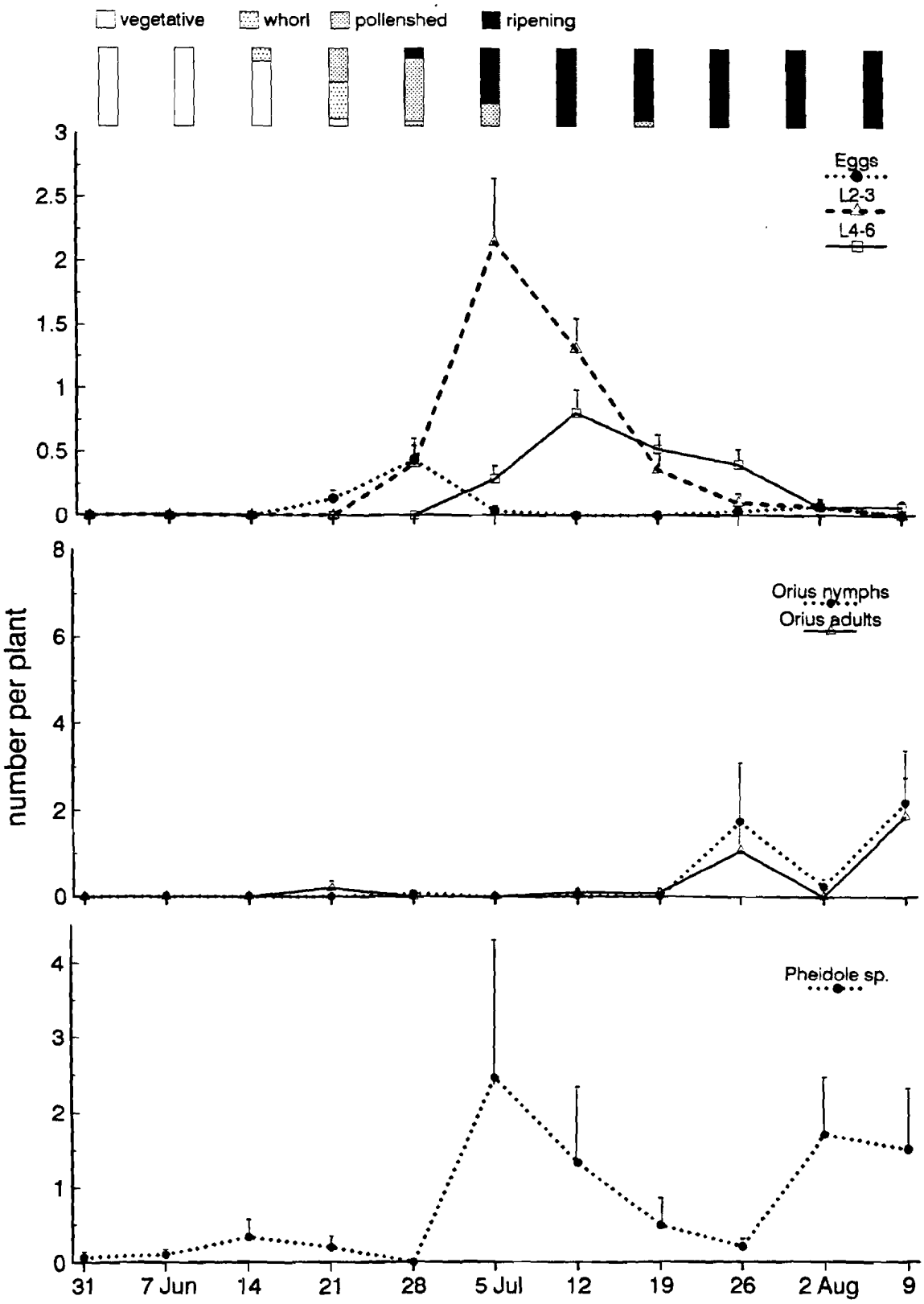

Figure 5.10. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Kakamega. IX. Sorghum, long rains 1989.

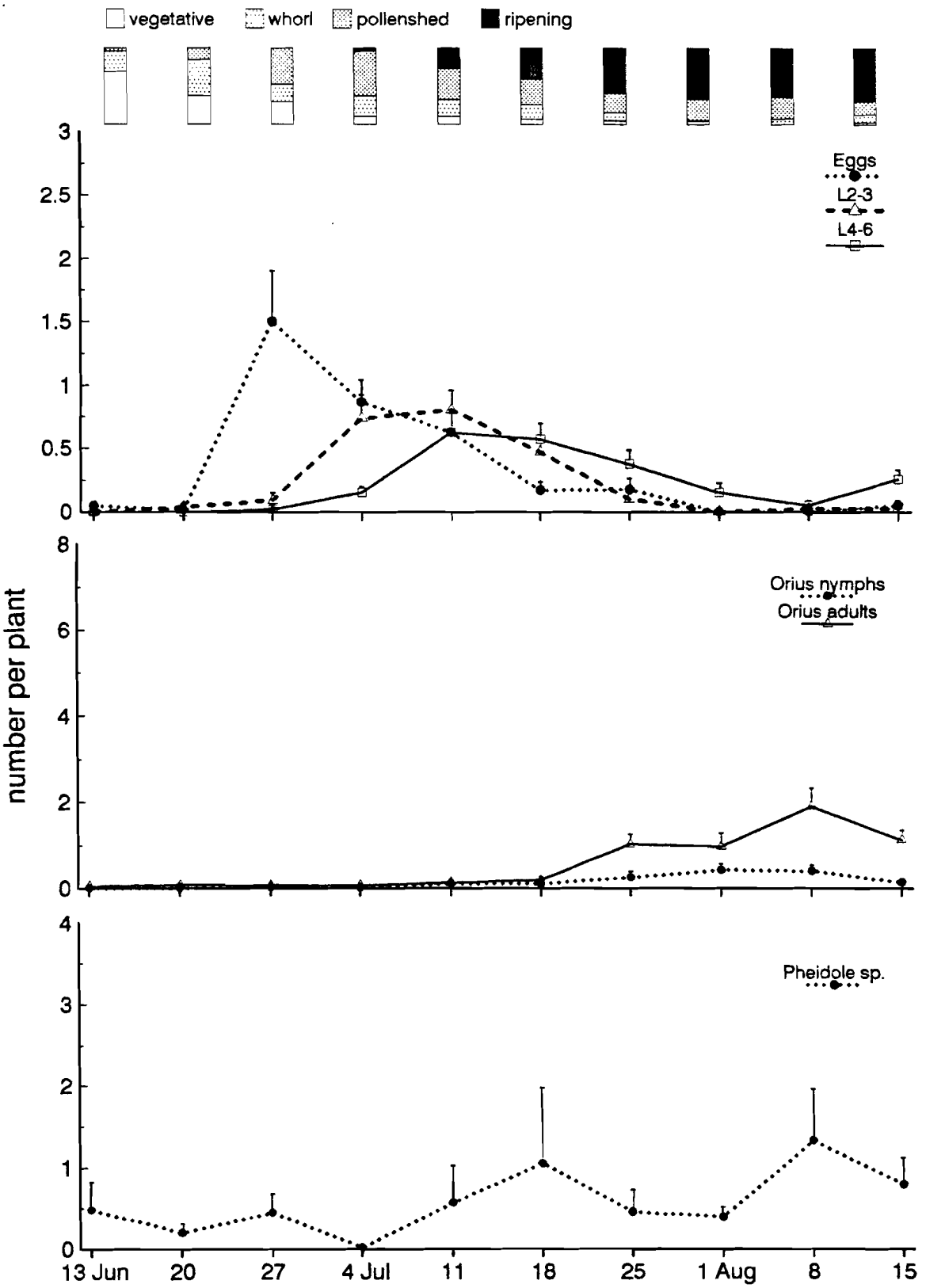

Figure 5.11. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Kakamega. X. Sorghum, long rains 1990.

Table 5.5. Partial lifetables for *H. armigera* eggs and larvae on sorghum, Kakamega.

short rains 1988/89

x	d_xF	l_x	d_x	$100\,q_x$
Eggs[1]		25.98		
	failed to hatch		0.00	0.0
	parasitism		1.90	7.3
	unknown		23.66	91.1
L2-3		0.42		
	parasitism/pathogens		0.00	0.0
	unknown		0.24	55.4
L4-6		0.19		
	parasitism		0.00	0.0
	total mortality			99.3

short rains 1989/90

x	d_xF	l_x	d_x	$100\,q_x$
Eggs[1]		0.0		
L2-3		0.0		
L4-6		0.0		

long rains 1989

x	d_xF	l_x	d_x	$100\,q_x$
Eggs[1]		4.91		
	failed to hatch		0.00	0.0
	parasitism		0.00	0.0
	unknown		0.06	1.1
L2-3		4.85		
	parasitism/pathogens		0.99	20.4
	unknown		2.98	61.5
L4-6		0.88		
	parasitism		0.01	1.2
	total mortality			82.3

long rains 1990

x	d_xF	l_x	d_x	$100\,q_x$
Eggs[1]		23.91		
	failed to hatch		1.20	5.0
	parasitism		2.92	12.2
	unknown		18.30	76.5
L2-3		2.69		
	parasitism/pathogens		0.08	2.9
	unknown		1.74	64.9
L4-6		0.87		
	parasitism		0.14	16.1
	total mortality			96.9

[1] Corrected recruitment estimate Nd (see text).

Table 5.6. Recruitment and survival estimates averaged over the four sampled seasons. Kakamega, 1988-90.

	l_x	% survival
SUNFLOWER		
Eggs	24.8	20.7
L2-3	5.1	39.1
L4-6	2.0	
total survival		8.1
MAIZE		
Eggs	11.7	5.1
L2-3	0.6	43.3
L4-6	0.3	
total survival		2.2
SORGHUM		
Eggs	13.7	14.5
L2-3	2.0	24.6
L4-6	0.5	
total survival		3.5

6. Natural mortality of *Helicoverpa armigera* on smallholder crops in Kibos, Nyanza Province, Kenya.

Introduction

In this study, the population ecology of *H. armigera* and its natural enemies was followed on three crops at Kibos, in much the same way as it was done in the previous section at Kakamega. Kibos is situated in the Lake Victoria Basin, near Kisumu town, on black cotton soil. The climate in this area is different from that in Kakamega, in that temperatures are higher, there is less rain, and there is a long dry season. Crops included for this study are cotton, maize and sorghum.

Materials and methods

Experimental field site
The study site was at KARI's Cotton Research Sub-centre, Kibos, Nyanza Province. The study was conducted in the long rains of 1989 and 1990. Because the short rains in the lake basin are erratic, few farmers plant during this season.

Mono-crop plots of cotton, maize and sorghum were grown in 4 replicates within 0.4 ha field plot. Individual plot sizes were calculated such that at most 10% of the plants would be sampled (i.e. destructively) by the end of the season (for cotton 26x18 m, maize 18x18 m, sorghum 15x18 m). After the 1989 crop, the plot was moved to a site 150 m away. Thus, some factors might have changed after the first season. Varieties and spacings are given in Annex 5.

Meteorological data were obtained from the nearby Kisumu airport. Average temperature values were calculated from daily min.-max. values (Figure 6.1).

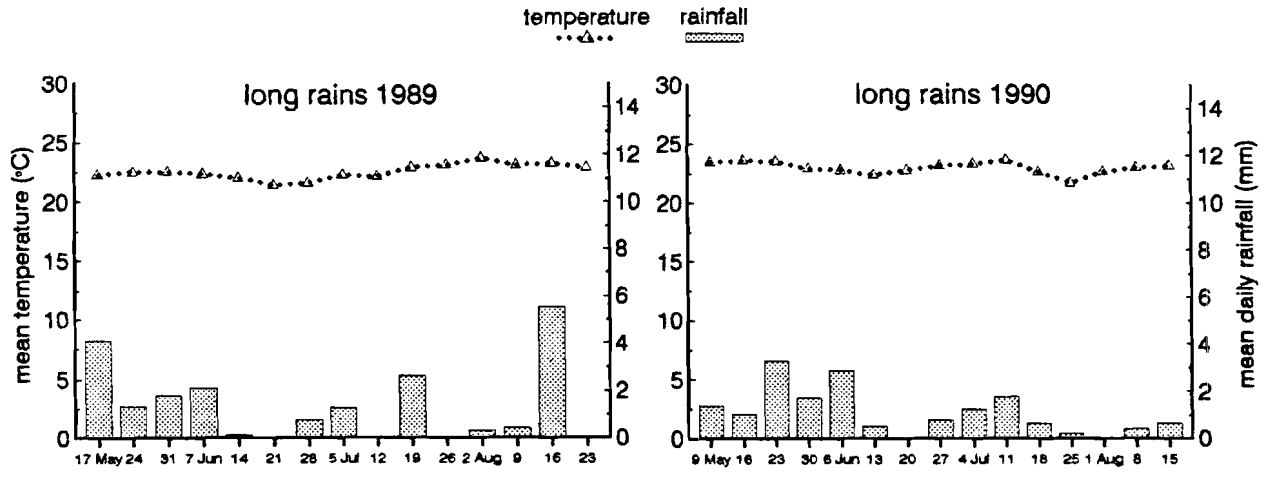

Figure 6.1. Mean temperature and mean daily rainfall during the two sample seasons, Kibos.

Sampling methods
Sampling was conducted weekly from monday to friday, during the morning hours (7.30-11.00 a.m.). The same procedure was followed as described in Section 2.2.

Results and Discussion

1989
During the long rains of 1989, *H. armigera* infestation levels were very low on maize and sorghum (Figures 6.4, 6.6). A low oviposition peak during the early pollen shed of the cereals gave rise to even lower larval levels later on, indicating a considerable mortality. On cotton (Figure 6.2), an early oviposition peak at the end of May gave rise to a moderate level of larvae (1 per plant) on the young crop. Although oviposition continued until the end of July, with a small peak at July 26, eggs laid from the end of May onwards did not give rise to many larvae. This indicates that mortality was relatively low during the first three sampling weeks, but was much higher later on.

Predominant predators on the three crops were anthocorids, and *Myrmicaria*, *Camponotus* and *Pheidole* ants. Less common predators were coccinellids, chrysopids and spiders.

Adult anthocorids colonised the three crops and increased in numbers reaching about three adults per plant on cotton. Figure 6.2 shows the very high reproductive potential of anthocorids; nymph levels started building up strongly to reach densities of 17, 10 and 12 per plant on cotton, maize and sorghum, respectively. Anthocorids may be an important factor causing mortality *H. armigera* eggs. In the beginning of the season when anthocorid densities were low, egg survival was high. Later in the season anthocorid densities increased and egg survival decreased. However, besides the predatory potential of anthocorids, there is evidence that factors involving host plant quality may have a major impact on egg survival, as discussed in Sections 11 and 13.

Ants were quite common, especially on cotton.

Figure 6.8 shows the healthy and damaged fruiting plant parts of cotton. Squares increased in numbers from the onset of sampling, followed by flowers and bolls later on. Note that these density estimates are not indicative of total numbers produced per plant, but depend on how fast a fruiting part will develop into the next stage. For example, flowers are a short-lived stage that quickly develop into bolls. Consequently, the density of flowers will be lower than that of bolls. About 25% of the bolls were damaged by *H. armigera*, which is high considering the low infestation levels of *H. armigera*. With an average density of approx. 0.3 larvae per plant, as many as five bolls were attacked per plant. In the Lake Basin area, *H. armigera* levels can be much higher than this, and therefore a higher level of damage is to be anticipated.

1990
During the long rains of 1990, *H. armigera* infestation levels were even lower than in 1989. On maize and sorghum, *H. armigera* was virtually absent (Figures 6.5, 6.7). On cotton (Figure 6.3), two egg peaks were observed, suggesting two generations. However, egg mortality from eggs to L2-3 was extremely high. Anthocorid adult levels on cotton were similar to those in the preceding year, but nymph levels did not build up as in 1989. In contrast to cotton, anthocorid levels on maize and sorghum were very low. Maize and sorghum were obviously suffering from lack of rain, and this has likely affected their attraction for anthocorids, and ovipositing *H. armigera* moths alike. The levels of the ant species were very similar to those of 1989.

Figure 6.9 shows the healthy and damaged fruiting plant parts of cotton in 1990. Although the numbers of squares were similar to the results of the preceding season, the cotton plants produced only few bolls. This was not due to *H. armigera* attack, because damage was almost nil. This is not surprising since larval levels were very low. The low production of bolls may be explained by the lack of rains during the season (see Figure 6.1 for climate data).

Conclusion

At Kibos, *H. armigera* infestation levels during the seasons studied were lower than normal for the area. There was some *H. armigera* damage on cotton in 1989, but little in 1990. Damage is largely caused by the first generation of *H. armigera* in the young crop. Later on, *H. armigera* is kept in check, probably by the combined impact of predation and host plant quality.

Ovipositing *H. armigera* moths preferred cotton to maize or sorghum. This limits the prospects of using the latter crops as trap crops in cotton production. On the other hand, at our sites East of the Rift Valley, *H. armigera* moths seemed to prefer maize (var. Coast Composite and Katumani) to the other crops. This difference may be related to the variety of maize.

On cotton, it seems that the first generation of *H. armigera* escapes from predation because anthocorids have not yet colonised the crop. Measures involving an early attraction of anthocorid adults and an increased build-up of nymph levels on young cotton fields could improve control of *H. armigera* in the young crop, and thus reduce damage, but require further study (see Priority Tasks for Follow-up).

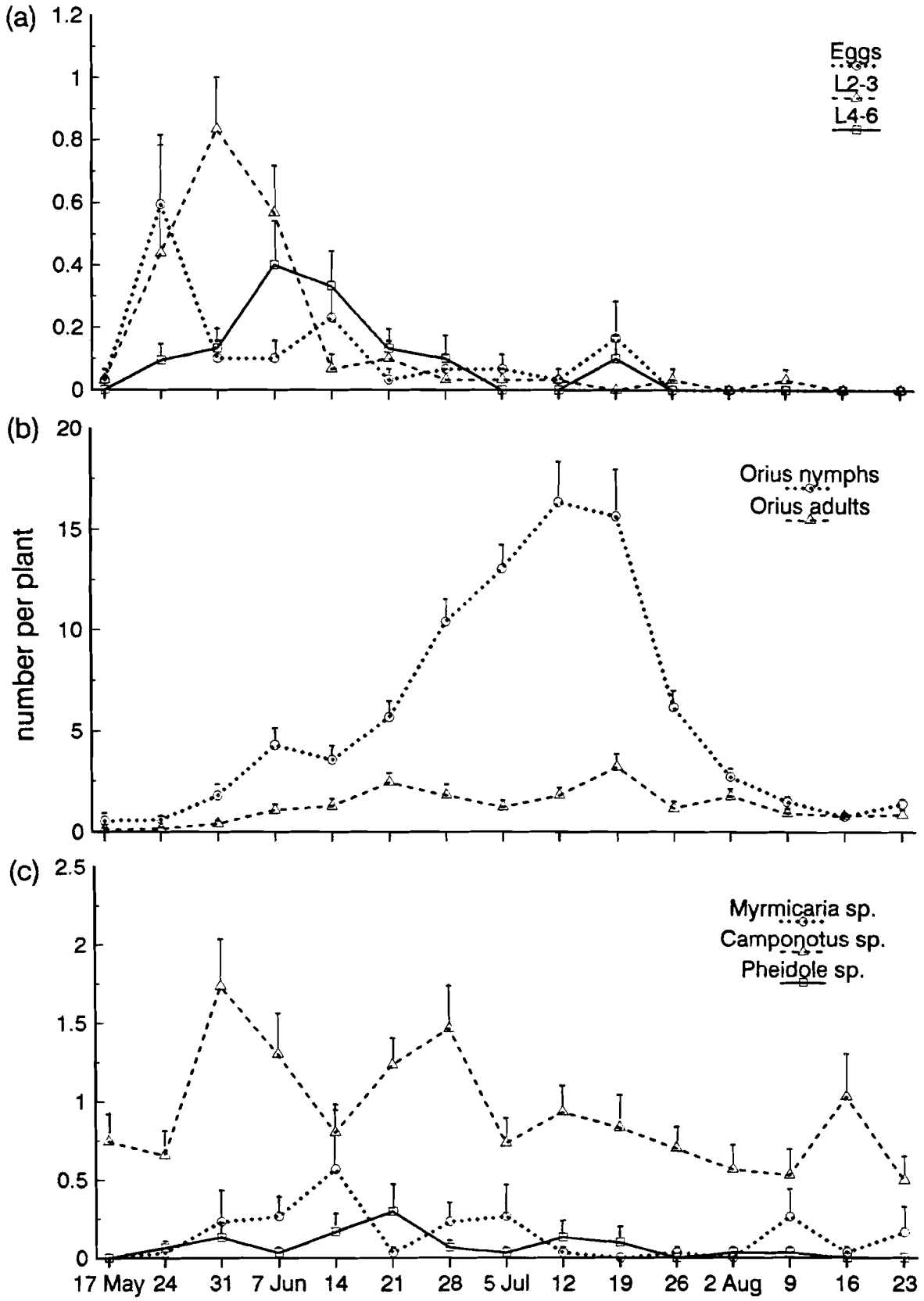

Figure 6.2. Seasonal population densities of *H. armigera* stages and their predators at Kibos. I. Cotton, long rains 1989.

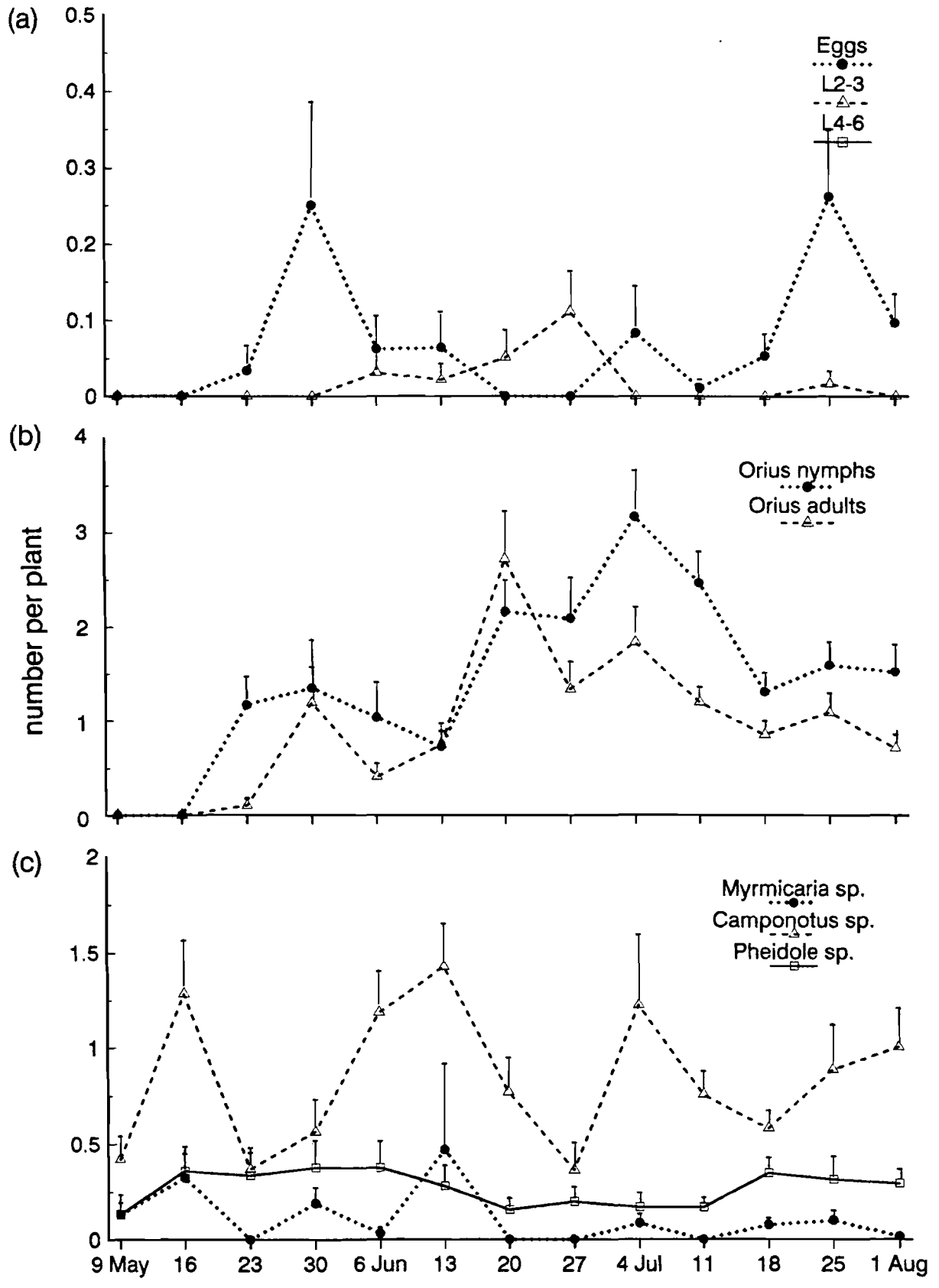

Figure 6.3. Seasonal population densities of *H. armigera* stages and their predators at Kibos. II. Cotton, long rains 1990.

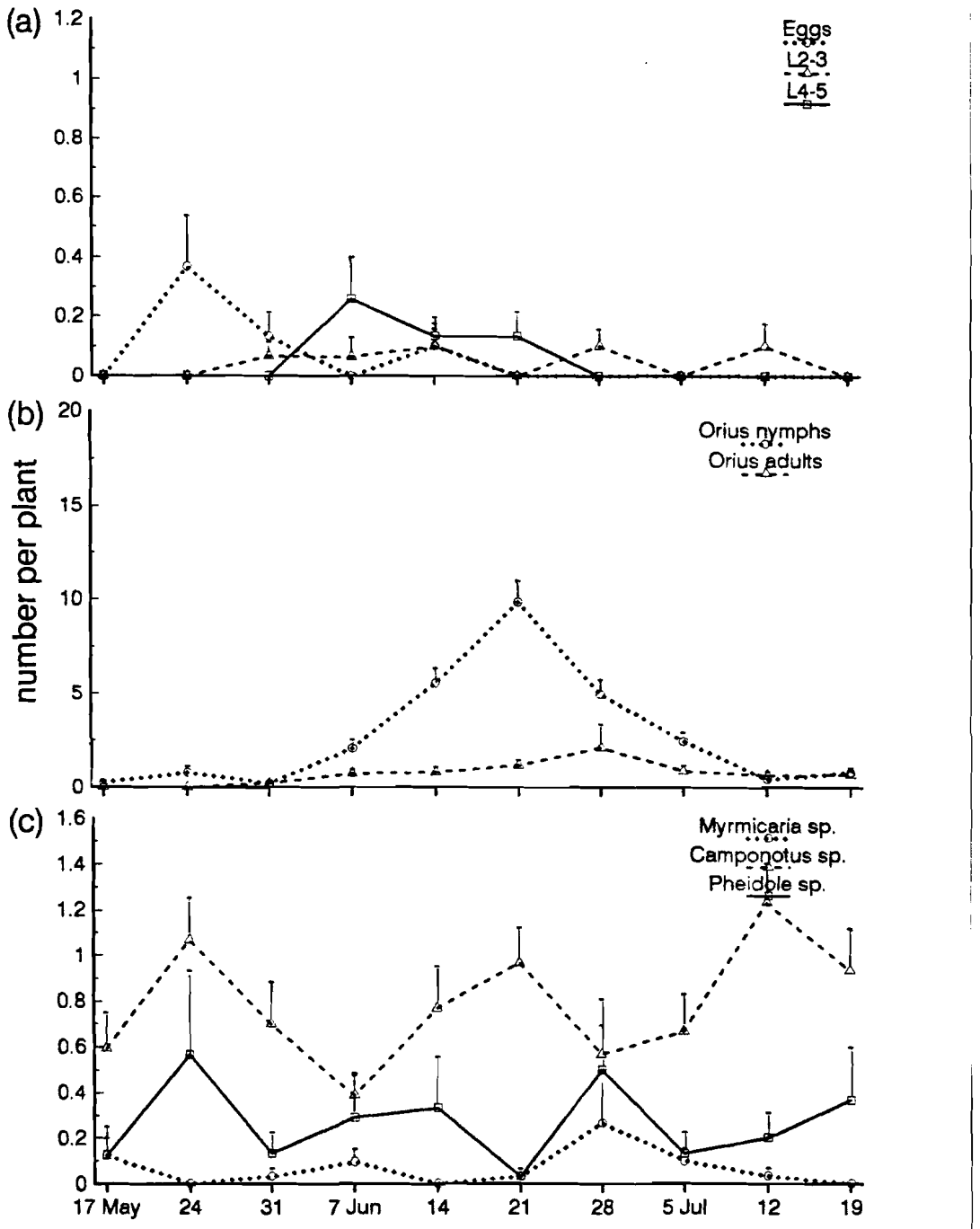

Figure 6.4. Seasonal population densities of *H. armigera* stages and their predators at Kibos. III. Maize, long rains 1989.

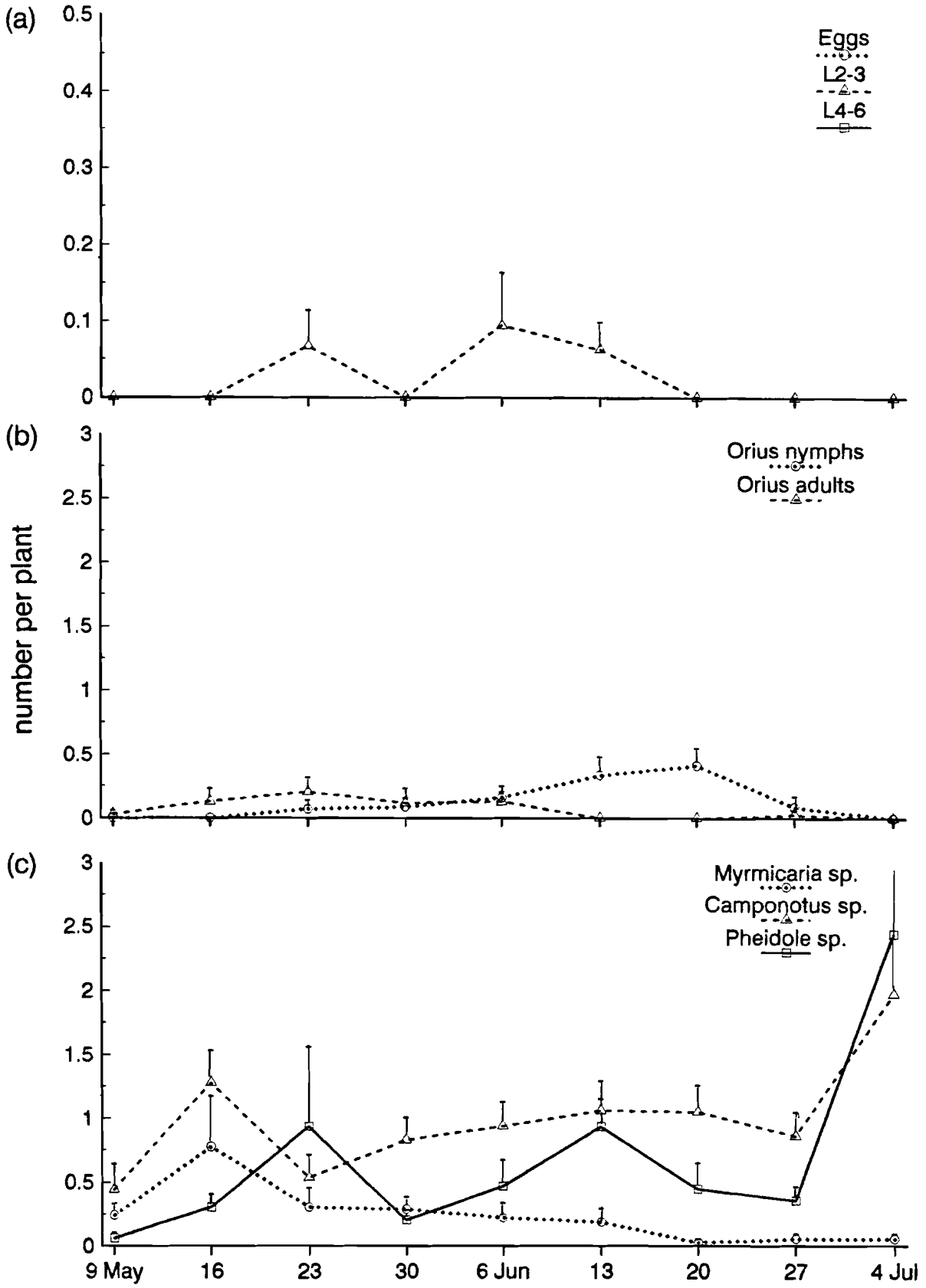

Figure 6.5. Seasonal population densities of *H. armigera* stages and their predators at Kibos. IV. Maize, long rains 1990.

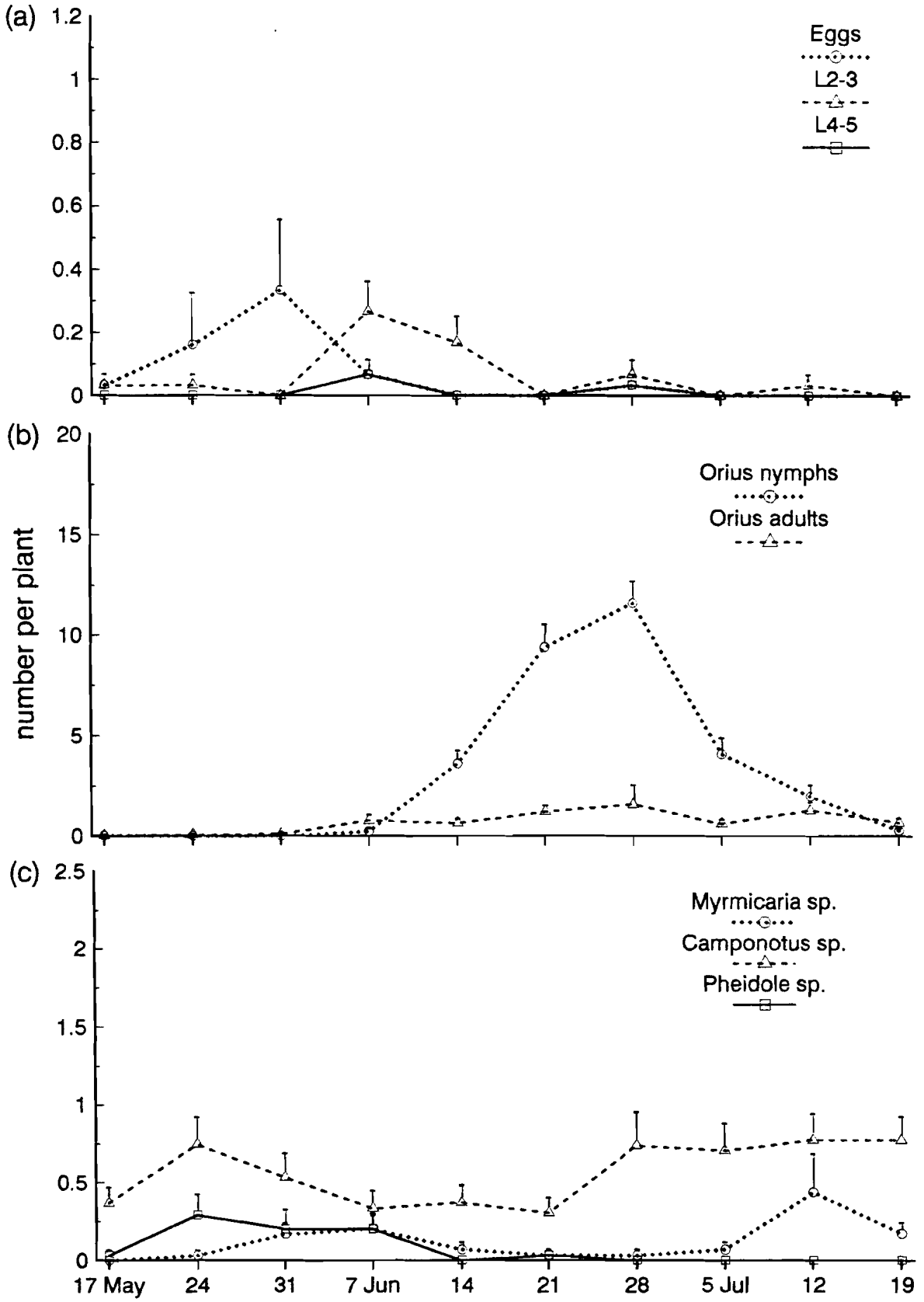

Figure 6.6. Seasonal population densities of *H. armigera* stages and their predators at Kibos. V. Sorghum, long rains 1989.

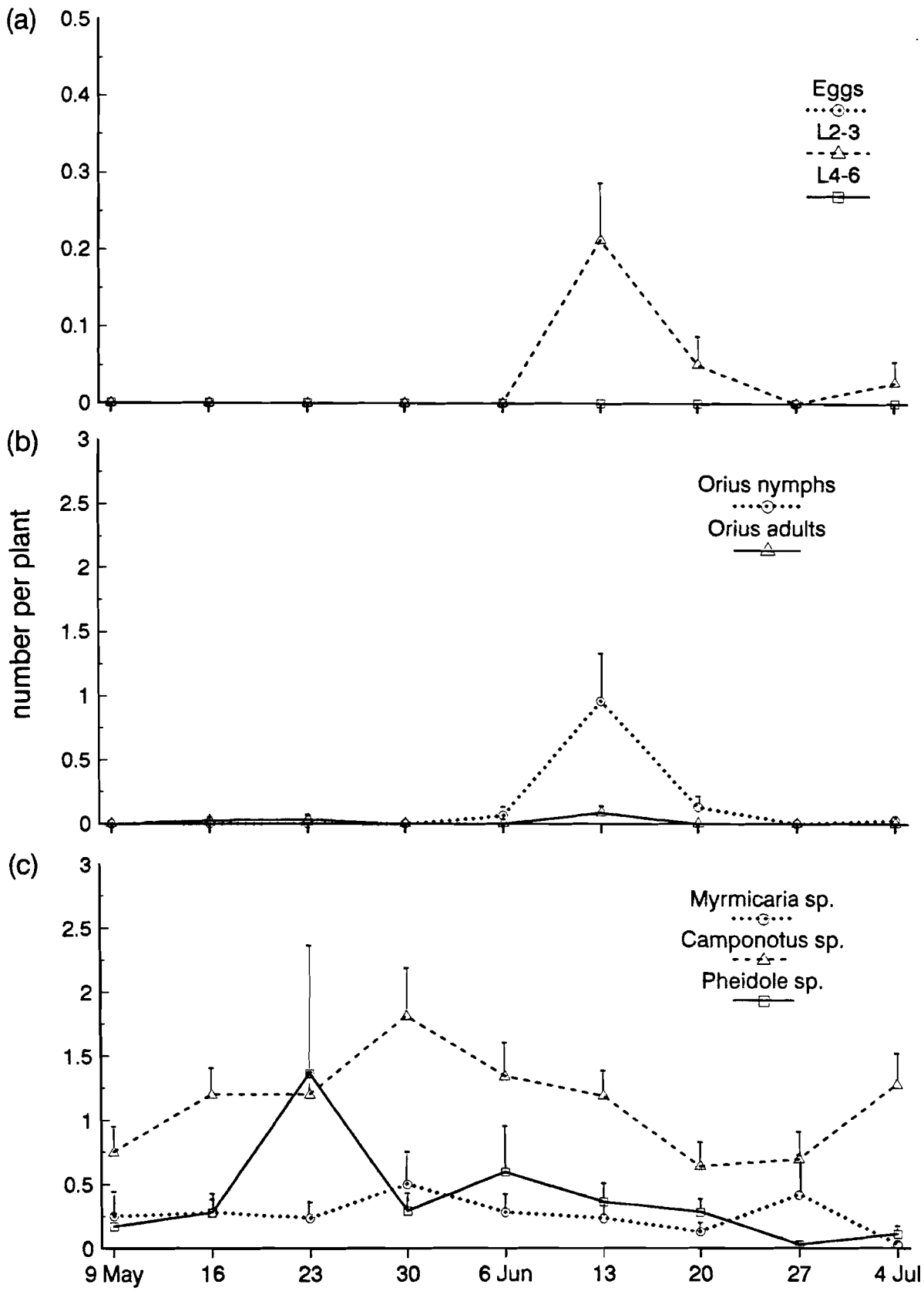

Figure 6.7. Seasonal population densities of *H. armigera* stages and their predators at Kibos. VI. Sorghum, long rains 1990.

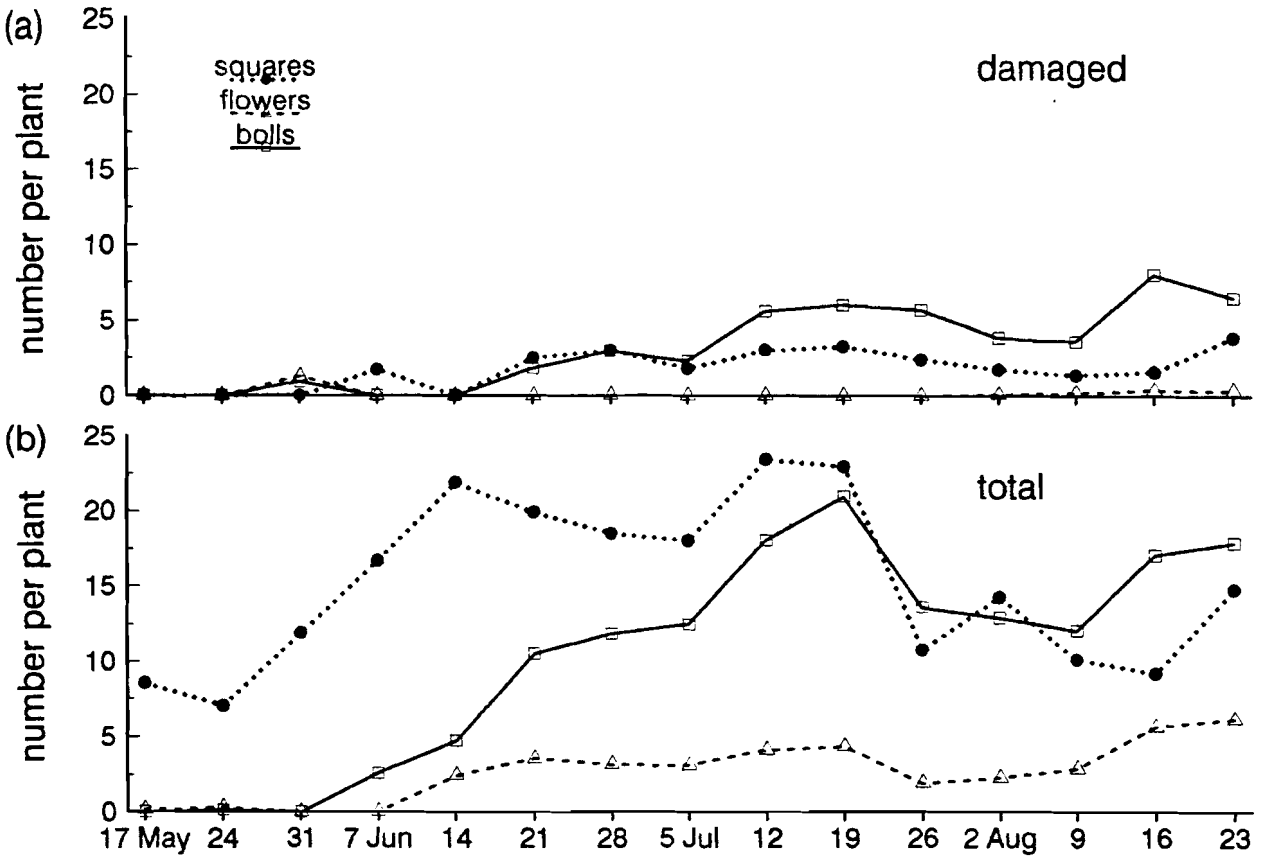

Figure 6.8. Seasonal availability of fruiting plant parts of cotton, Kibos, 1989. (a) plant parts damaged by *H. armigera*; (b) total plant parts.

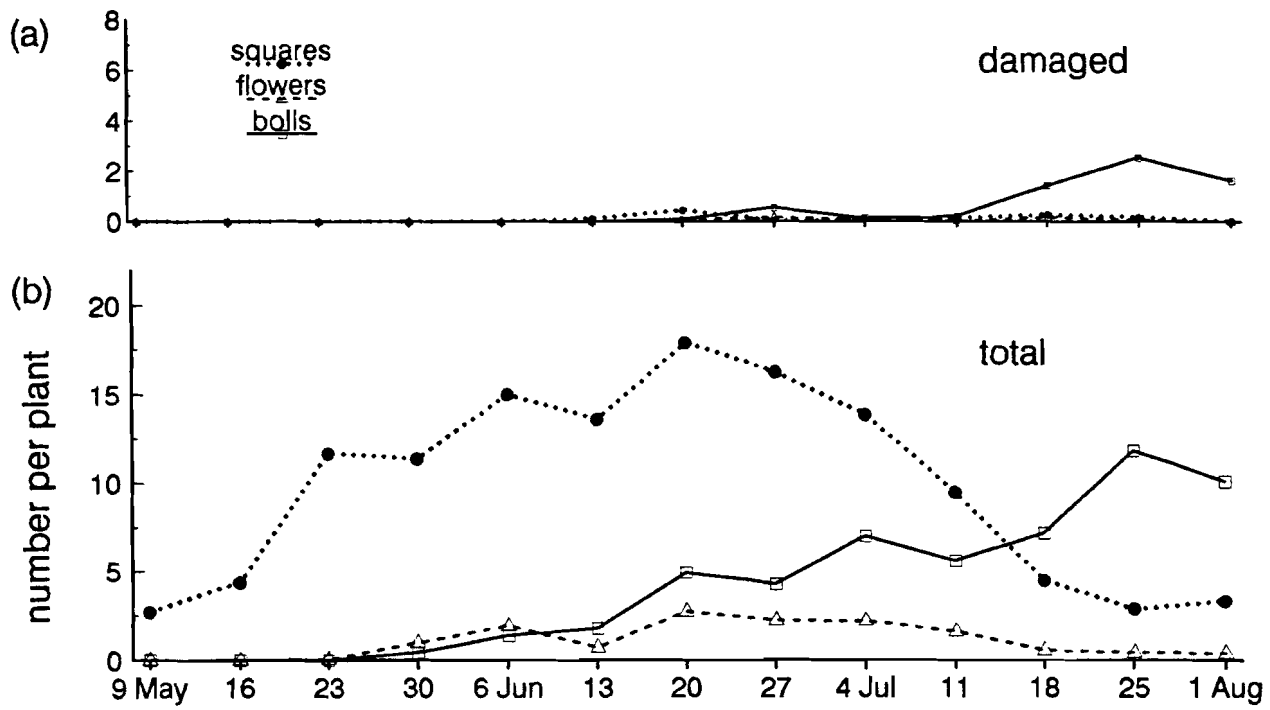

Figure 6.9. Seasonal availability of fruiting plant parts of cotton, Kibos 1990. (a) plant parts damaged by *H. armigera*, (b) total plant parts.

7. Natural mortality of *Helicoverpa armigera* on smallholder crops in Mwea Tebere, Central Province, Kenya

Introduction

This study parallels that described in the last Section for Kibos. The population ecology of *H. armigera* and its natural enemies was monitored over four growing seasons: 1988-1989 short rains (season 1), 1989 long rains (season 2), 1989-1990 short rains (season 3) and 1990 long rains (season 4).

Materials and methods

Experimental field site

The study site was at KARI's Mwea Tebere National Fibre Research Centre (NFRC) (Section 2.1), using the same plots as those used for observations of micro-habitat selection (Section 4).

Sampling was carried out every three weeks for the first season and weekly for the subsequent seasons. Twenty randomly chosen plants of each crop, split between the three replicates, were sampled as described in Section 2.2.

To sample ground dwelling natural enemies, pitfall traps were used as described and presented in Section 10.

Meteorological data were obtained from records collected by KARI staff at Mwea Tebere NFRC.

Results

In general *H. armigera* incidence at this site was low; only occasionally did the number of eggs recorded exceed 2 per plant. The incidence of the common predators, *Orius* spp., *Pheidole* sp. and *Acantholepis* sp., fluctuated widely between crops and seasons.

Other predators which were observed frequently during sampling included a staphylinid, *Paederus* sp., and coccinellids, *Cheilomenes lunata* and *Cheilomenes sulphurea*.

Maize

The incidence of different stages of *H. armigera* and its natural enemies on maize is given in Figures 7.1-7.4 for seasons 1-4 respectively.

In season 1 (short rains 1988-89) a peak of 2.5 eggs/plant are laid (Figure 7.1); there is little mortality in the young larval stages, but high mortality in the late larval stages. *Orius* numbers are low, peaking with the young larvae of *H. armigera*. *Pheidole* sp. increases through the season, becoming common by the time the larvae of *H. armigera* are too large to be at risk from this small ant.

In season 2 (long rains 1989) there is a single small peak of oviposition by *H. armigera* in late May (Figure 7.2); this is followed by high mortality of young larvae. The frequency of *Orius* spp. starts to build up with the *H. armigera* oviposition peak, and continues while the young *H. armigera* larvae are present. Adult *Orius* spp. and *Pheidole* sp. are not common until late in the season.

The incidence of *H. armigera* in season 3 (short rains 1989-90) (Figure 7.3) is similar to that noted a year earlier in season 1. The build up of *Orius* spp. and *Pheidole* sp. doesn't come until most *H. armigera* larvae are too large to be at risk.

Season 4 (long rains 1990) (Figure 7.4) differs from that found previously. Only very small numbers of *H. armigera* eggs are laid, and there is high mortality of the larvae, such that by half way through the season *H. armigera* ceases to be recorded. *Orius* spp. are more common than in the earlier seasons, and are present from an early stage of the crop. *Acantholepis* sp. (Ant 5) is common on the crop from early in the season, but *Pheidole* sp. doesn't start to build up in numbers until later in the season.

Maize-bean intercrop

A maize-bean intercrop plot was included in the experimental design for season 3 (short rains 1989-90). The beans matured after one month, and thereafter the plots were similar in structure to those of the maize monocrop. There were no significant differences in the populations of *H. armigera* and predators between the intercrop and monocrop plots. However, this is an area which merits further investigation. The benefits of intercropping are sometimes suggested to be mediated through natural enemies, but there is no good experimental demonstration of such an effect.

Sunflower

The results from the four seasons are presented in Figures 7.5-7.8 for seasons 1-4 respectively.

Season 1 (Figure 7.5) shows an early small peak of oviposition followed by high mortality of the larvae. The populations of *Orius* spp. and *Pheidole* sp. populations do not build up until too late in the season to be useful.

In season 2 (Figure 7.6) an extended period of low level oviposition leads to small populations of larvae. The build up in numbers by *Orius* spp. and *Pheidole* sp. coincides with the middle of the egg-laying.

H. armigera populations are higher in season 3 (Figure 7.7) and this could be linked to the fact that neither predator group builds up in numbers until the end of the season, when they are abundant.

In the final season (Figure 7.8) oviposition by *H. armigera* is extremely low and sporadic. Predator populations increase in the middle of the season to high levels.

Cotton

The results from the cotton plots are given as Figures 7.9-7.12 for seasons 1-4 respectively.

Season 1 (Figure 7.9) is characterised by low numbers of *H. armigera*, and moderate numbers of natural enemies. Season 2 (Figure 7.10), is similar, except *Orius* spp. never get established on the cotton plants. In season 3 (Figure 7.11) the incidence of *H. armigera* is higher, but although *Pheidole* sp. is common, *Orius* spp. are absent until right at the end of the season.

Season 4 (Figure 7.12) shows initial low peaks of eggs and small larvae, but thereafter, numbers of *H. armigera* are very low. Numbers of *Pheidole* sp. are moderate except for a peak at the end of August, whereas *Orius* spp. are present in increasing numbers from the beginning of the season.

Bean

Bean matured very early and had a low incidence of *H. armigera* attack, so data collected from this crop was not analysed.

Parasitoids and pathogens

No pathogens were found and parasitism was very rare in all the seasons. The few incidences of parasitism involved the egg parasitoids *Trichogrammatoidea* spp. and *Telenomus ullyetti* and the larval parasitoids *Charops* sp. and *Linnaemya longirostris.*

Discussion

The population density of *H. armigera* was low during the vegetative phase of the crops but increased to a maximum just prior to or during the reproductive phase of the host plants. Incidence of *H. armigera* and the dominant predators is summarised in Table 7.1.

Table 7.1. Average numbers per plant per sampling occasion of *H. armigera* stages, the common predators, and their degree of temporal overlap. Data from Mwea Tebere for all seasons.

		H. armigera			*Orius* spp.		*Pheidole* sp.	
crop	season	egg	L1-3	L4-6	total	overlap[a]	total	overlap[a]
MAIZE	1	0.6	.76	.08	.09	x	1.5	x
	2	.2	.03	.04	.3	-	3.3	-
	3	.5	.6	.03	.2	-	4.7	-
	4	.1	.04	.01	.8	-	11.9	-[b]
SUNFLOWER	1	.2	.8	.2	1.4	-	9.5	-
	2	.02	.3	.08	1.8	x	5.8	x
	3	.3	1.1	.2	2.3	-	12.8	-
	4	.02	.02	.01	2.5	-	4.8	-
COTTON	1	.06	.2	.02	.8	x	2.8	x
	2	.0	.06	.05	.01	-	1.8	x
	3	.3	.8	.1	1.9	-	3.5	x
	4	.05	.05	.01	2.1	-	3.8	-

[a] a subjective estimate as to whether the predators were relatively common at the same time as the eggs and young larvae of *H. armigera*; - little overlap; x some overlap.

[b] but note *Acantholepis* sp. was common and overlapped with eggs and small larvae of *H. armigera*.

Maize had the most eggs in all the seasons, and the fewest larvae in all except one season, indicating the high mortality of eggs on this crop. Larval cannibalism of eggs and larvae has been shown to be a major mortality factor which regulates the population of *H. armigera* on maize (Twine

1971), but this mortality may also be attributed to the exposed position of the eggs on the upper leaf surfaces where they are liable to predation, or to be mechanically dislodged by rubbing of leaves, wind or rain. Sunflower always had the most larvae. Cotton generally had fewest eggs. *H. armigera* incidence was relatively high in the short rains (season 1 and 3) and low in the long rains (seasons 2 and 4); numbers were particularly low in the final season.

Orius spp. were generally quite common towards the end of the season, but mostly missed the peaks of *H. armigera* eggs and young larvae. The population of *Orius* spp. on maize was consistently lower than on the other crops. *Pheidole* sp. was always commoner than *Orius* spp. but except on cotton did not usually coincide with the peaks of *H. armigera* eggs and young larvae.

When the oviposition on each crop is plotted on a common time scale for each season (Figure 7.13), it can be seen that oviposition peaks earlier on maize, followed by sunflower (in season 3) and cotton. This reflects the developmental stage of the crops. However, the time when *H. armigera* larvae and natural enemies were most abundant was the same for all the crops.

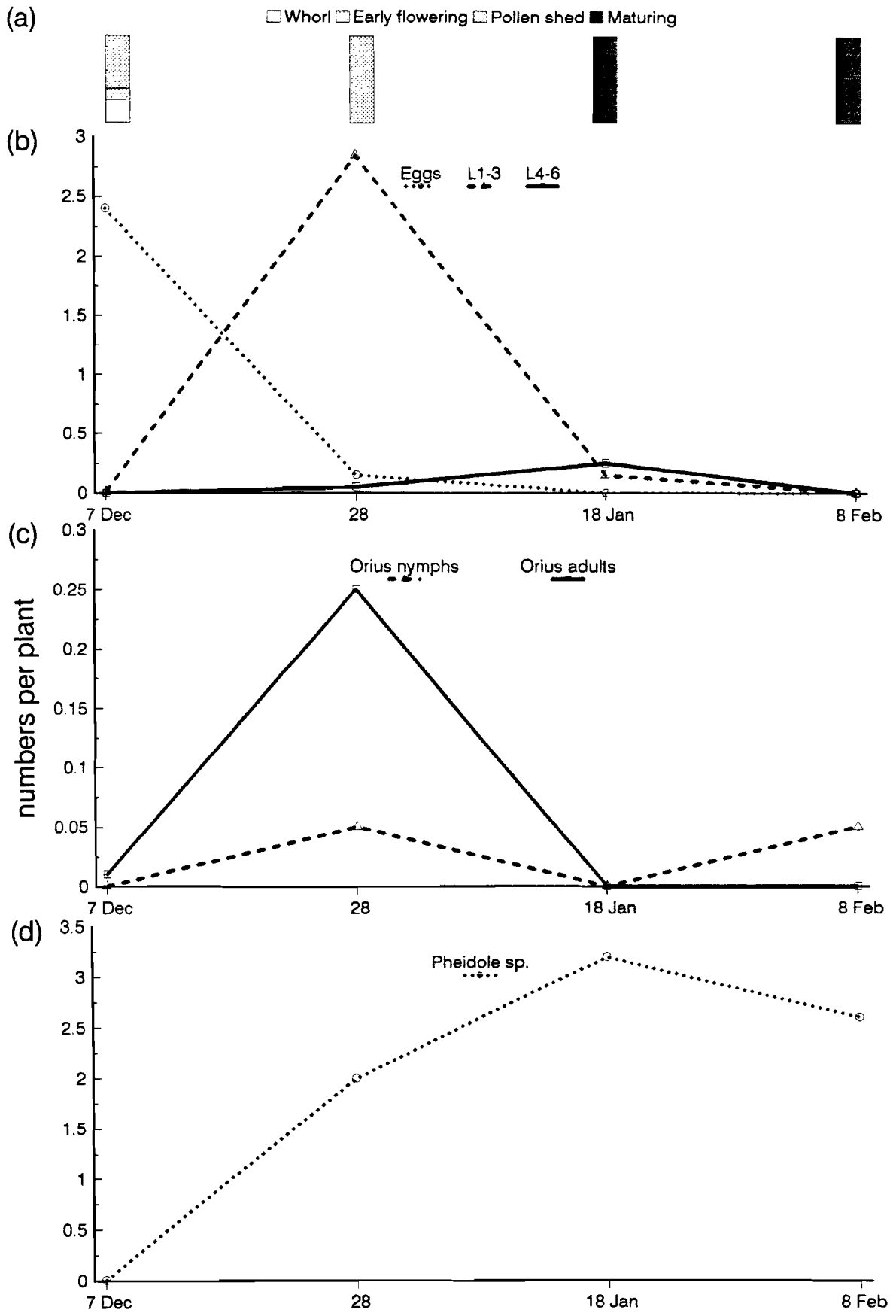

Figure 7.1. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Mwea Tebere. I. Maize, short rains 1988-89.

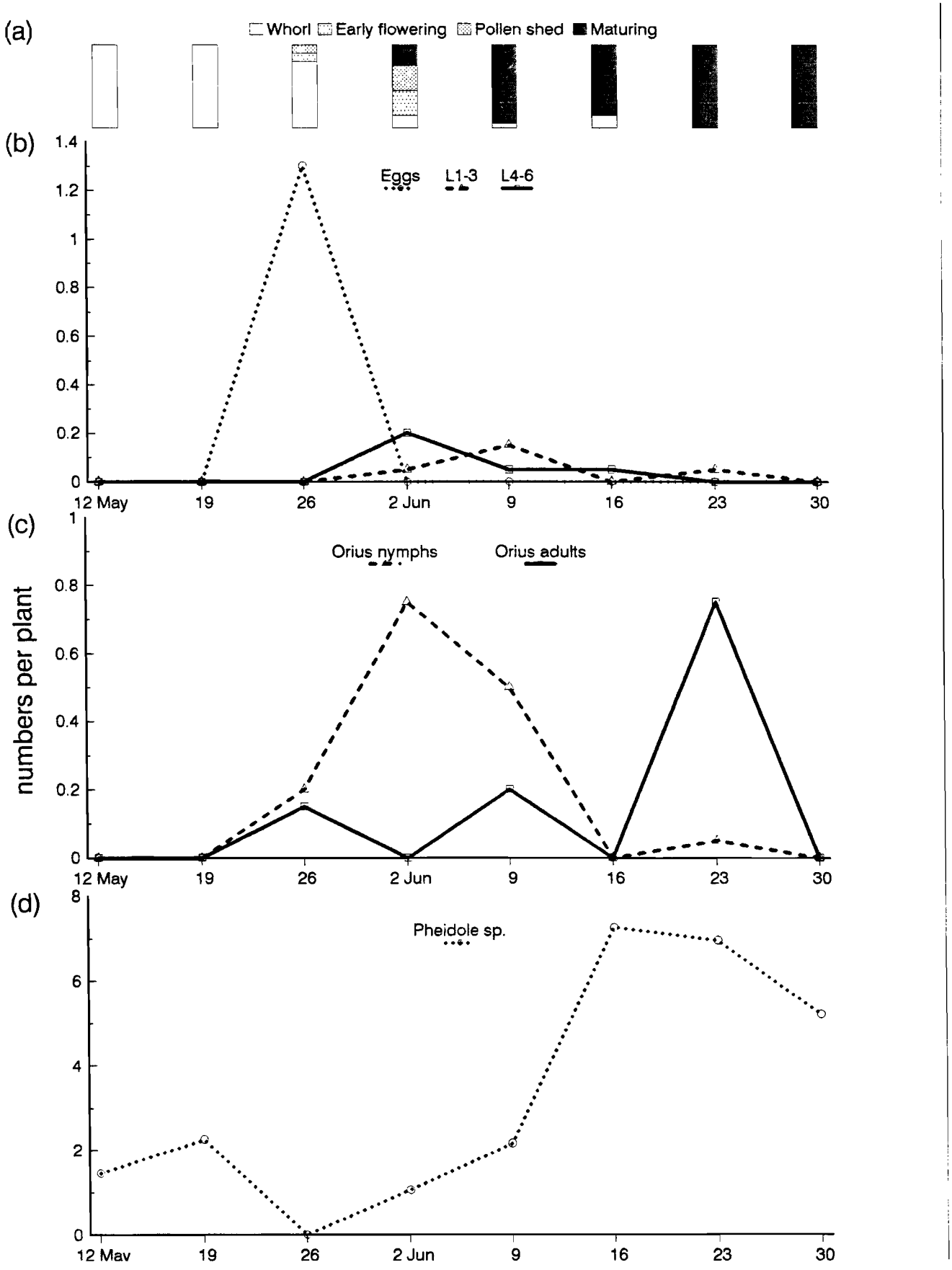

Figure 7.2. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Mwea Tebere. II. Maize, long rains 1989.

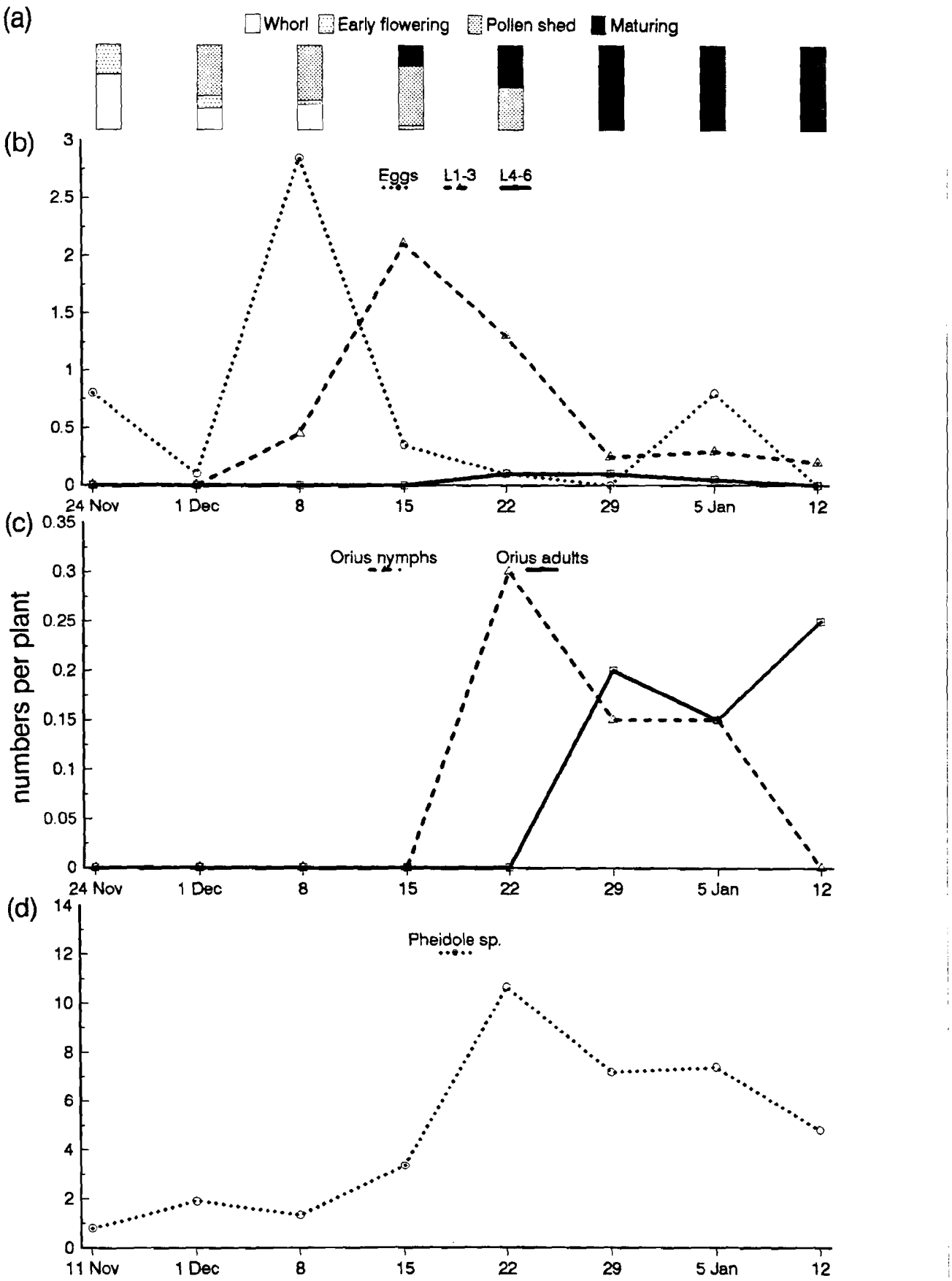

Figure 7.3. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Mwea Tebere. III. Maize, short rains 1989-90.

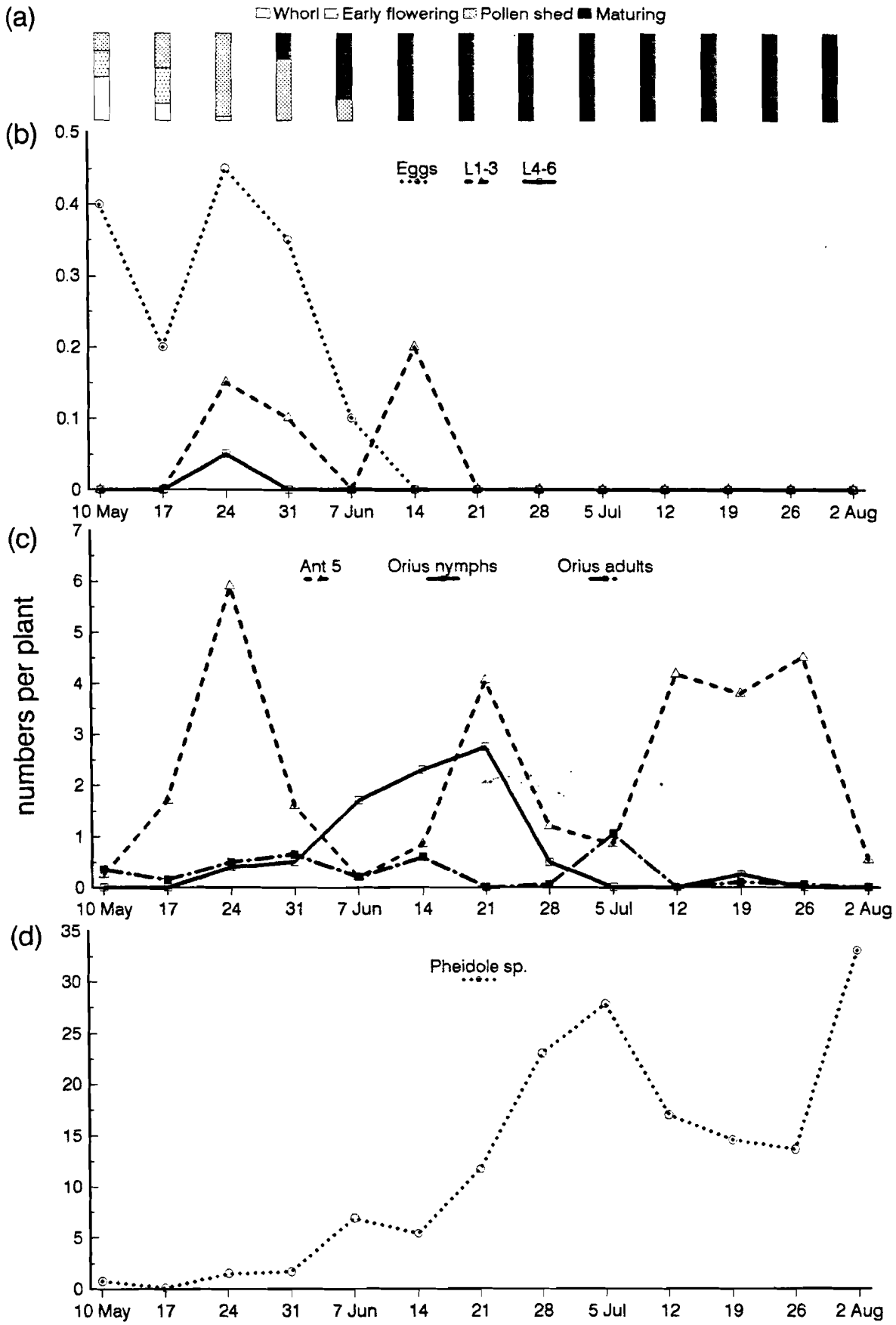

Figure 7.4. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Mwea Tebere. IV. Maize, long rains 1990. Note that "Ant 5" in (c) is *Acantholepis* sp.

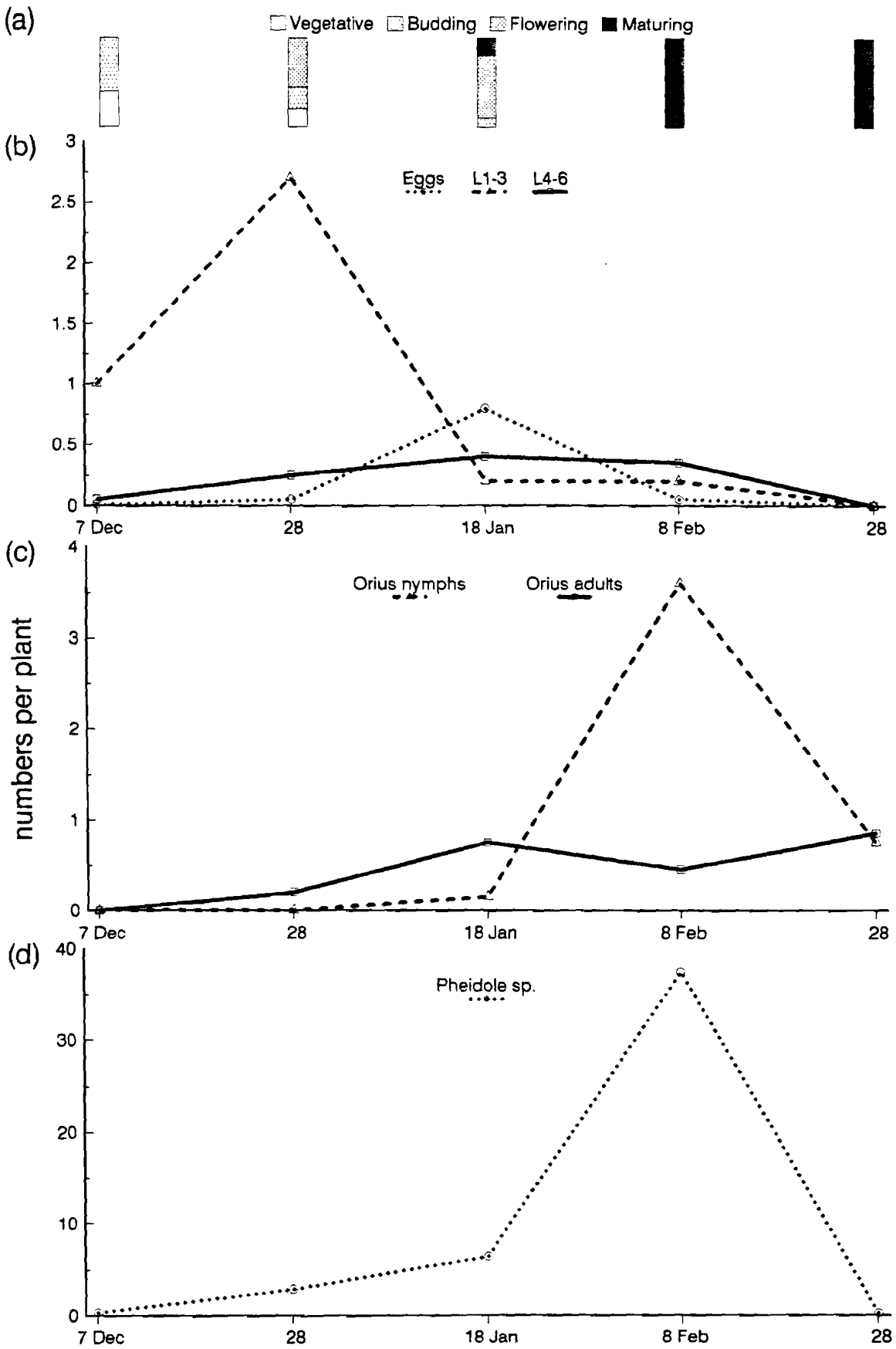

Figure 7.5. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Mwea Tebere. V. Sunflower, short rains 1988-89.

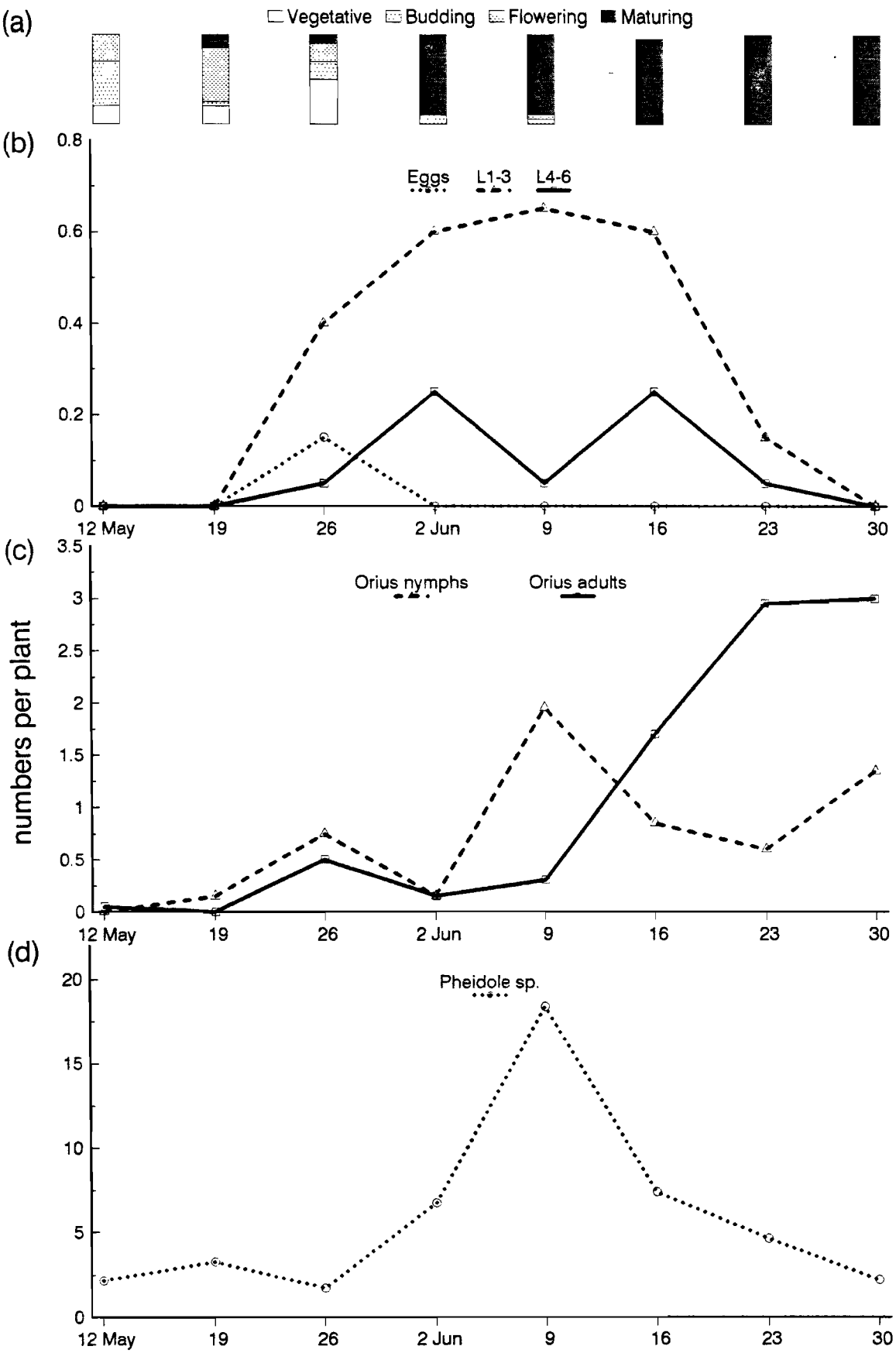

Figure 7.6. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Mwea Tebere. VI. Sunflower, long rains 1989.

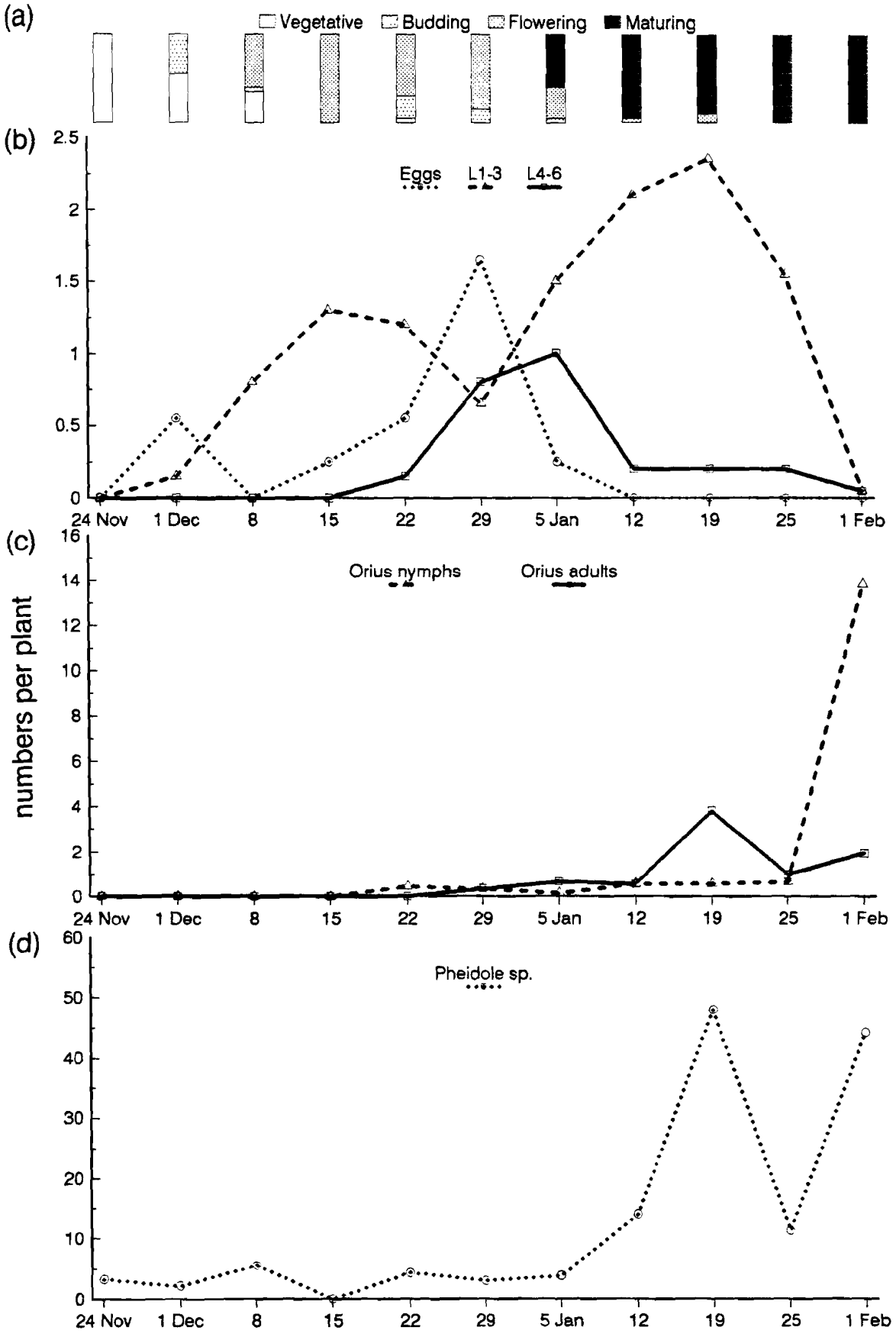

Figure 7.7. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Mwea Tebere. VII. Sunflower, short rains 1989-90.

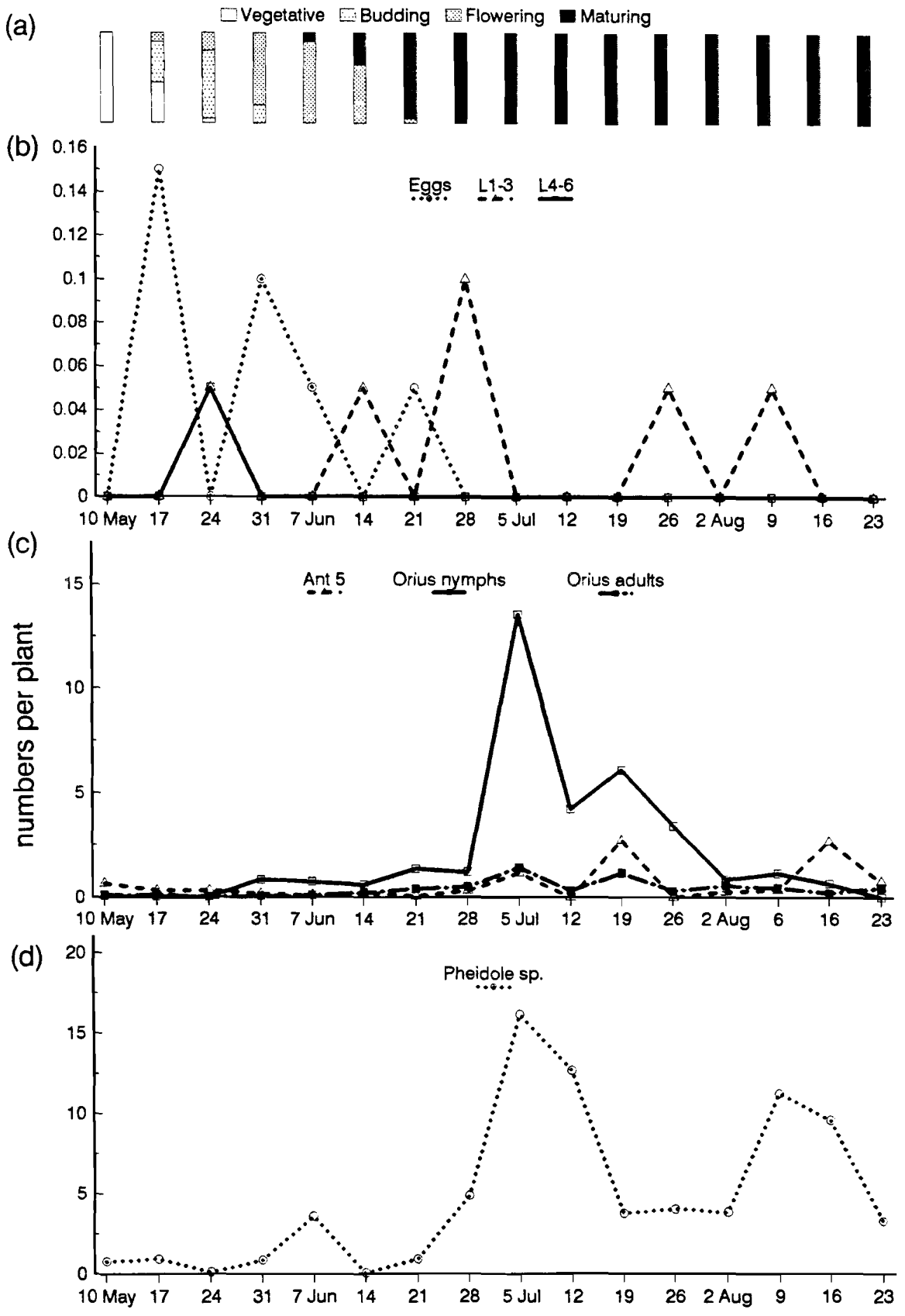

Figure 7.8. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Mwea Tebere. VIII. Sunflower, long rains 1990. Note that "Ant 5" in (c) is *Acantholepis* sp.

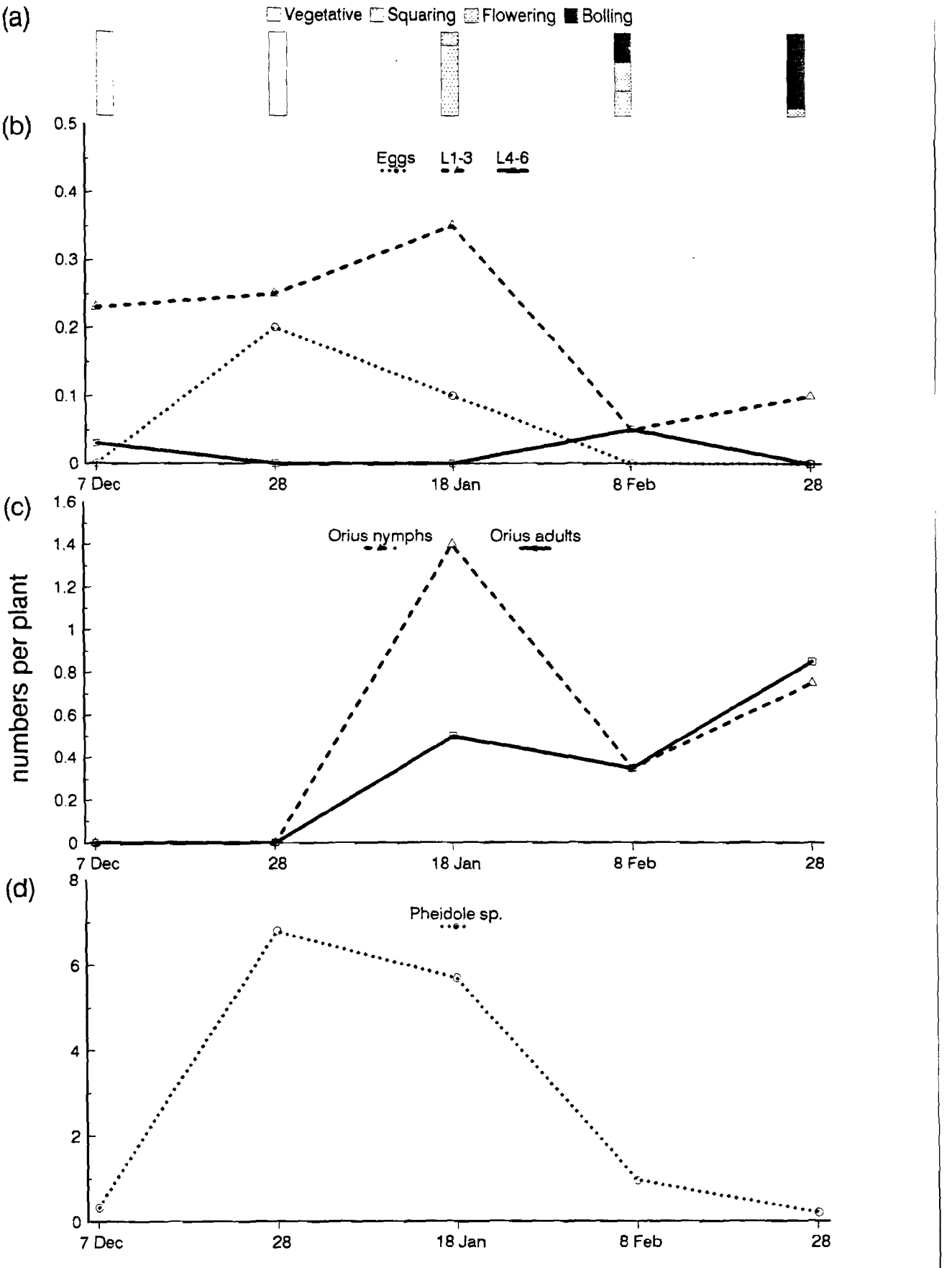

Figure 7.9. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Mwea Tebere. IX. Cotton, short rains 1988-89.

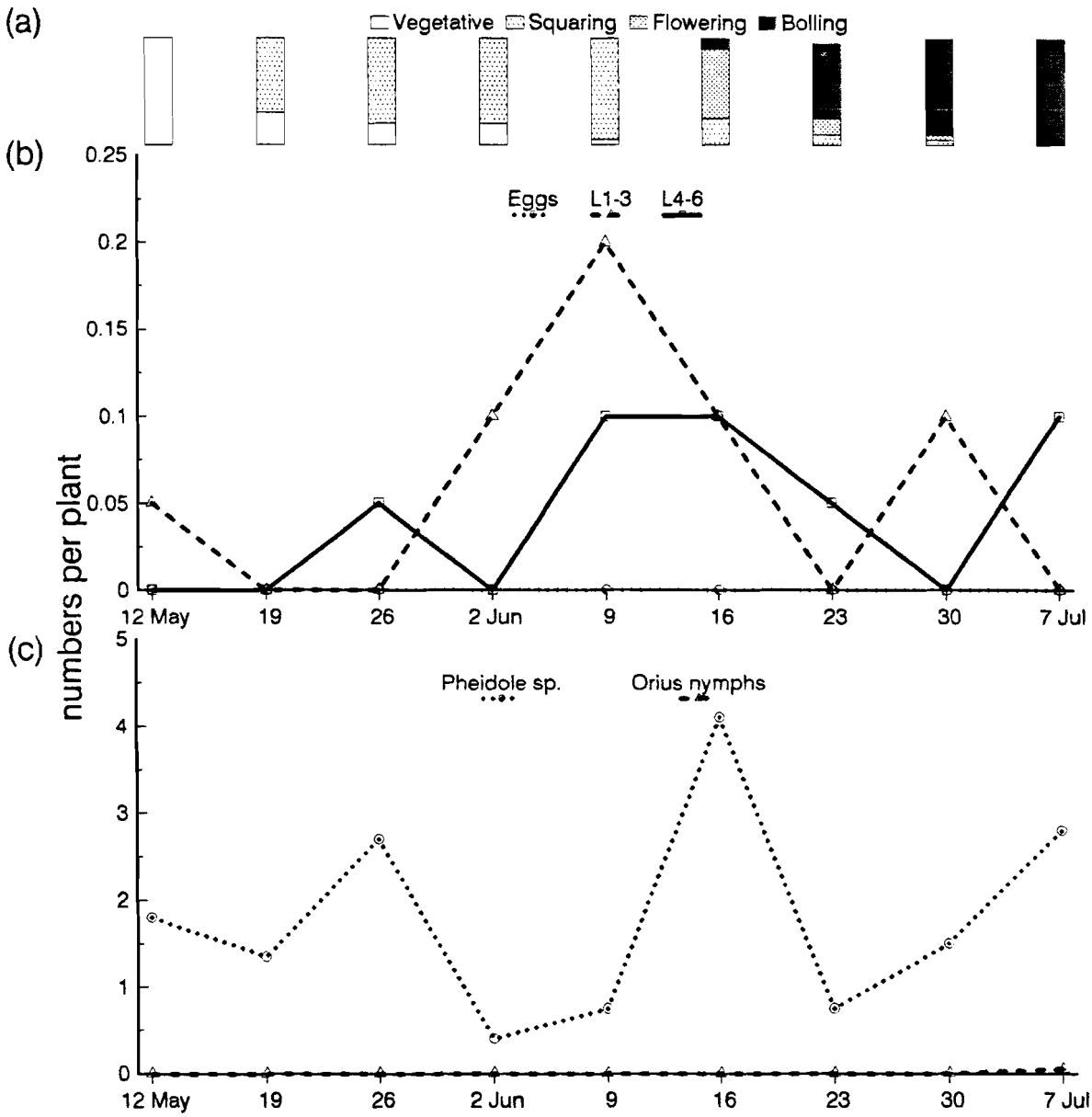

Figure 7.10. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Mwea Tebere. X. Cotton, long rains 1989.

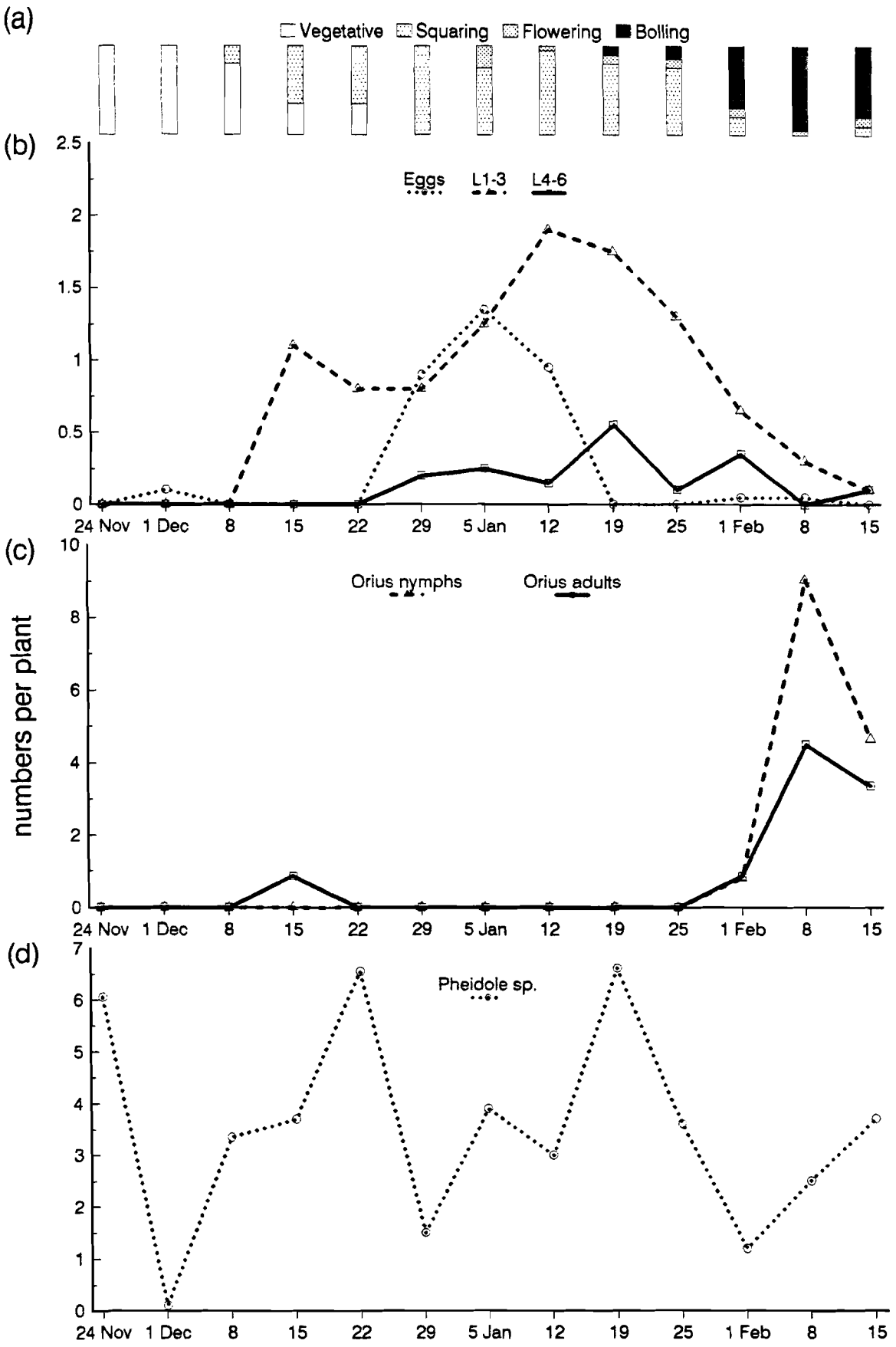

Figure 7.11. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Mwea Tebere. XI. Cotton, short rains 1989-90.

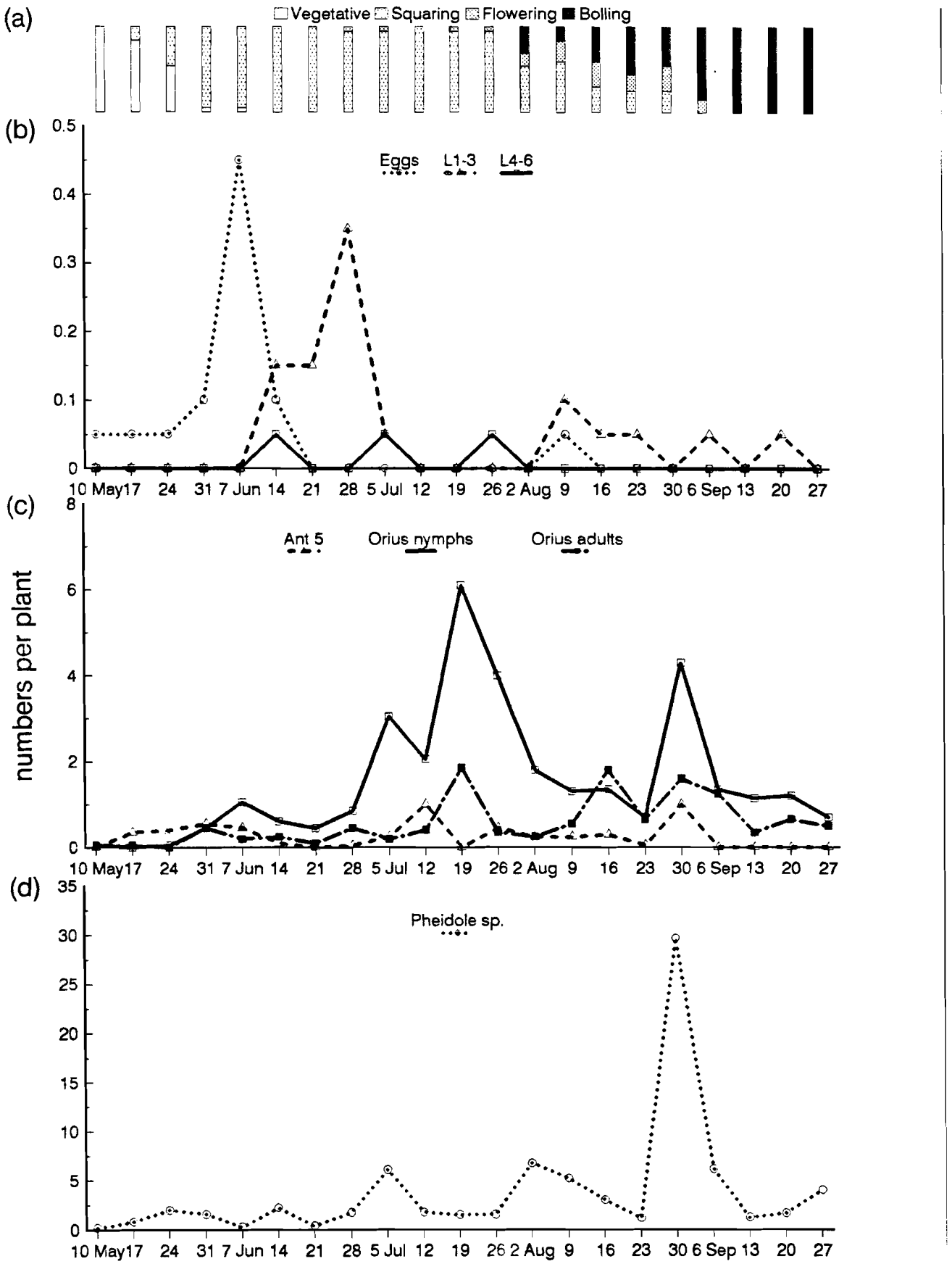

Figure 7.12. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Mwea Tebere. XII. Cotton, long rains 1990. Note Ant 5 in legend of (c) is *Acantholepis* sp.

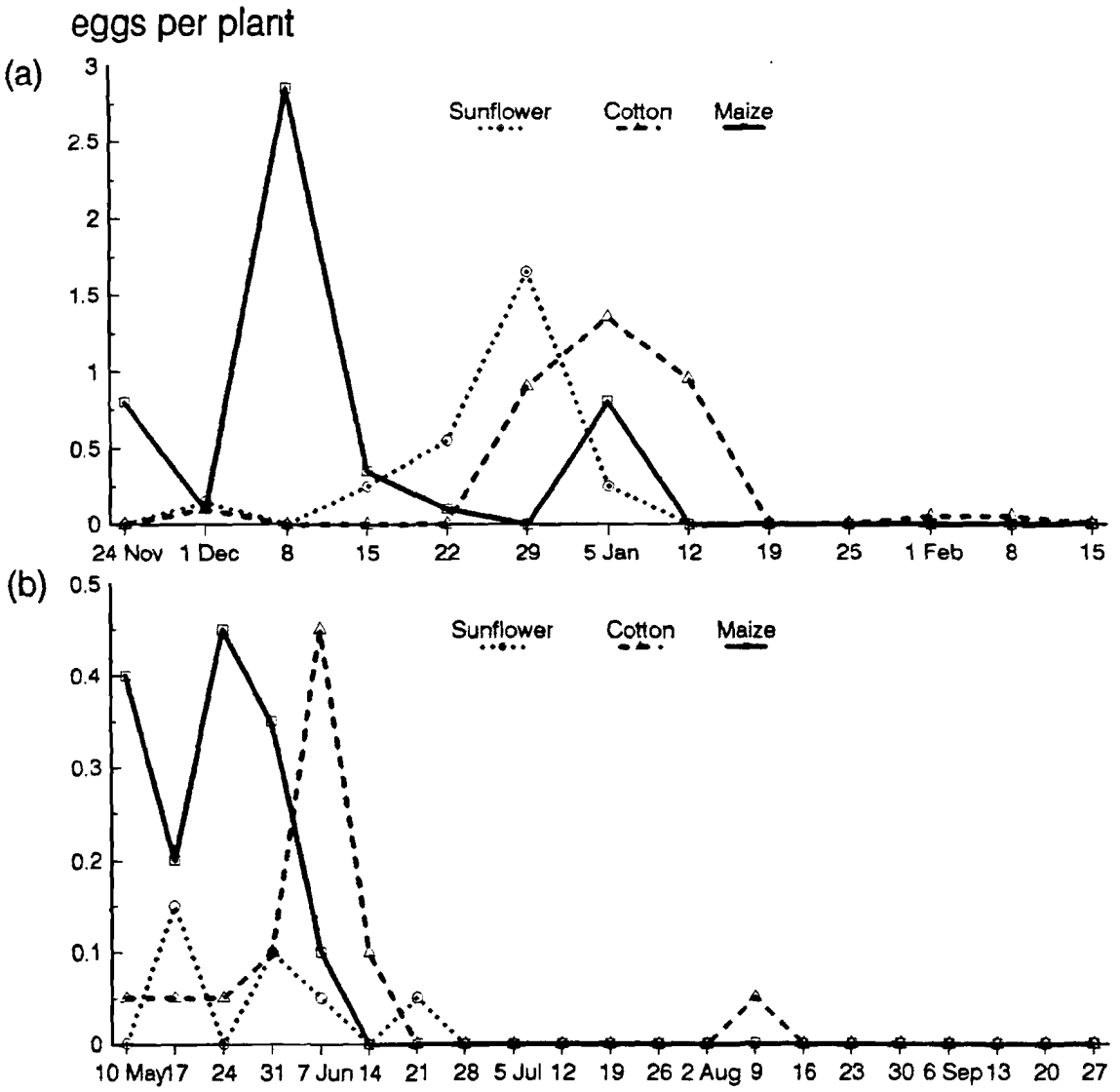

Figure 7.13. Oviposition by *H. armigera* on different crops at Mwea Tebere; (a) short rains 1989-90; (b) long rains 1990.

8. Natural mortality of *Helicoverpa armigera* on smallholder crops in Makueni, Eastern Province, Kenya.

Introduction

This study parallels those described in Section 6 for Kibos and Section 7 for Mwea Tebere. The population ecology of *H. armigera* and its natural enemies was monitored at Makueni over three growing seasons: 1988-1989 short rains (season 1), 1989 long rains (season 2) and 1989-1990 short rains (season 3).

Materials and methods

The study site was at KARI's Makueni sub-station of the National Dryland Farming Research Centre (NDFRC) (Section 2.1), using the same plots as those used for observations of micro-habitat selection (Section 4).

Sampling was carried out every three weeks for the first two seasons and weekly for the final season. Twenty randomly chosen plants of each crop, split between the three replicates, were sampled as described in Section 2.2.

To sample ground dwelling natural enemies, pitfall traps were used as described and presented in Section 10.

Meteorological data were obtained from records collected by KARI staff at Makueni sub-station.

Results

Apart from *Orius* spp. and *Pheidole* sp. other predators encountered regularly during sampling included a staphylinid, *Paederus* sp., and coccinellids *Cheilomenes lunata*, *C. sulphurea*, *C. propinqua* and *Scymnus* sp.

Maize

The incidence of different stages of *H. armigera* and its natural enemies on maize is given in Figures 8.1-8.3 for seasons 1-3 respectively.

In season 1 (short rains 1988-89) (Figure 8.1) the numbers of eggs and young larvae of *H. armigera* declined rapidly from an initial high peak. Predators were only present early in the season when they were rare.

In season 2 (long rains 1989) (Figure 8.2), a low initial peak of oviposition by *H. armigera* gave rise to very low numbers of larvae. *Orius* spp. reached a low peak when young *H. armigera* larvae were present, while numbers of *Pheidole* sp. increased steadily through the season to reach more than 25 per plant by the end of the season.

Season 3 (short rains 1989-90) (Figure 8.3) was sampled weekly, the figures show a clear succession of eggs, young larvae and old larvae; there was little mortality of eggs and young larvae, but relatively few reached the late larval stage. *Orius* spp. nymphs and adults only became common after the larvae were too large to be at risk. *Pheidole* sp. increased through the season to peak at 15 per plant near the end of the season.

Sorghum

The incidence of different stages of *H. armigera* and its natural enemies on sorghum is given in Figures 8.4-8.6 for seasons 1-3 respectively.

Eggs and larvae of *H. armigera* were scarce during season 1 (Figure 8.4) as were all groups of predators. In season 2 (Figure 8.5) there were almost no *H. armigera* eggs and larvae, but *Orius* spp. and *Pheidole* sp. were commoner, especially towards the end of the season.

The succession of eggs, young larvae and old larvae is very clear in season 3 (Figure 8.6); a peak of 10.4 eggs per plant at the early flowering stage is followed by peaks of 5.3 young larvae and 2.2 large larvae. *Orius* spp. and *Pheidole* sp. only started to increase as the crop matured, so would have presented no threat to the *H. armigera* eggs and young larvae.

Pigeon pea

The incidence of different stages of *H. armigera* and its natural enemies on pigeon pea is given in Figures 8.7-8.9 for seasons 1-3 respectively.

In season 1 (Figure 8.7), an extended peak of quite high rates of oviposition (6-9 per plant) by *H. armigera* led to moderate numbers of small larvae (5 per plant) and low numbers of large larvae. There were very few predators during the season.

Low levels of oviposition by *H. armigera* only developed towards the end of season 2 (Figure 8.8), and were followed by corresponding increases in the number of larvae. Numbers of *Pheidole* sp. and *Orius* spp. were very low.

In season 3 (Figure 8.9), oviposition by *H. armigera* started at flowering with a peak of 10 eggs per plant, and continued at rather lower levels declining towards the end of the season. Numbers of *H. armigera* larvae also increased from flowering, but declined to low levels by the end of the season. Numbers of *Orius* spp. and *Pheidole* were low and erratic throughout the season.

Cotton

The incidence of different stages of *H. armigera* and its natural enemies on cotton is given in Figures 8.10-8.12 for seasons 1-3 respectively.

During season 1 (Figure 8.10) low levels of *H. armigera* eggs and larvae were found through the season. Coccinellids and *Orius* spp. increased towards the end of the season, and could have contributed to the reduction of *H. armigera* towards the end of the season.

H. armigera was present in very low numbers in season 2 (Figure 8.11), while *Pheidole* were quite common, and *Orius* spp. increased towards the end of the season.

In the final season (Figure 8.12) *H. armigera* was more common and eggs reached a maximum count of 3.4/plant at the early squaring stage, with a second peak in the middle of the squaring stage. Young and old larvae peaked in mid-late squaring phase, and the numbers suggest there was not a lot of mortality. The population of *Orius* spp. nymphs and adults did not increase until the late squaring stage by which time the *H. armigera* larvae were too large too be susceptible to this predator. *Pheidole* sp. were most abundant at the vegetative and squaring stages, when they could have contributed to the mortality of the first peak of eggs.

Bean

Results from bean were not analysed because the crop matured very quickly and had low incidences of *H. armigera*.

Sunflower

Sunflower was included in the study only in season 3. Oviposition peaked at 11.1/plant during the early budding stage and larvae at the late flowering and early maturing stages. The numbers of large larvae suggested there was little mortality from the egg stage. *Orius* spp. and *Pheidole* sp. populations did not increase on sunflower until late in the season, and so were unlikely to have any impact upon *H. armigera* numbers.

Parasitoids and pathogens

No pathogens were found infecting *H. armigera*. Parasitism was very low, estimated from laboratory reared field-collected eggs and larvae. Less than 4% of the eggs were parasitised, mainly by *Trichogrammatoidea armigera* and *Telenomus ullyetti*. Even fewer larvae (less than 2%) were parasitised, mainly by *Apanteles* sp.

Discussion

At Makueni, the population of *H. armigera* was low during the vegetative crop stage and higher at the onset of the reproductive stages. The strong preference of ovipositing females for the flowering stages of the host plants has been reported for maize and sorghum (Parsons 1940b; Roome 1975; Teakle *et al.* 1985), sunflower (Coaker 1959; Khaemba & Mutinga 1982) and cotton (Wardhaugh *et al.* 1980).

When the oviposition on different crops is plotted on a common time scale for each season (Figure 8.14) it can be seen that there is some sequence in oviposition, at least in the short rains. Maize and sorghum are used first for oviposition, followed by sunflower and then pigeon pea. Referring back to the phenology figures (8.1-8.13) this does seem to be linked to the development stage of the crops.

The highest density of *H. armigera* eggs was recorded from pigeon pea. Studies in India (Jayaraj 1981) have showed that *H. armigera* preferentially laid eggs on pigeon pea, when offered other hosts including cotton, sorghum, field bean, tomato etc. However sunflower, which was included in the studies for only one season, had the highest peak and total incidence of larvae followed by pigeon pea.

Table 8.1 summarises the data from this site for each crop and season, giving the average number per plant of each stage of *H. armigera* and the dominant natural enemies *Orius* spp. and *Pheidole* sp. *H. armigera* was common on maize and pigeon pea in season 1, and on sorghum, pigeon pea and sunflower in season 3, whereas in season 2 (long rains 1989) it was only present in low numbers on all crops. *Orius* were scarce in season 1, but commoner in seasons 2 and 3, and show a preference for sorghum and sunflower, while apparently avoiding pigeon pea. *Pheidole* sp. was absent in season 1, but common on maize, cotton and sunflower in seasons 2 and 3, while almost none were found on pigeon pea.

It can also be seen from Table 8.1, that although predators were sometimes common, they mostly did not overlap in time with the susceptible stages of *H. armigera* (eggs and young larvae). When this overlap is present, the population of L4-6 *H. armigera* is always low, suggesting that when predators are in the right place at the right time they do have significant impact. Overall, predation cannot have been a major mortality factor at Makueni during our study as they predators were not normally common when susceptible *H. armigera* were available.

In this limited data set, there is the suggestion that *H. armigera* was relatively unimportant in the long rains. This could, at least on this occasion, have been due to heavy rain in April 1989 (237mm) which could well have reduced the *H. armigera* population by dislodging eggs and young larvae from the plants.

Similarly, the incidence of *H. armigera* in all stages decreased markedly between 13 and 30 December 1988, which could have been due to a downpour of 22.5 mm on 22 December.

Table 8.1. Average numbers per plant per sampling occasion of *H. armigera* stages, the common predators, and their degree of temporal overlap. Data from Makueni for all seasons.

		H. armigera			*Orius* spp.		*Pheidole* sp.	
crop	season	egg	L1-3	L4-6	total	overlap[a]	total	overlap[a]
maize	1	2.9	.06	.01	.09	x	.0	
	2	.2	.1	.1	.3	x	15.3	-
	3	.7	.5	.1	.2	-	5.3	-
sorghum	1	.2	.4	.3	.0	.0		
	2	.02	.02	.0	1.5	-	1.3	-
	3	1.0	1.1	.4	.4	-	.9	-
pigeon pea	1	3.4	1.3	.3	.0	.0		
	2	.9	.4	.1	.1	x	.1	x
	3	2.3	.7	.3	.1	-	.1	x
cotton	1	.6	.3	.1	.7	-	.0	
	2	.2	.0	.02	1.9	-	3.2	x
	3	.7	.6	.4	1.6	-	4.0	x
sunflower	3	2.1	2.4	2.2	1.5	-	3.7	-

[a] a subjective estimate as to whether the predators were relatively common at the same time as the eggs and young larvae of *H. armigera*; - little overlap; x some overlap.

The two central sites: Mwea Tebere and Makueni

Whereas *H. armigera* was most abundant on sunflower and maize at Mwea Tebere (Section 7), at Makueni is was commonest on pigeon pea and sunflower. Although oviposition preference is not always an indication of feeding preference, both Pearson (1958) and Rens (1977) observed that *H. armigera* oviposited and fed on maize in preference to cotton when grown in adjacent plots. *H. armigera* is said to be a serious pest of cotton in all cotton growing areas of Kenya (Muthamia 1971). The low relative incidence of this pest on cotton in our study may be due to the preference of the female moths for the adjacent crops.

Natural enemies have been reported to play an important role in suppressing the population densities of *Heliothis* spp. (Ewing & Ivy 1943; Fletcher & Thomas 1943; King *et al.* 1982; Parsons & Ullyett 1934; Ridgeway *et al.* 1982). As noted above, the population density of *H. armigera* on the study crops was low early in the season but increased during the flowering phase before dropping as the crops matured. This decline coincided with an increase in the population of the predators, especially *Orius* spp. and *Pheidole* sp. This increased predator population is likely to have prevented any further recruitment of *H. armigera* eggs and young larvae, and thereby depressed the pest population.

On most crops at Mwea Tebere and Makueni, there were more *H. armigera* and fewer predators during the short rains than in the following long rains season. A possible explanation for this seasonal difference could be that the longer and more severe dry season preceding the short rains season (3 months at Mwea Tebere and 5 at Makueni) reduced the population of *H. armigera* and its natural enemies to very low levels. After the onset of the short rains, *H. armigera* population

increase or immigration outpaced that of the predators, leading to a high *H. armigera* populations and relatively low predator populations. However the short rains extended into December or January, effectively shortening the dry season to one to two months before the long rains. This might have led to survival of *H. armigera* and its predators so that *H. armigera* was unable to "escape" from its predators in the following long rains. Similarly, Coaker (1959) working in southern Uganda, has suggested that *H. armigera* was not a serious pest of cotton there because the climate allowed the pest and its natural enemies to survive throughout the year. Asynchrony in the colonisation of crops by *Helicoverpa* spp. and their natural enemies is considered by Fitt (1989) to be one of the major factors limiting the effectiveness of natural control. The delays in population build up by the predators in our studies, are also critical to their effectiveness.

Another explanation for the differences between seasons is that the heavy April rains at the beginning of the long rains (243 mm in season two and 376 mm in season four at Mwea Tebere and 237 mm in Makueni) could have further reduced the *H. armigera* population by dislodging eggs and young larvae from the plants.

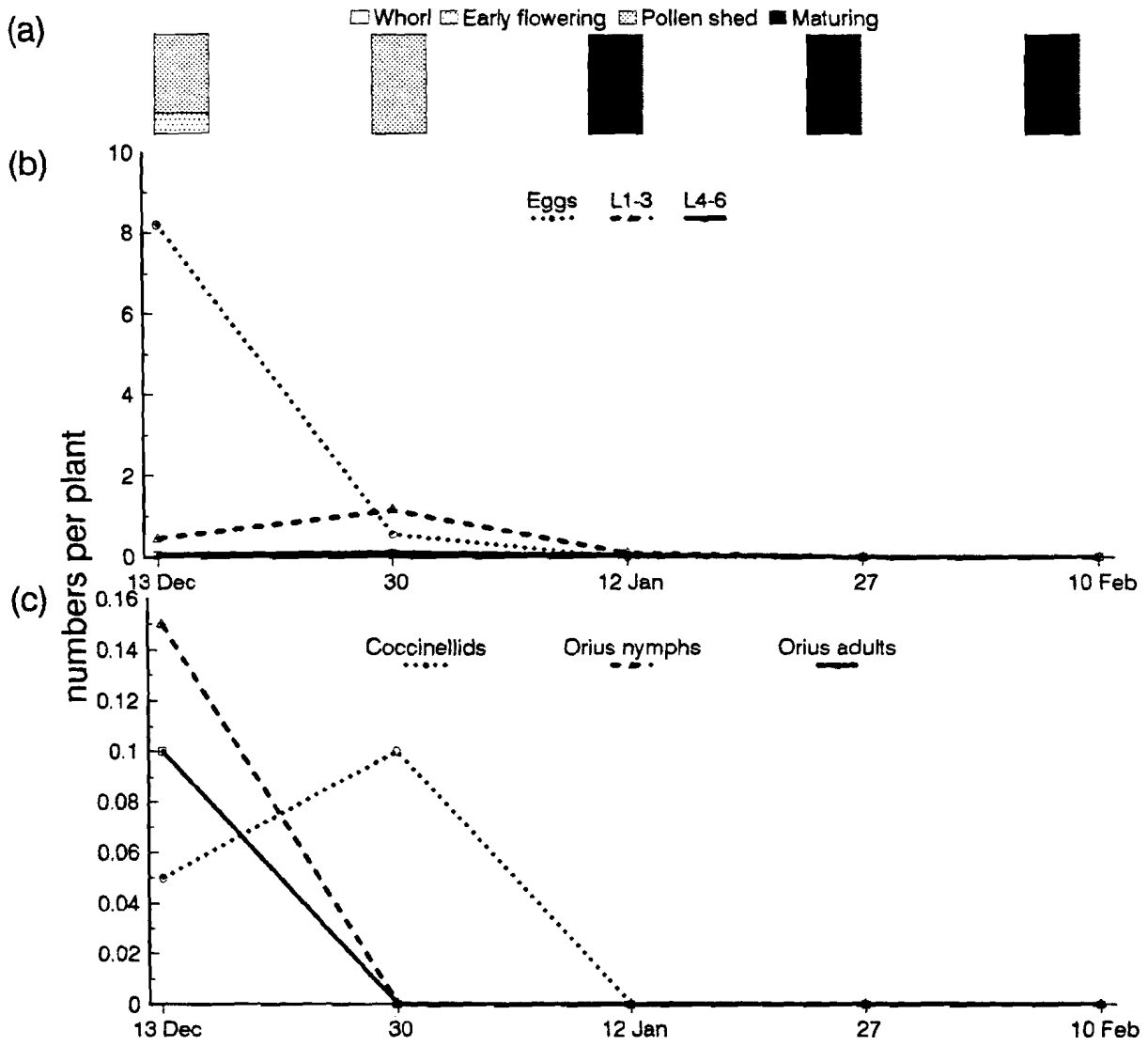

Figure 8.1. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Makueni. I. Maize, short rains 1988-89.

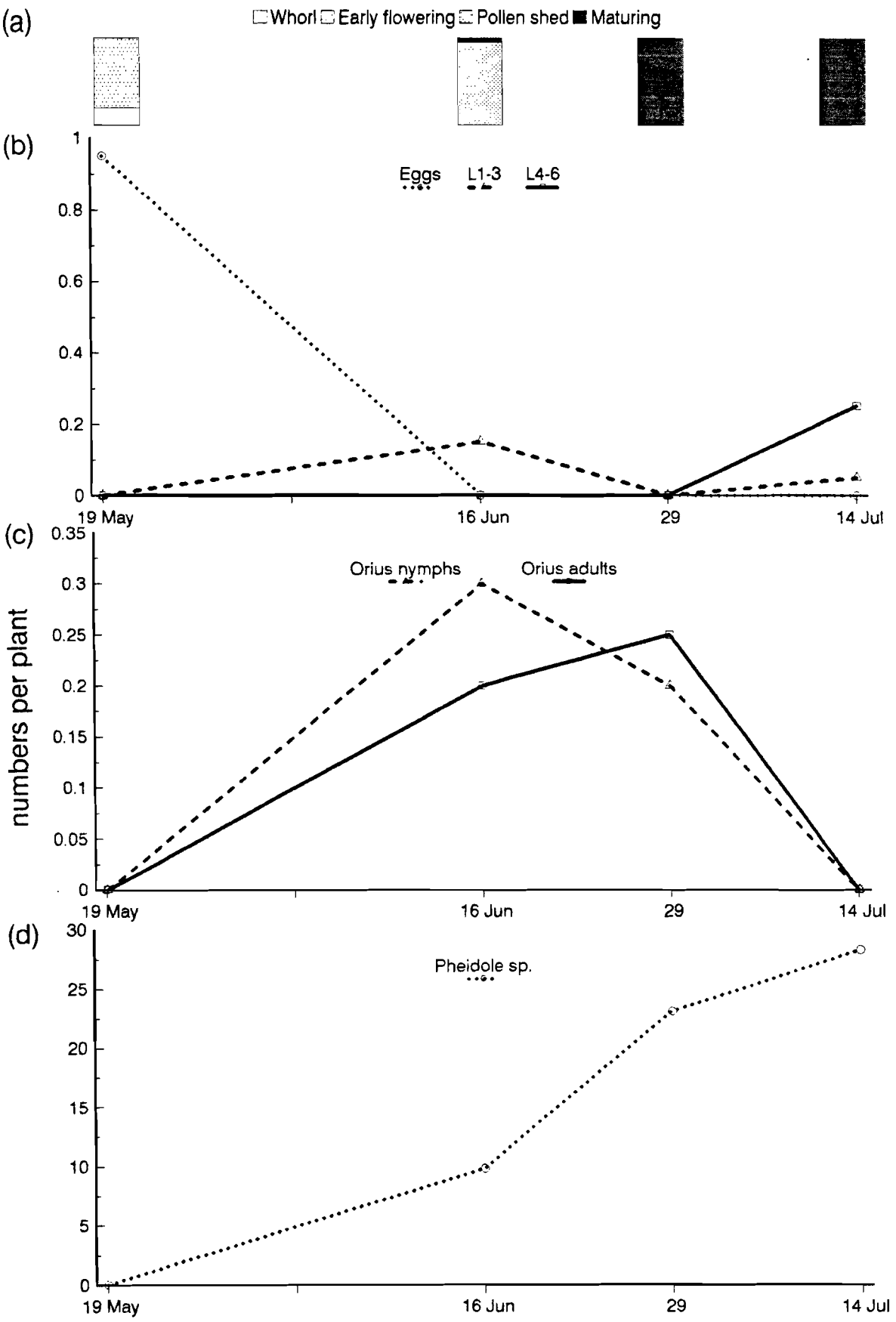

Figure 8.2. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Makueni. II. Maize, long rains 1989.

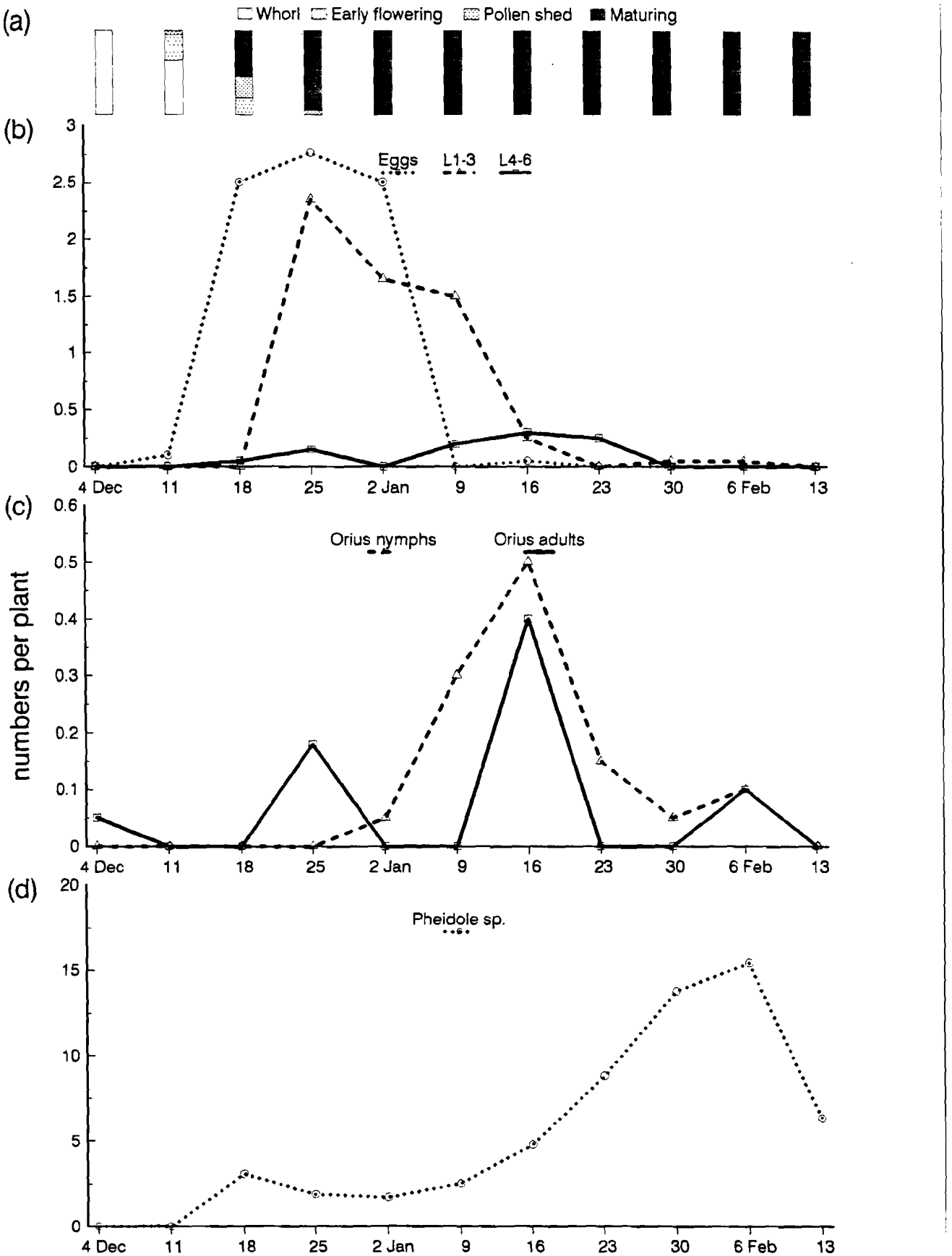

Figure 8.3. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Makueni. III. Maize, short rains 1989-90.

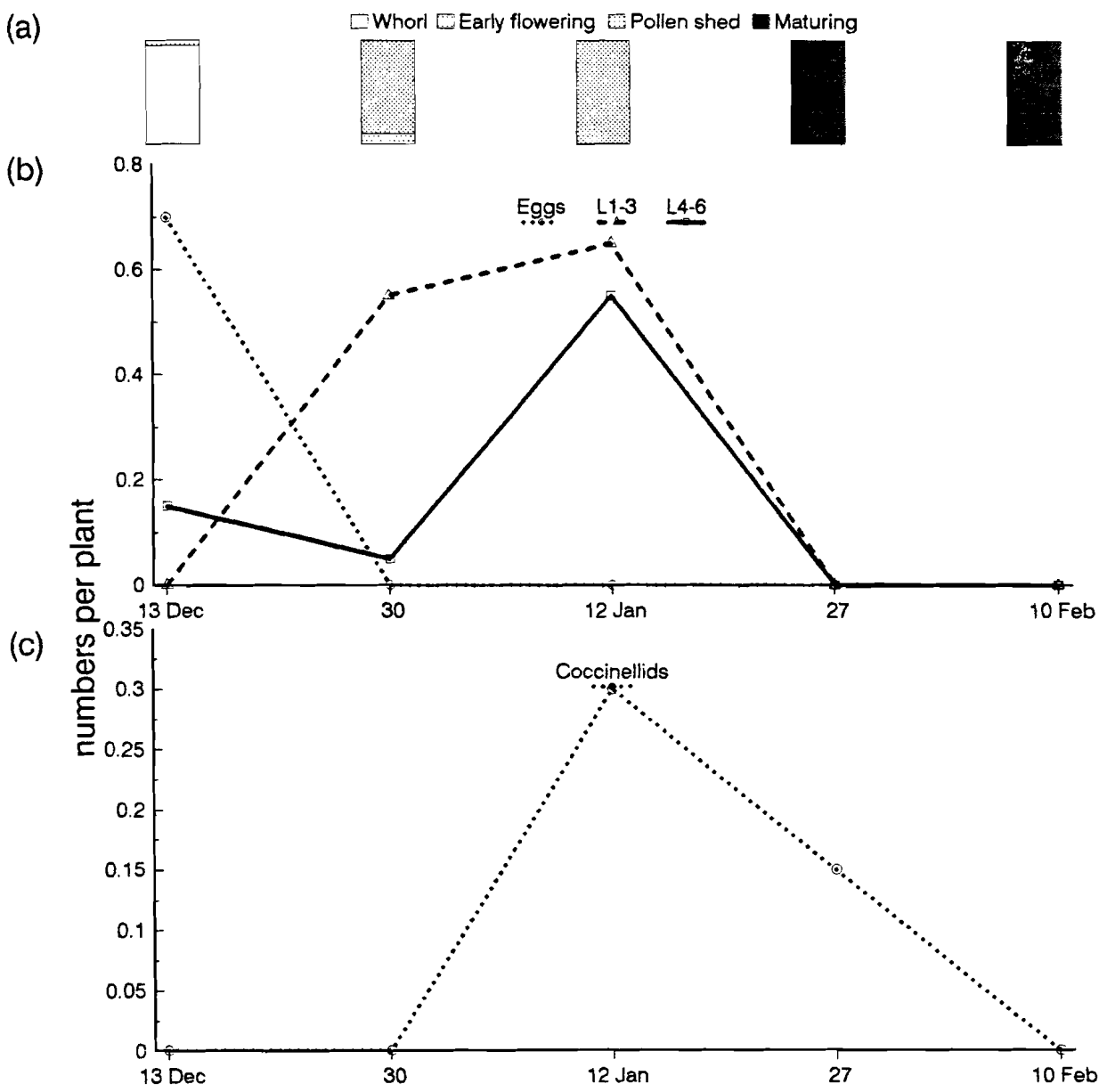

Figure 8.4. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Makueni. IV. Sorghum, short rains 1988-89.

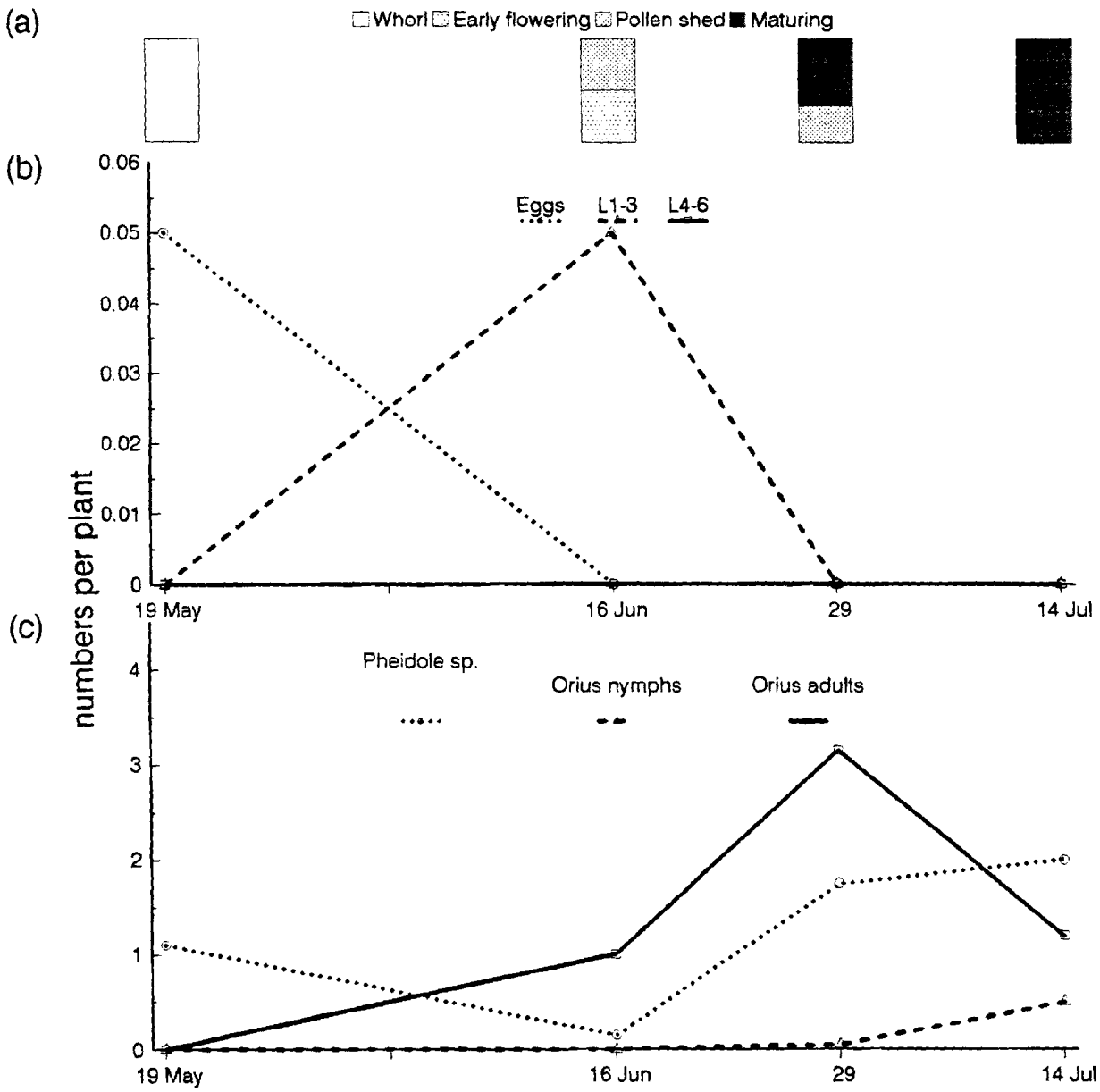

Figure 8.5. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Makueni. V. Sorghum, long rains 1989.

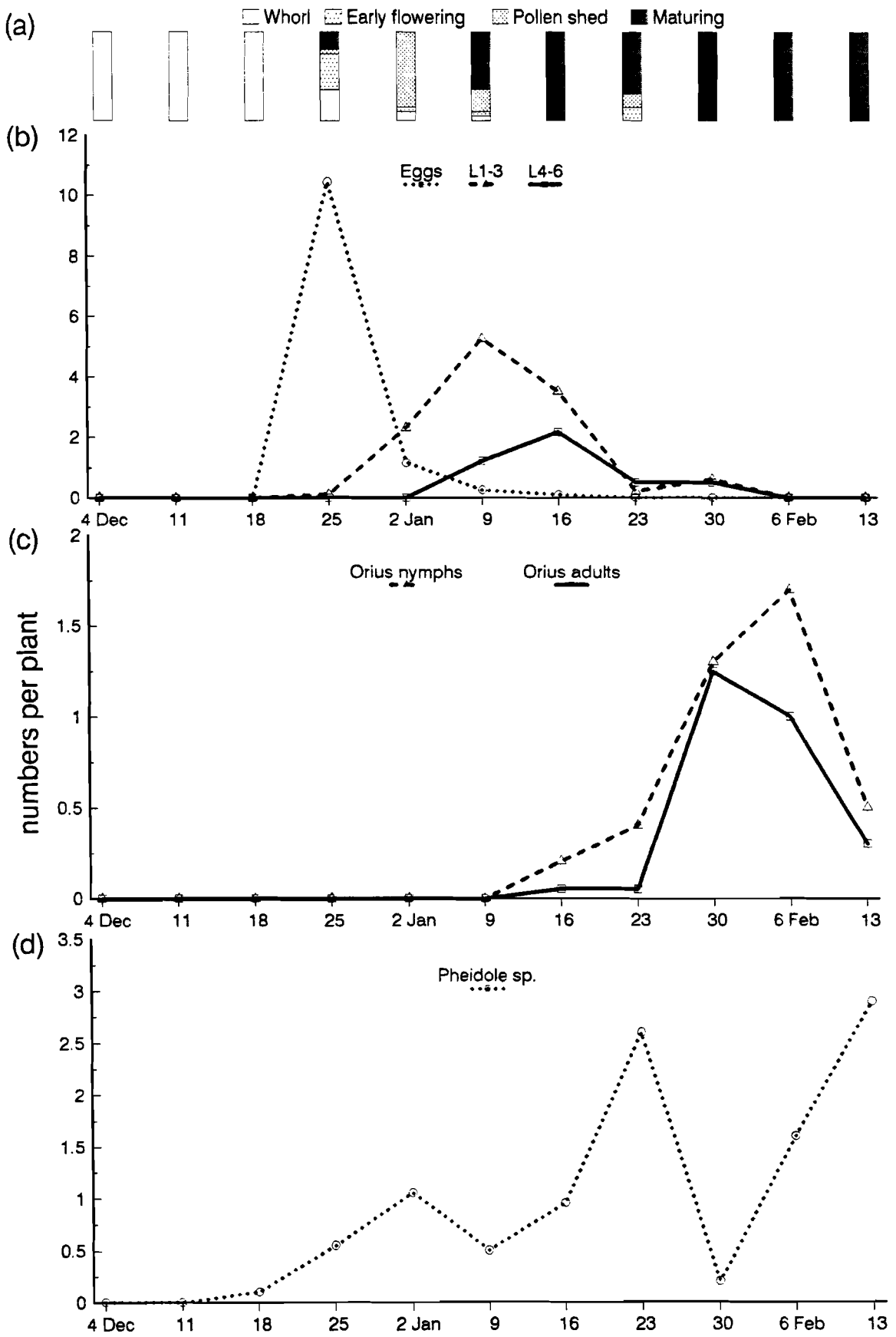

Figure 8.6. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Makueni. VI. Sorghum, short rains 1989-90.

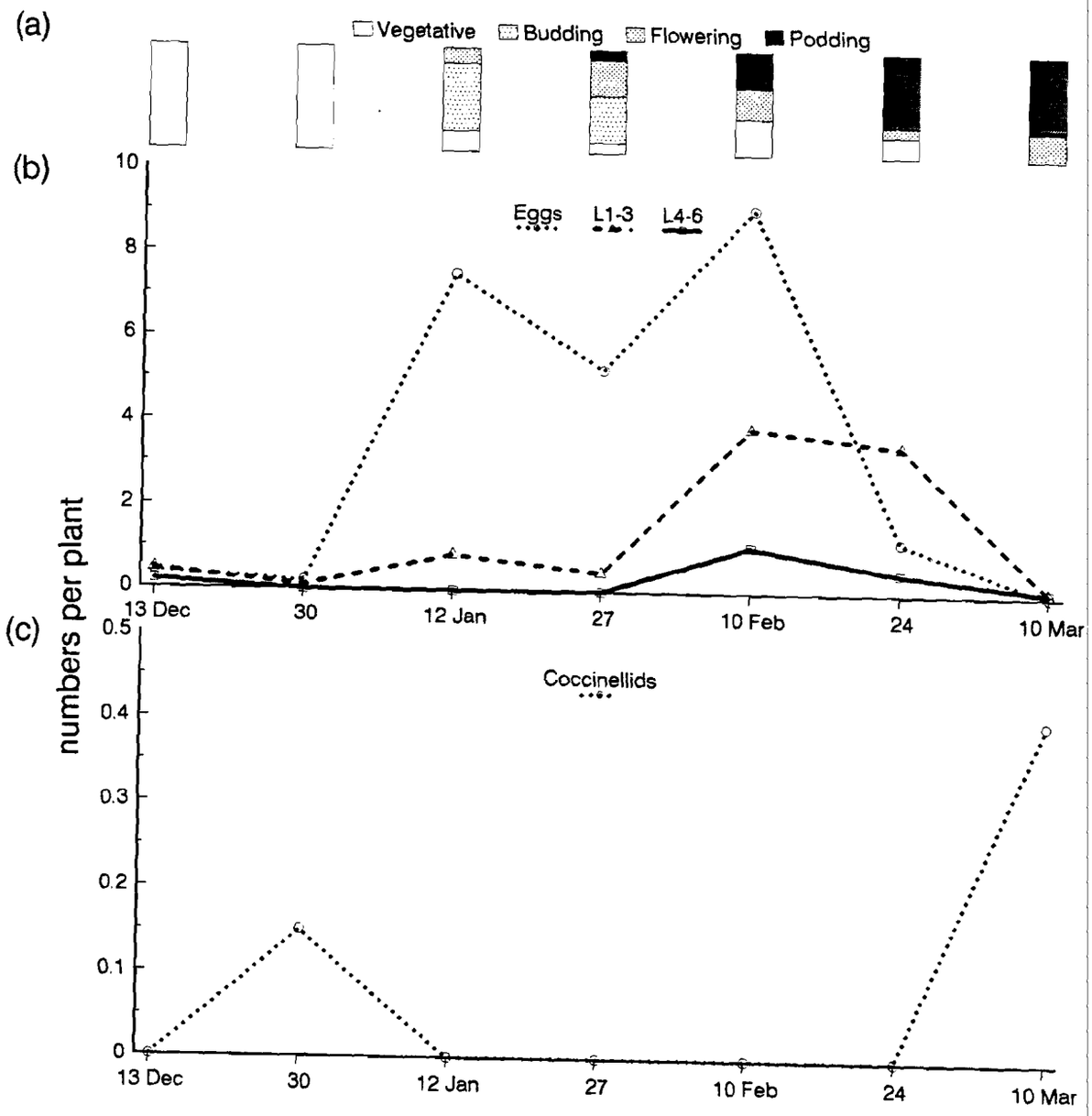

Figure 8.7. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Makueni. VII. Pigeon pea, short rains 1988-89.

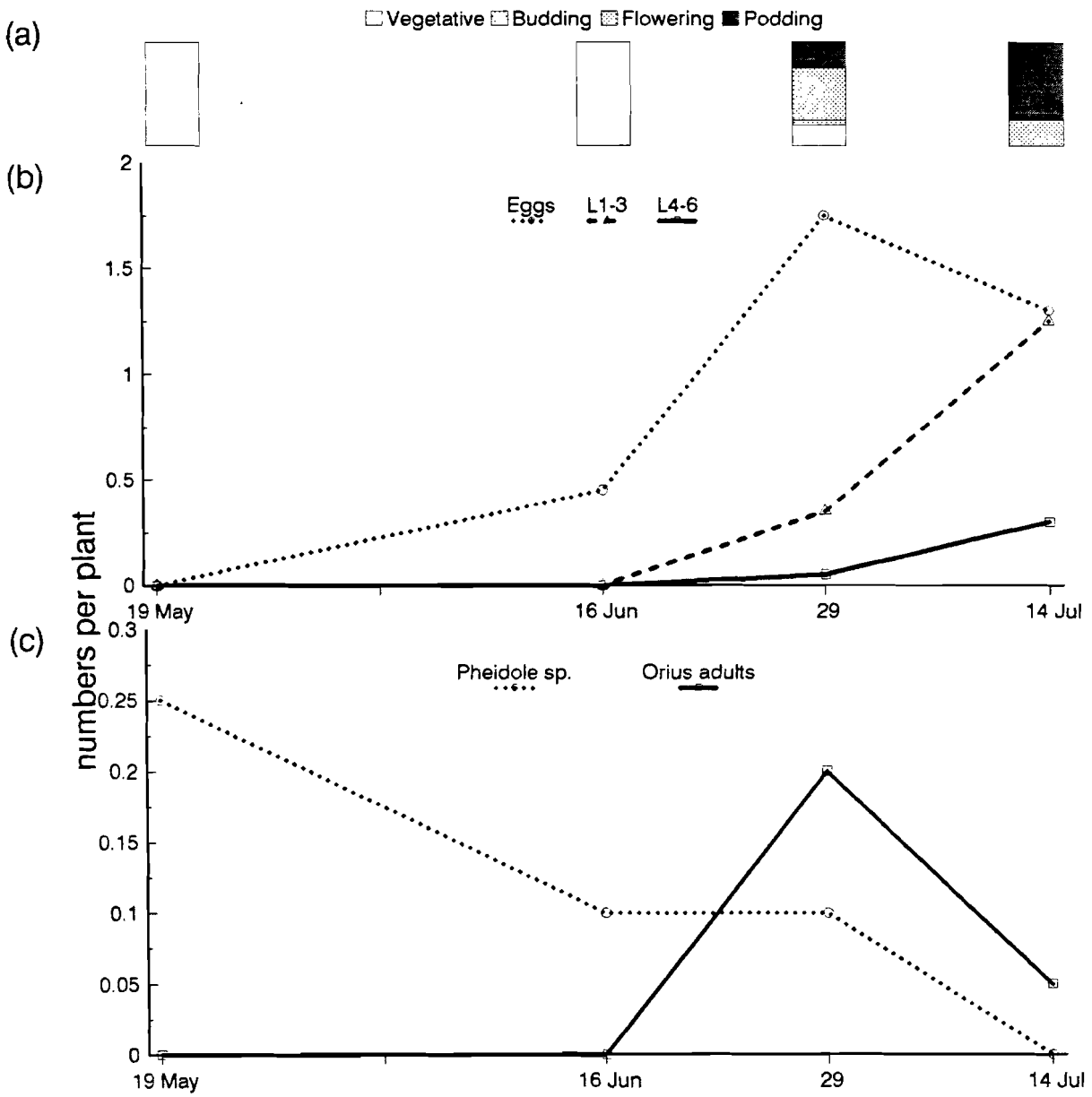

Figure 8.8. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Makueni. VIII. Pigeon pea, long rains 1989.

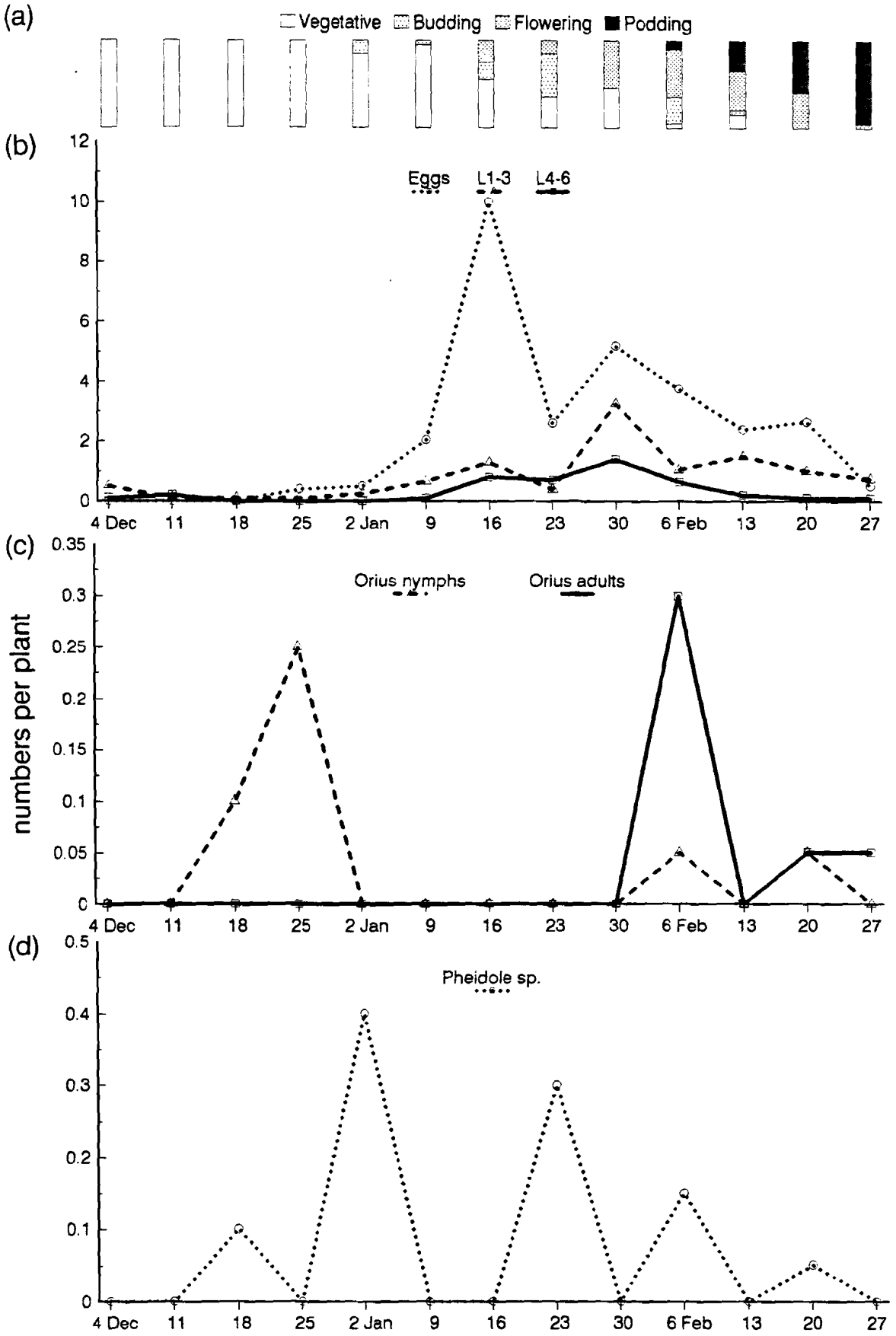

Figure 8.9. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Makueni. IX. Pigeon pea, short rains 1989-90.

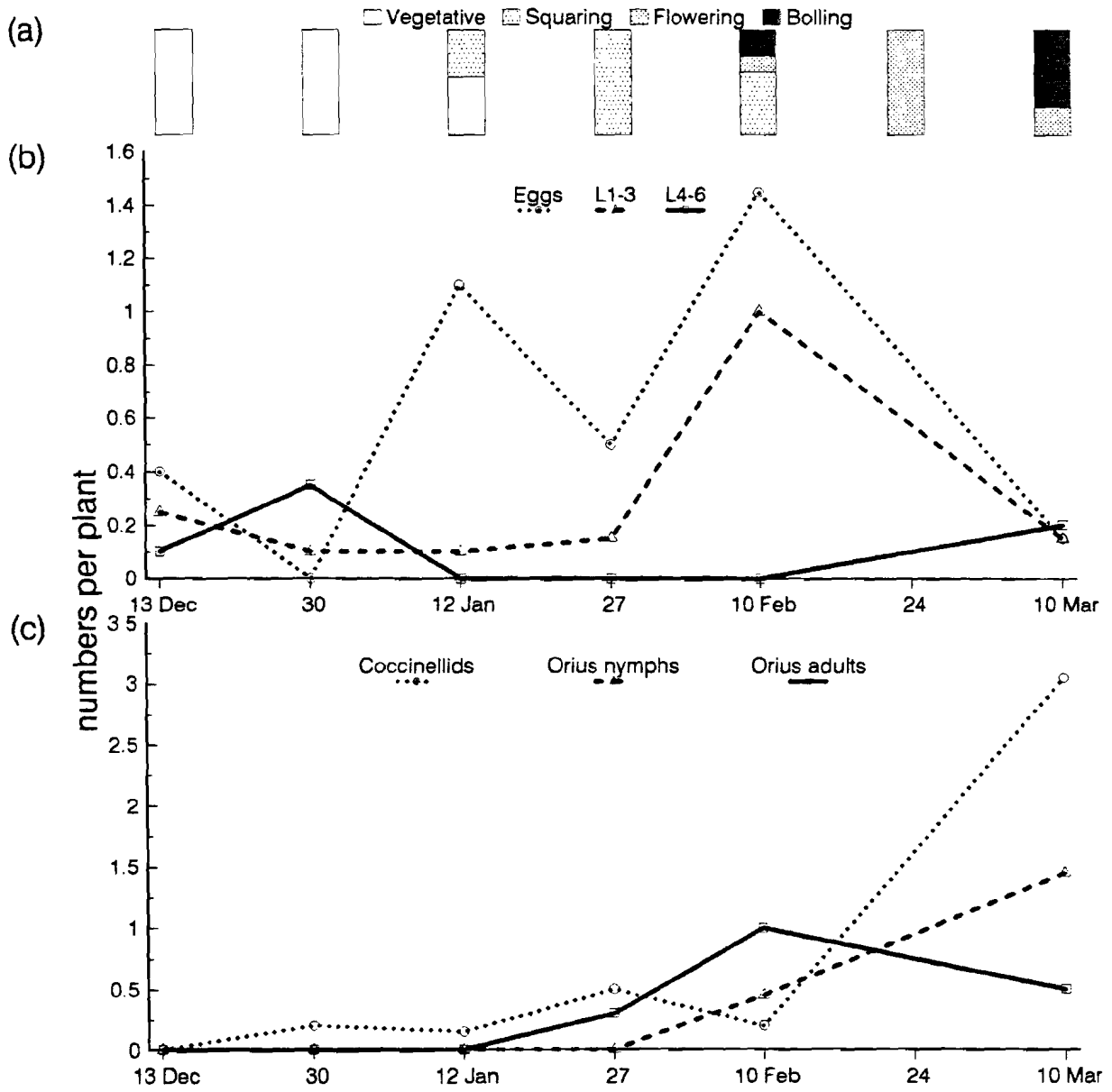

Figure 8.10. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Makueni. X. Cotton, short rains 1988-89.

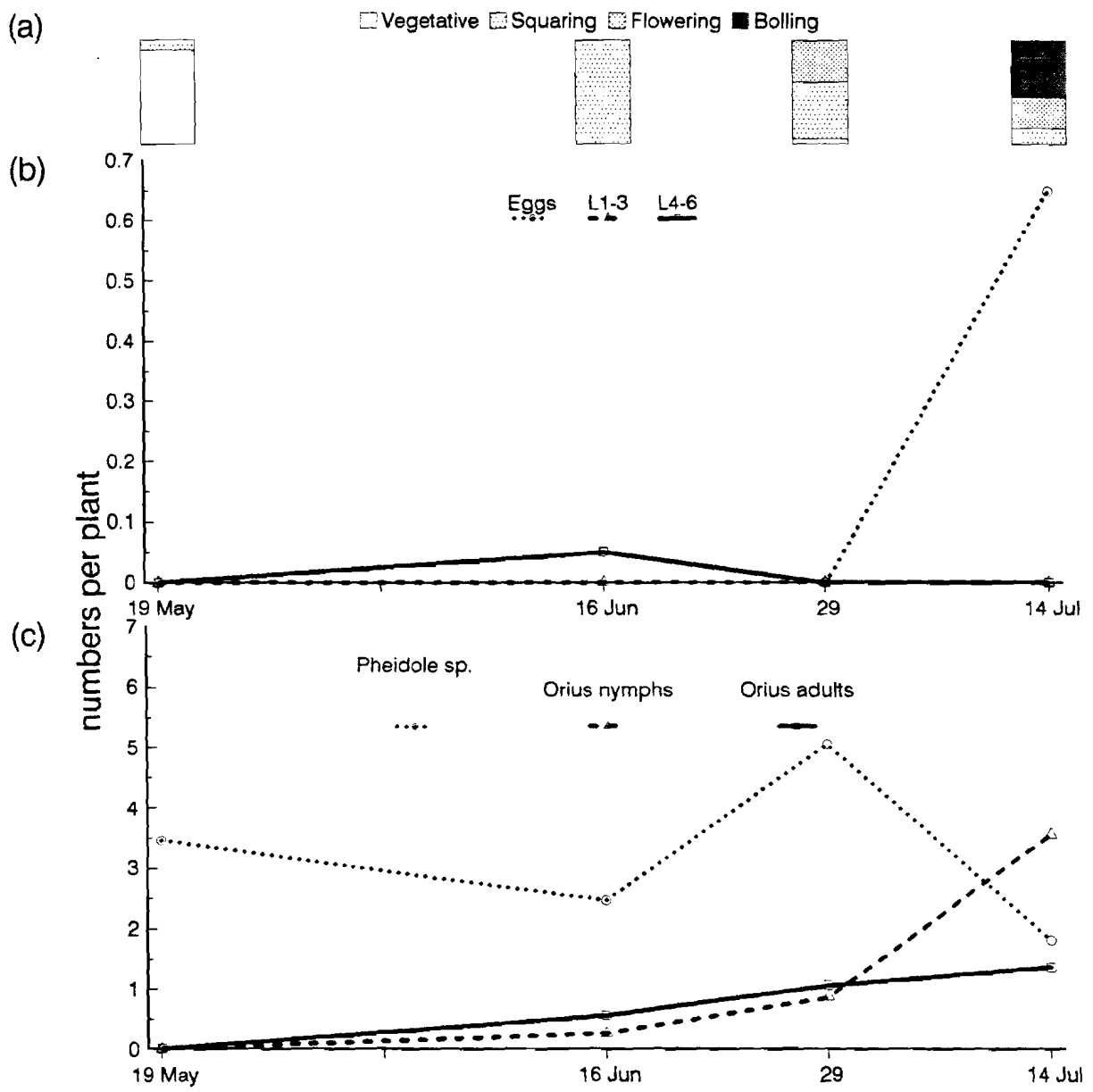

Figure 8.11. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Makueni. XI. Cotton, long rains 1989.

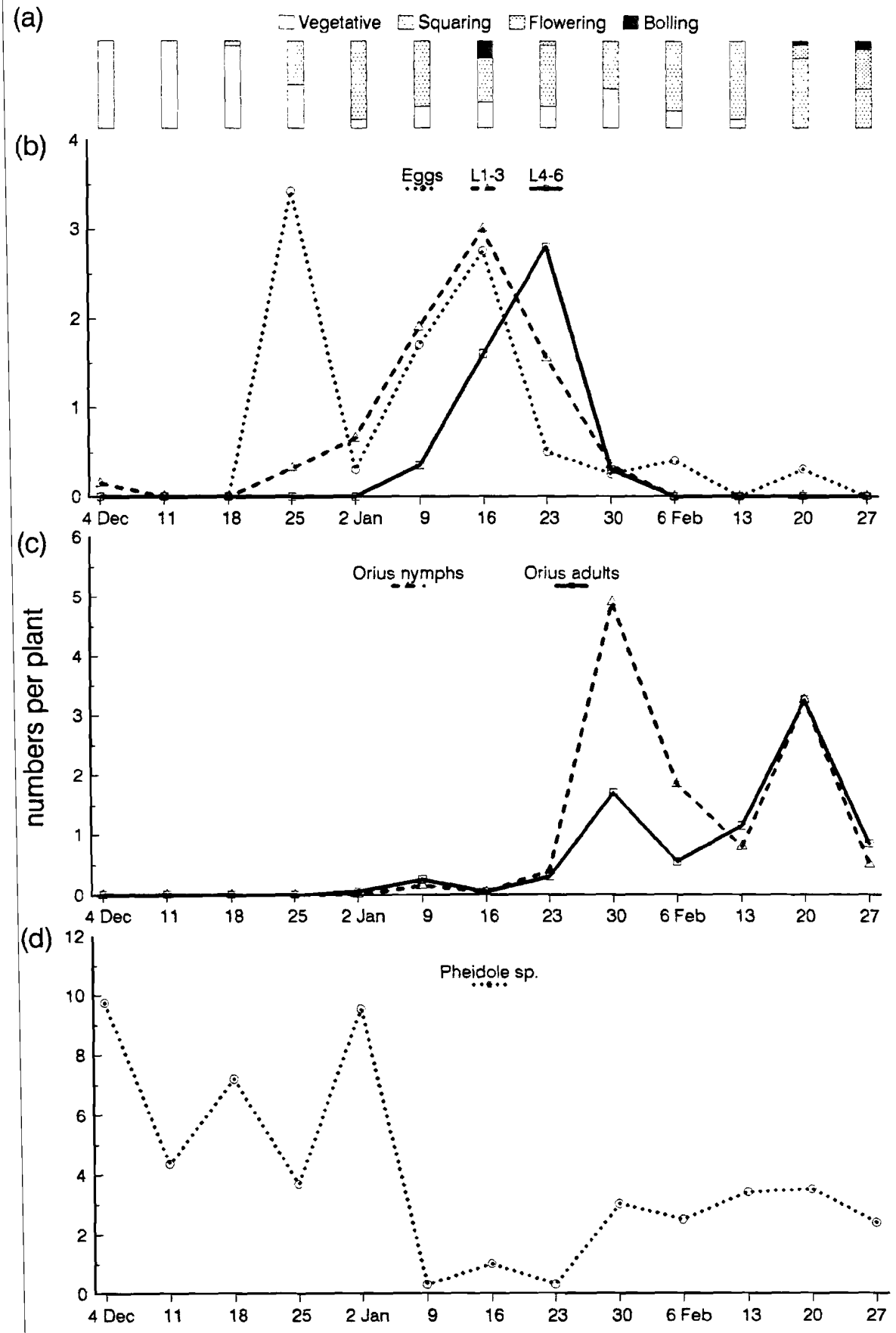

Figure 8.12. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Makueni. XII. Cotton, short rains 1989-90.

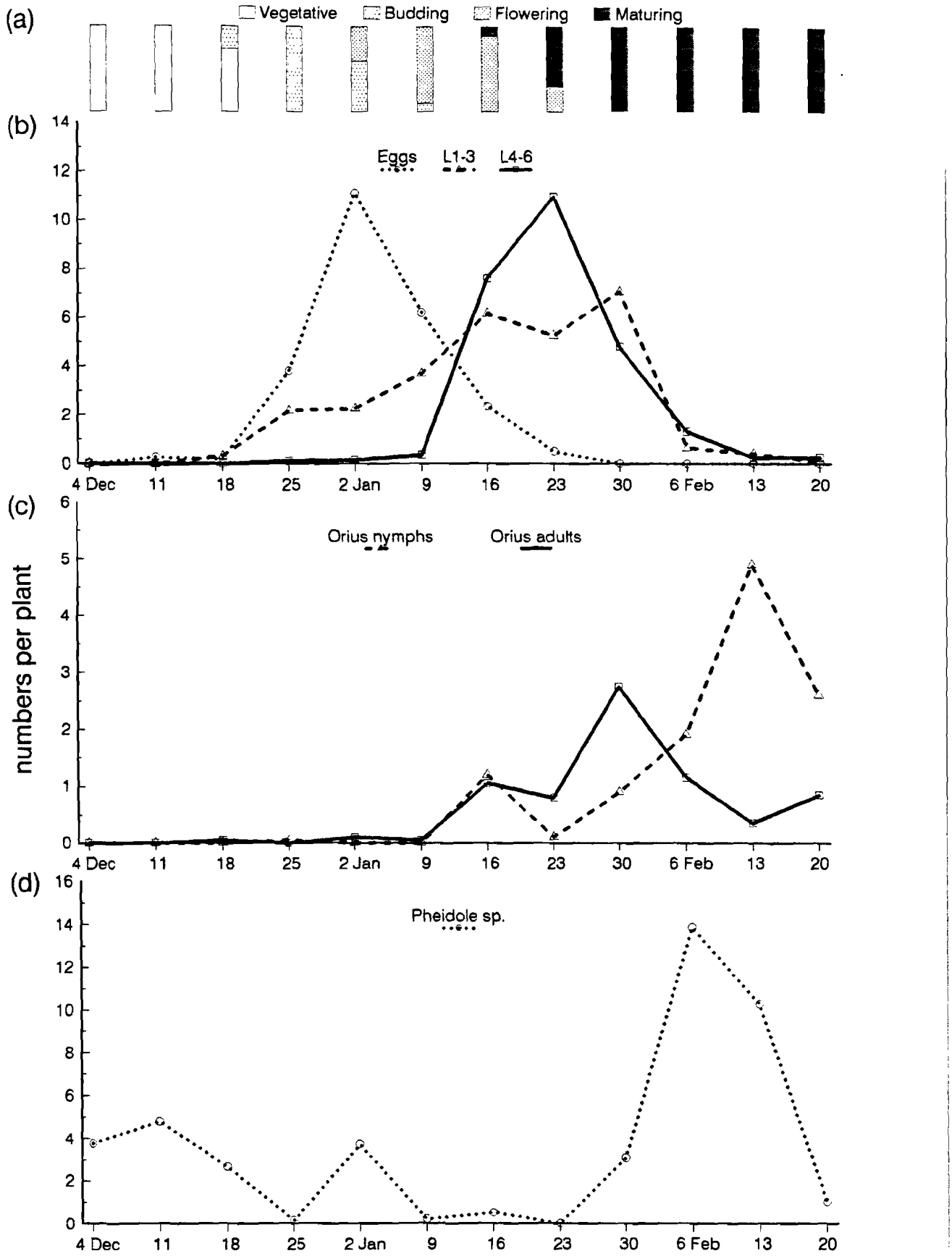

Figure 8.13. Crop stage and seasonal population densities of *H. armigera* stages and their predators at Makueni. XIII. Sunflower, short rains 1989-90.

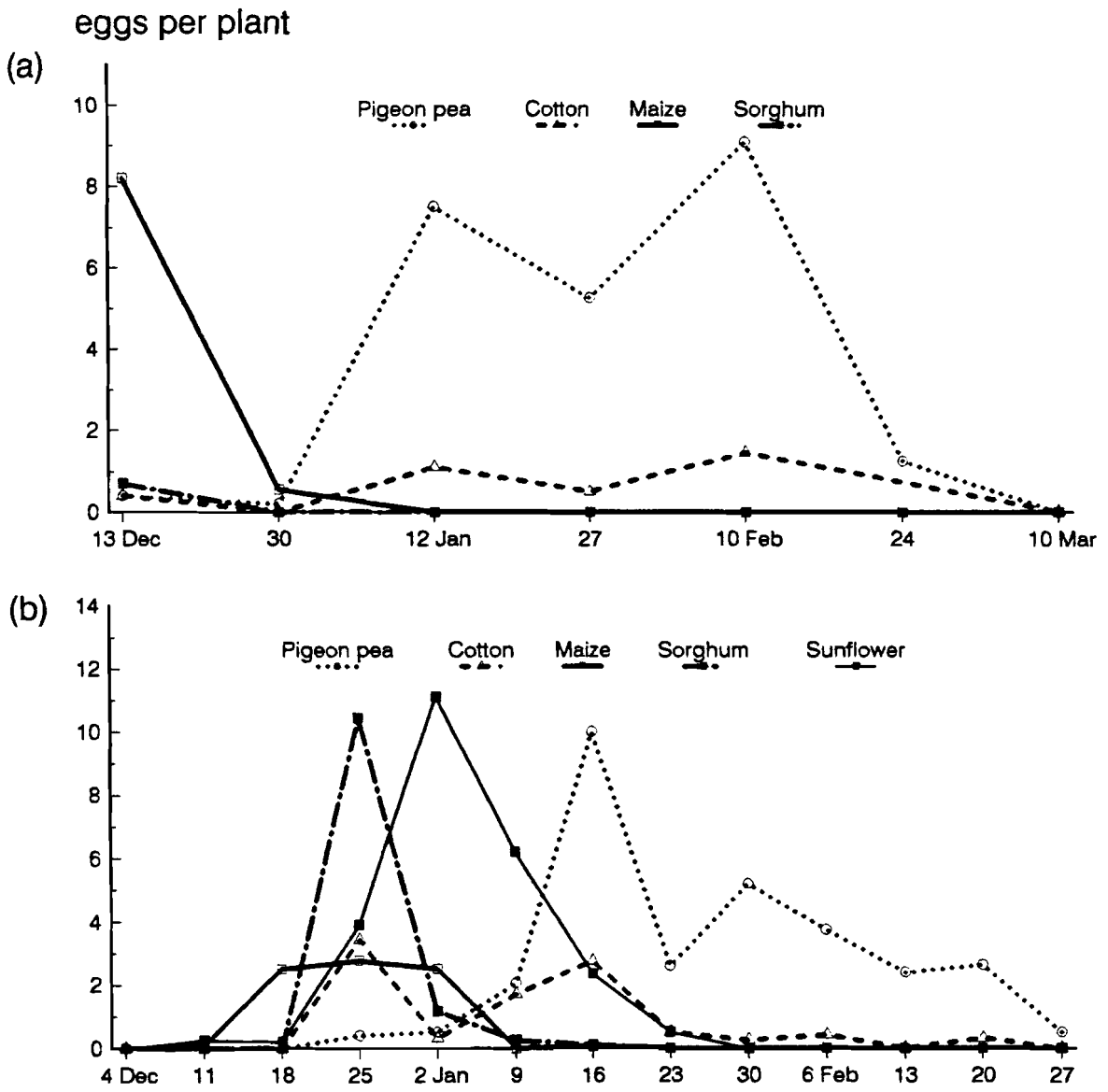

Figure 8.14 Oviposition by *H. armigera* on different crops at Makueni; (a) short rains 1989-90; (b) short rains 1989-90.

9. The occurrence of *Helicoverpa armigera* and its major predators in Kenya: a comparison of sites.

During the course of the project, *Helicoverpa armigera* and natural enemies were studied for 1-4 seasons throughout Kenya. These sites were introduced in Section 2.1.

Of these, Kakamega, Kibos and Lugari, were intensively sampled sites (with 8-15 sampling occasions during each season), Mwea Tebere, Makueni and Msabaha were initially minor sampling sites for one season (with 4-7 sampling occasions during the season), but were then upgraded to intensive sites (with 9-16 sampling occasions per season), Kisii and Mtwapa were minor sites (with 3-6 sampling occasions per season).

Figures 9.1-9.4 depict the occurrence of eggs, larvae, ants and anthocorids, respectively, in every site. These data are average densities per plant over the sampled crop seasons (starting just before flowering or pollen shed until ripening of the crop). At the coast, *H. armigera* was rarely present throughout our study.

It should be noted that differences between sites could have been influenced by differences in experience or effort of samplers.

Although ants may be local in their occurrence, the abundance of *Pheidole* sp. found at the Mwea Tebere site was duplicated in farmers fields in the area. Throughout Western Kenya, the ant community was rather similar, with *Myrmicaria* (not found East of the Rift Valley), *Camponotus*, and *Pheidole* as the most common genera.

Anthocorids were clearly more abundant to the West, rather than to the East of the Rift Valley, and were most abundant on cotton and sunflower.

Highest oviposition of *H. armigera* was found in Makueni, followed by Kakamega and Mwea Tebere. Oviposition at the coast was very low. From Figure 9.1 it seems that maize is preferred for oviposition east of the Rift Valley, whereas west of the Rift Valley it is the least preferred crop. This may have to do with maize varieties; var. Katumani and Coast Composite were grown in the east, and H-511 and H-614 were grown in the west.

Larval densities do not reflect the egg densities found at the different sites; at Lugari few eggs give rise to high numbers of larvae, while in Makueni low numbers of larvae were found after high numbers of eggs. This indicates that the degree of natural mortality is higher in some sites than in others. Larval densities were very low at the coast.

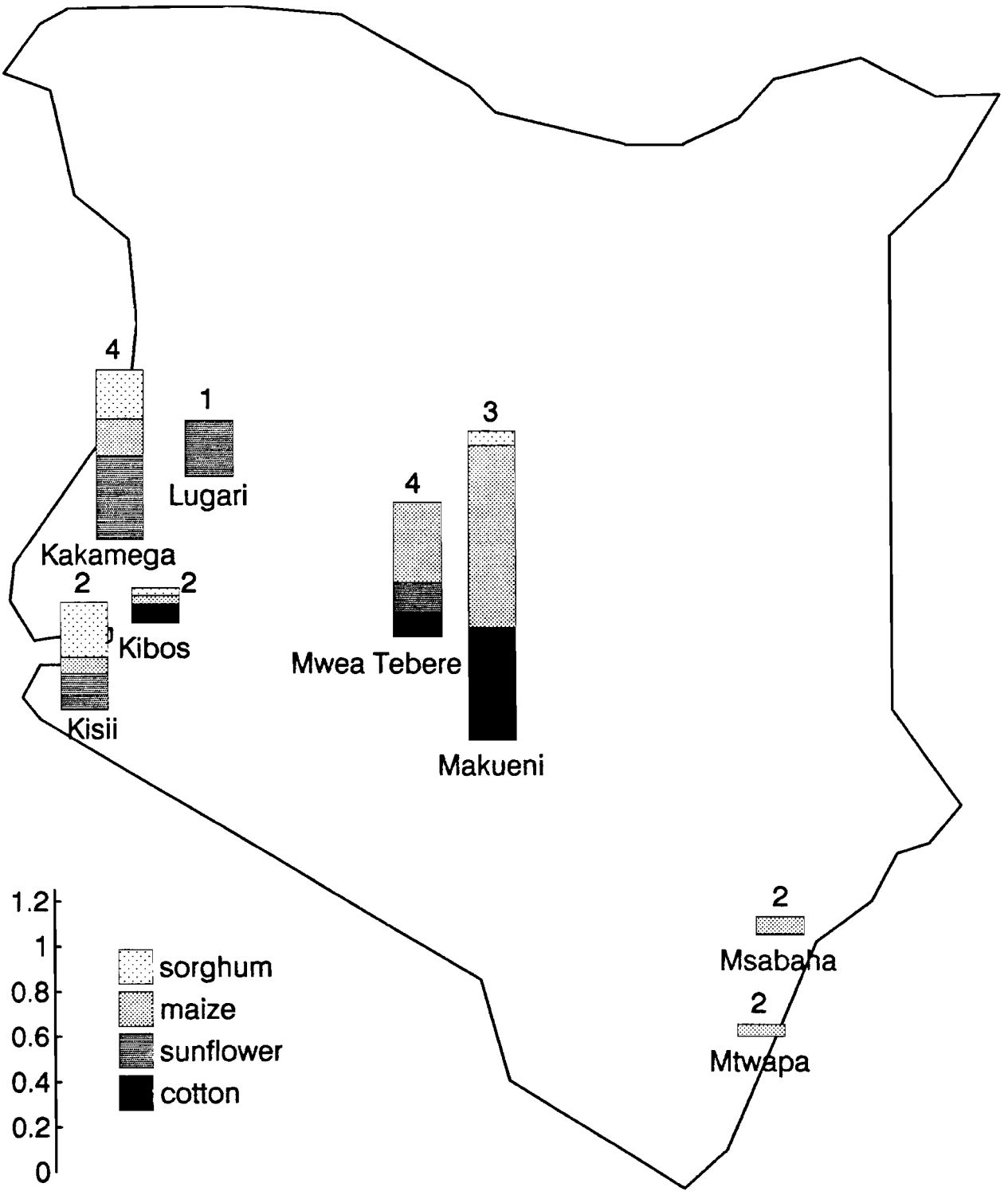

Figure 9.1. Occurrence of *H. armigera* eggs (average number per plant during the season, from the pre-flowering to ripening stage of the crop) in smallholder crops in Kenya, 1988-90. Numbers of sample seasons are indicated.

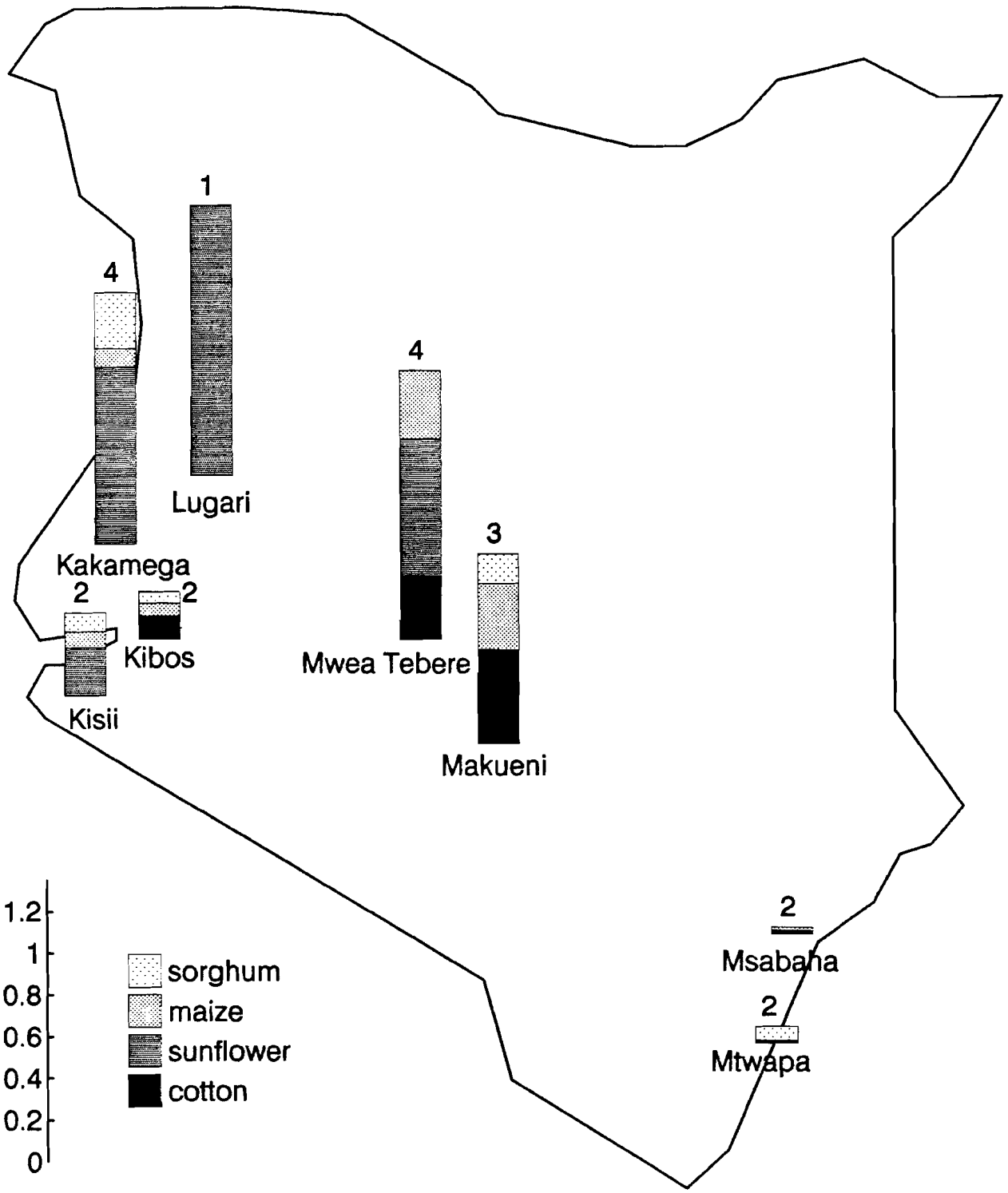

Figure 9.2. Occurrence of *H. armigera* larvae (average number per plant during the season, from the pre-flowering to ripening stage of the crop) in smallholder crops in Kenya, 1988-90. Numbers of sample seasons are indicated.

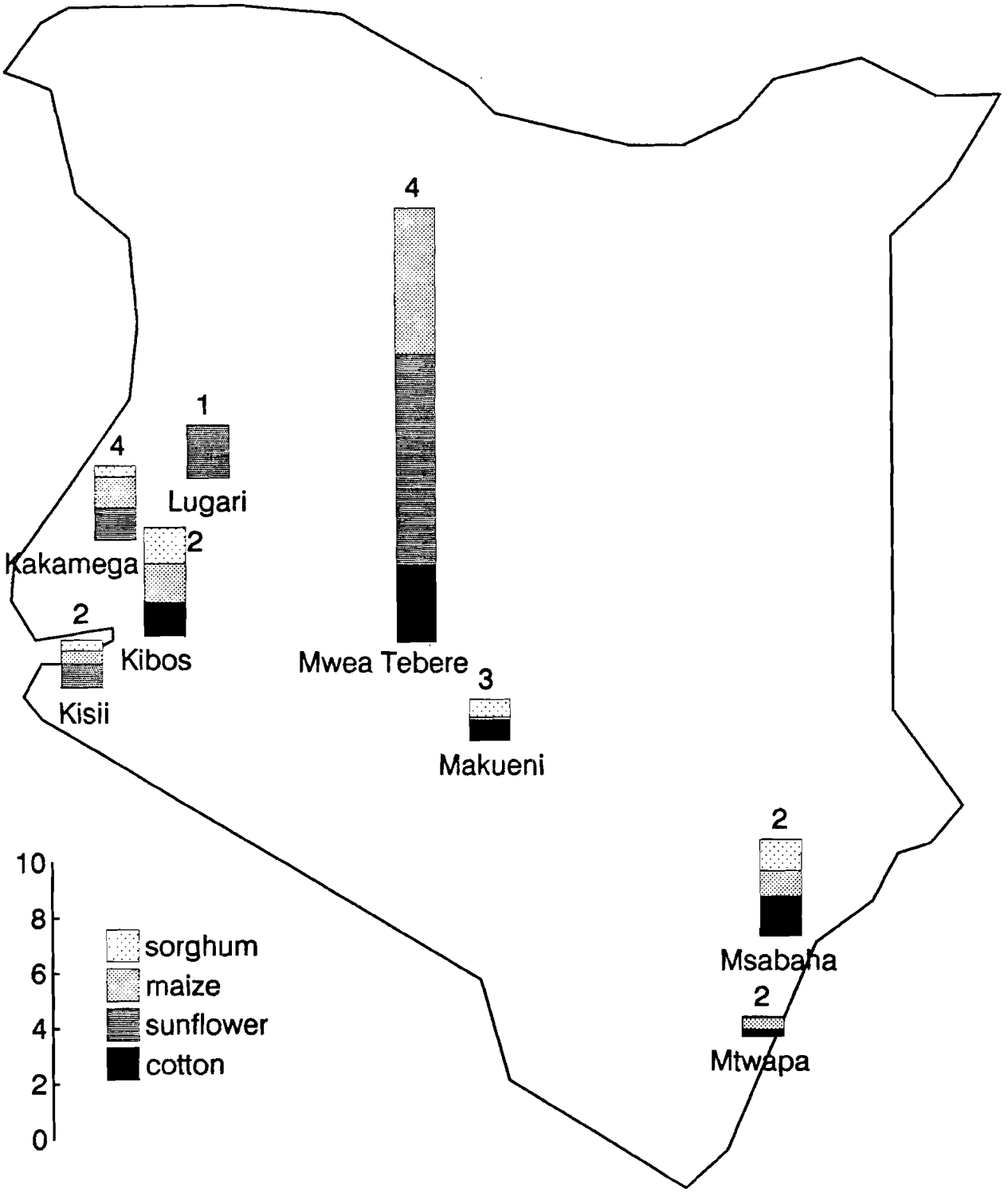

Figure 9.3. Occurrence of ants (average number per plant during the season, from the pre-flowering to ripening stage of the crop) in smallholder crops in Kenya, 1988-90. Numbers of sample seasons are indicated.

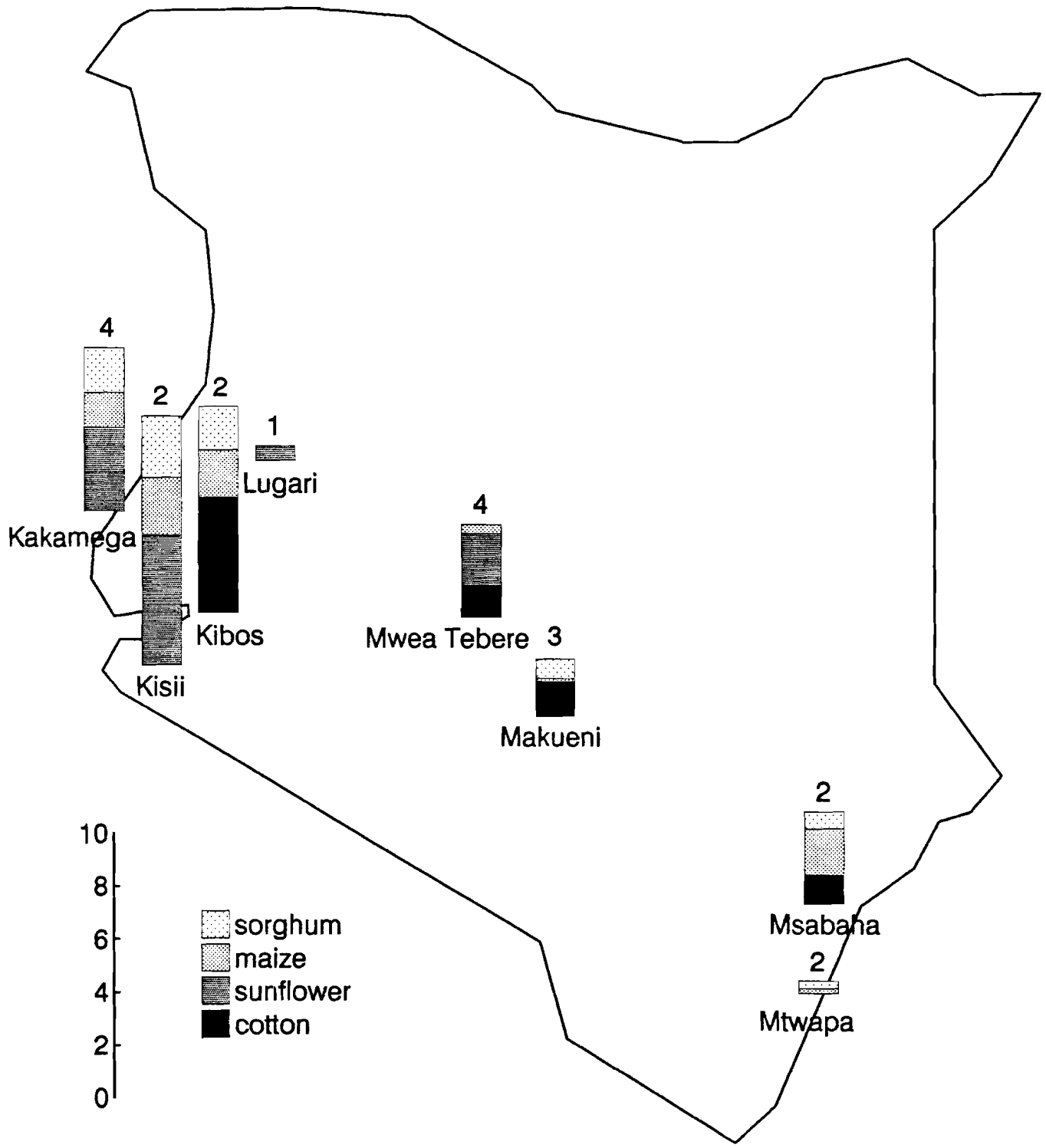

Figure 9.4. Occurrence of anthocorids (average number of adults and nymphs per plant during the season, from the pre-flowering to ripening stage of the crop) in smallholder crops in Kenya, 1988-90. Numbers of sample seasons are indicated.

10. Seasonal occurrence of ants and other predator groups in smallholder crops: pitfall trapping data.

Introduction

Densities of predators vary during the day, some being active at night, others during the day or during both day and night. When plants are sampled for predators during the day, the predators recorded are those that are active during that time, whereas nocturnal predators will be under-sampled during the day. Pitfall trapping overcomes this handicap, because it measures the predator activity on the ground surface during 24 hours per day, and does not under-sample certain species with respect to their time of activity.

Although pitfall traps do not measure activity on the plant where the eggs and larvae of *H. armigera* are situated, they do give a complete picture of the relative activity of predators on the ground surface. Moreover, pitfall trapping data are easy to obtain, and less subject to sampling variations or errors than plant-sampling data. For this reason, we used pitfall traps in addition to plant sampling to compare the seasonal occurrence of ant communities on the different crops.

In this section, we present pitfall trapping data for four different crops from Kakamega and Kibos, during four and two seasons respectively during 1988 to 1990. Results from Mwea Tebere and Makueni are also summarised.

Materials and methods

Pitfall jars (diameter 5.3 cm), filled with 1.5 cm of 5% formalin solution, were buried flush at the surface in the soil, and were roofed with a white-painted petri dish (diameter 9 cm), held on stiff wire about 8 cm above the jar, to keep rain and debris out. Six jars were put in a regular pattern in each of the replicated plots of sunflower, maize and sorghum at Kakamega, and cotton, maize and sorghum at Kibos (see Sections 5 and 6). After the first season (short rains 1989/90) at Kakamega, the experimental site was moved to a site nearby, and this strongly affected ant catches.

Traps were set weekly for six-day intervals. Catches from individual traps were put on 70% alcohol and were recorded at a later date.

Among the large complex of arthropods that are caught in pitfall traps, we focused on ants, because of their demonstrated on *H. armigera*.

Results and Discussion

Interpreting the data causes some problems. A high level of activity in a certain crop, could indicate a preference of ants for that crop. On the other hand, it is possible that ants do not like that crop, and consequently spend less time in the plants, and more on the ground surface where they are trapped. Therefore, comparison with plant data is desirable.

Kakamega

In general, ants were already present in the field when the crops were still very young. This contradicts earlier suggestions that ant communities are of little value to annual cropping systems because they take too long to build up in numbers (Carroll & Risch 1983). Figures 10.1 and 10.2 show that the build-up is rather quick, reaching a maximum at about the time that *H. armigera* larvae become abundant (for *H. armigera* data of the same sites see Sections 5 and 6).

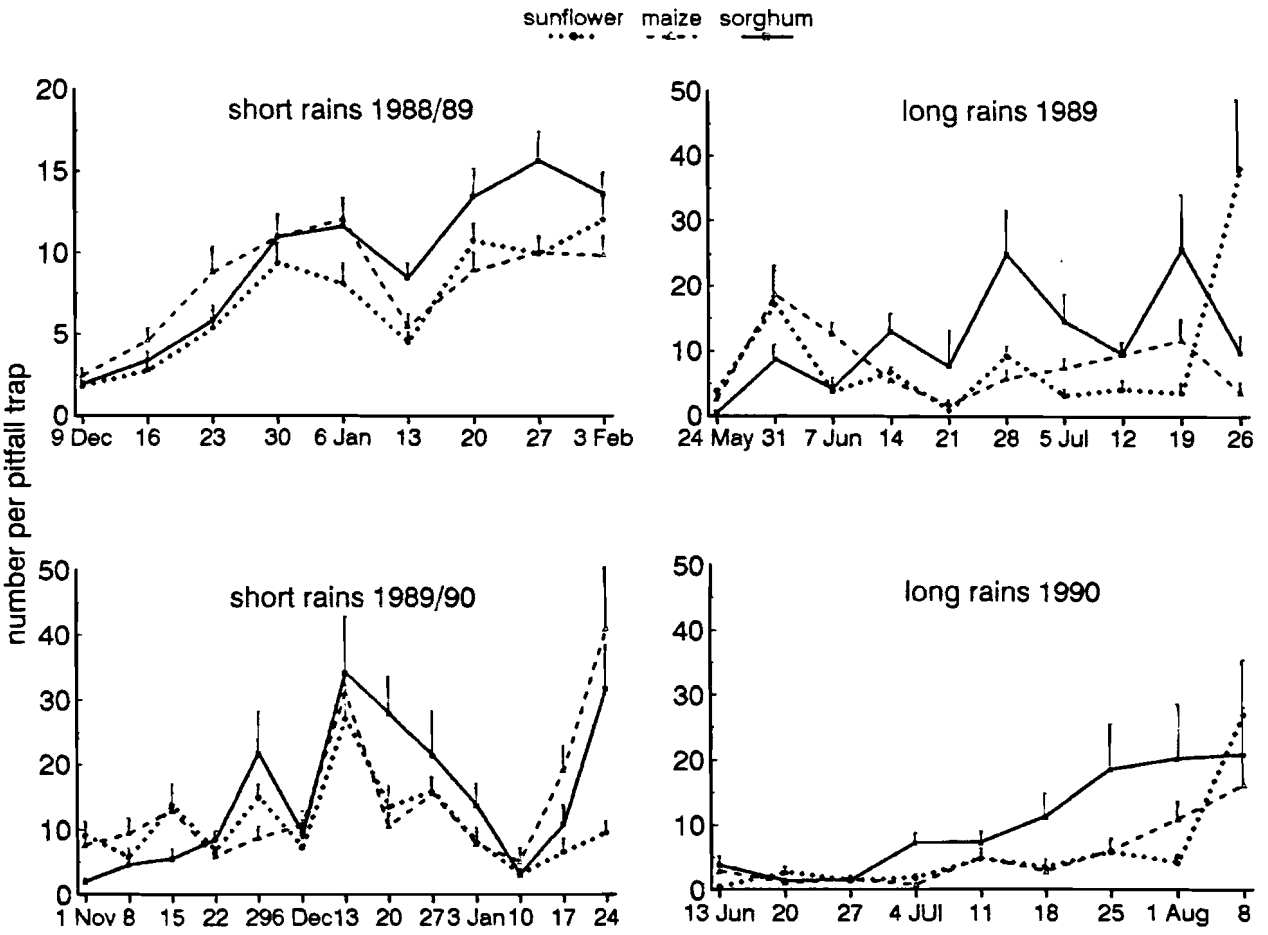

Figure 10.1. Seasonal catches of ant species in pitfall traps in three crops. Kakamega, 1988-90.

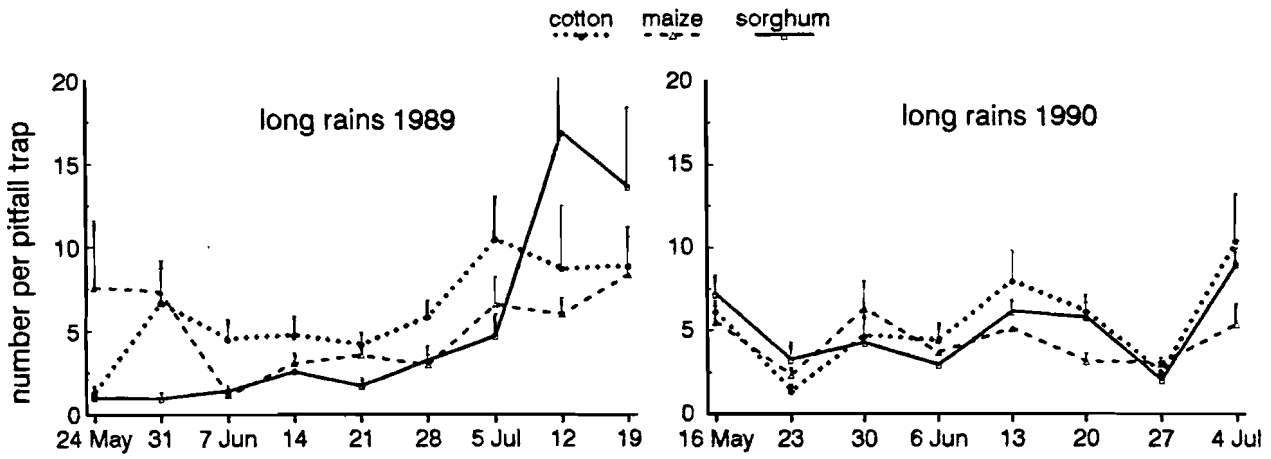

Figure 10.2. Seasonal catches of ant species in pitfall traps in three crops. Kibos, 1989-90.

During the short rains 1989/90, *Myrmicaria* sp. was predominant. Then, the plot was moved to a nearby site for the next three seasons. Here, *Pheidole* sp. was the predominant ant. Thus, the first graph (short rains 1989/90) shows predominantly the density of *Myrmicaria* sp., and the other three graphs show mostly the densities of *Pheidole* sp. The densities of *Myrmicaria* at the first site were lower than densities of the tiny *Pheidole* at the nearby site. Moreover, standard error bars are smaller for the former than for the latter. This indicates that *Pheidole* sp. was more aggregated or erratic in its distribution.

There are no strong differences between the crops studied. In general, ant activity towards the end of the season was slightly higher in sorghum plots than in sunflower or maize plots.

Kibos

As was the case at Kakamega, ants were already present in the field at Kibos when the crops were still young. Ant activity remained rather constant throughout the season. The diversity of ants at Kibos was higher than that of Kakamega, where only one dominant genus was found at a time. At Kibos, several species were common, but the most abundant were *Pheidole* sp., *Camponotus* sp. and *Myrmicaria* sp.

Generally, the ant activity was similar in the three crops, although it was slightly higher in cotton plots than in maize or sorghum plots.

Mwea Tebere

Among the arthropod fauna common in the pitfall traps were ants, beetles, crickets and spiders. On all the plots, ants were common, especially *Pheidole* sp. and the *Acantholepis* sp. (Ant 2). In all the crops, *Pheidole* sp. ants were most abundant from mid- to late- season, as was found when sampling the crop plants (Section 7). *Acantholepis* sp. were much less common. Whereas most of the *Pheidole* sp. ants were recovered from the cotton plot pitfalls, when sampling the plants there were most on sunflower. Most of the *Acantholepis* sp. were trapped in maize plots. *Pheidole* sp. were most abundant during the 1988-89 short rains season and their numbers decreased after every season, e.g. on cotton plots there were 130 ants/trap/week during the 1988-89 short rains season as compared to 12 ants/trap/week during the 1990 long rains season.

Makueni

Ants, beetles, spiders and crickets formed the bulk of arthropods sampled in the pitfall traps. *Pheidole* sp. ants were predominant, although *Camponotus* sp. ants were also trapped occasionally. Sorghum plots had the highest number of these two ant species, while pigeon pea plots had the least. The numbers recorded were lower than those for Mwea Tebere. More ants were collected during the long rains than during the short rains seasons. From high numbers early in the season, the numbers of ants trapped decreased to low numbers before increasing again as the crops began to mature.

11. Stage-specific predation on a field population of *Helicoverpa armigera* on cotton. I. Kibos

Introduction

Studies in previous sections (e.g. Section 5) have shown that natural mortality of *H. armigera* stages can be very high, but varies from season to season. The role of parasitoids and pathogens is small. Predation is likely to be an important mortality factor, with ants and anthocorids as the predator groups most likely to be important. Their effect was to be evaluated in exclusion trials. The present study uses glue barriers to exclude ants and other crawling predators, and a combination of glue barriers and a selective insecticide to exclude both crawling and flying predators. The study is designed such that stage-specific mortality can be estimated for each treatment. Recruitment of larvae for the generation was estimated using Southwood's method (see Section 5), whereas for eggs the actual daily influx was measured.

The objectives were (1) to assess the level of predation, and the prey stages at which predation occurs, by ants and by anthocorids on a natural population of *H. armigera*, and (2) to evaluate the role of irreplaceable predation in the overall mortality of *H. armigera* stages.

Materials and methods

Experimental field plot
At the Kibos Cotton Research Sub-Centre, Nyanza Province, a 1.2 ha field was selected that had not received pesticide applications during the previous two years. The plot was surrounded by a strip of weeds 1-5 m wide, and was separated from sprayed plots by at least 100 m. Cotton (BPA-75, spacing 90x30 cm) was planted on 16 March 1990. The experimental design was a 3x3 latin square (3 treatments and 3 replicates) of 9 individual plots (Figure 11.1). Individual plot size was 20x20 m. In order to reduce the movement of arthropods between the treatments, the distance between plots was 20 m. This was especially important for sprayed plots which could act as a 'sink' of natural enemies. The area between plots was initially planted with beans (GLP-2, spacing 45x15 cm), which are fast-maturing, and were already harvested before sampling of cotton began. The rest of the time, the area between the plots was kept clear of weeds, so as to create a barrier for natural enemies.

Ant barriers were put on all plants in the barrier and sprayed+barrier treatments. A ring of insect trap coating (tanglefoot) was placed around the stem of each plant at about 10 cm above the ground. To prevent crawling predators from crossing over weeds or via branches touching the ground, plots were kept clear of weeds and cotton branches touching the ground were cut. Control plots were weeded in the same way and branches touching the ground were cut. The sprayed+barrier treatment was also sprayed weekly with a very low dosage of triazophos (0.053 kg a.i. per ha.), using a knapsack sprayer. In preliminary trials, triazophos was the most promising of 3 tested chemicals in killing anthocorids at low dosages, while having least effect on *H. armigera*.

Meteorological data were obtained from the nearby Kisumu airport. Average temperature values were calculated from daily min.-max. values.

Sampling methods
Sampling was conducted weekly from monday to friday, as described in Section 2.2. Every week, 30 plants were sampled per treatment. Data were pooled per week. Sampling started 7 May 1990 (52 D.A.P) and continued until 17 August 1990 (154 D.A.P.).

H. armigera eggs and larvae were taken to the laboratory, for emergence of parasitoids (see Section 2.2).

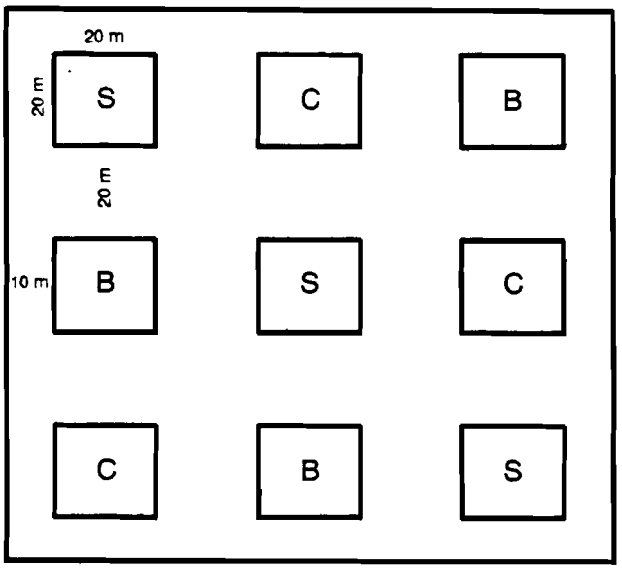

Figure 11.1. Layout of predator evaluation field plot, Kibos 1990.

Recruitment

For larvae, recruitment was estimated with Southwood's method, dividing the graphical area of the particular stage by its development period (see Section 5). Temperature-driven development was calculated from mean weekly temperature values (Figure 11.2), using the equations in Section 5. The first instar was excluded from recruitment estimates, because of under-sampling of this small stage. As discussed in Section 5, Southwood's method estimates, correctly speaking, not the number that enters a stage, but the number somewhere at the median of a stage, which is the resultant of the actual recruitment (N_r) minus the mortality that has already acted on the stage. For calculations of generational mortality, it is particularly important to measure true recruitment of the first stage into the system, the eggs. Therefore, we measured the actual influx of eggs.

For assessment of egg recruitment, 12 selected plants were checked every morning for eggs laid during the previous night, and any eggs laid were recorded and removed. Plants were used for 7 consecutive days, after which new plants were selected. The plants were selected with a random number table, 6 plants in unsprayed barrier plots, and 6 plants in sprayed barrier plots, in order to evaluate the effect of spraying on oviposition of *H. armigera*.

Results and discussion

Figure 11.3 shows the levels of *H. armigera* stages in the three treatments. Two distinct generations occurred during the season. Clearly, mortality was very high, with not much difference between treatments. Figure 11.4 shows that anthocorid densities were considerably lower in the sprayed+barrier treatment than in the other treatments. The level of ants (Figure 11.5) was effectively reduced in the barrier and sprayed+barrier treatments, but less so towards the end of the season.

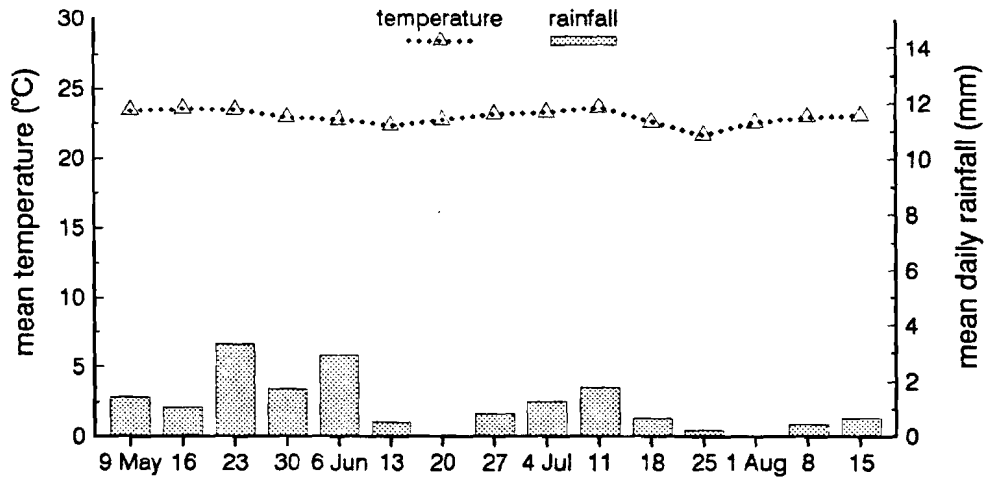

Figure 11.2. Mean temperature and mean daily rainfall during the sample season, pooled per week. Kibos, long rains 1990.

The daily recruitment of eggs is shown in Figure 11.6, where it can be seen that spraying had no effect on the rate of oviposition. Total egg recruitment during the season was 22.5 eggs per plant. Table 11.1 shows the recruitment and mortality of the different stages for each treatment.

Table 11.1. Recruitment (l_x) (number per plant) and percent mortality (100 q_x) of *H. armigera* in three treatments. Kibos, 1990.

	control		barrier		sprayed	
x	l_x	100 q_x	l_x	100 q_x	l_x	100 q_x
Generation 1						
Eggs[a]	8.50	91.6	8.50	94.4	8.50	96.2
L2-3[b]	0.72	65.4	0.48	24.0	0.32	27.5
L4-6[b]	0.25		0.36		0.23	
Total mortality		97.1		95.8		97.3
Generation 2						
Eggs[a]	14.00	97.0	14.00	93.9	14.00	95.2
L2-3[b]	0.42	71.6	0.86	93.7	0.66	86.7
L4-6[b]	0.12		0.05		0.09	
Total mortality		99.1		99.6		99.4

[a] Direct measurement of recruitment

[b] Estimate of recruitment, using Southwood's method

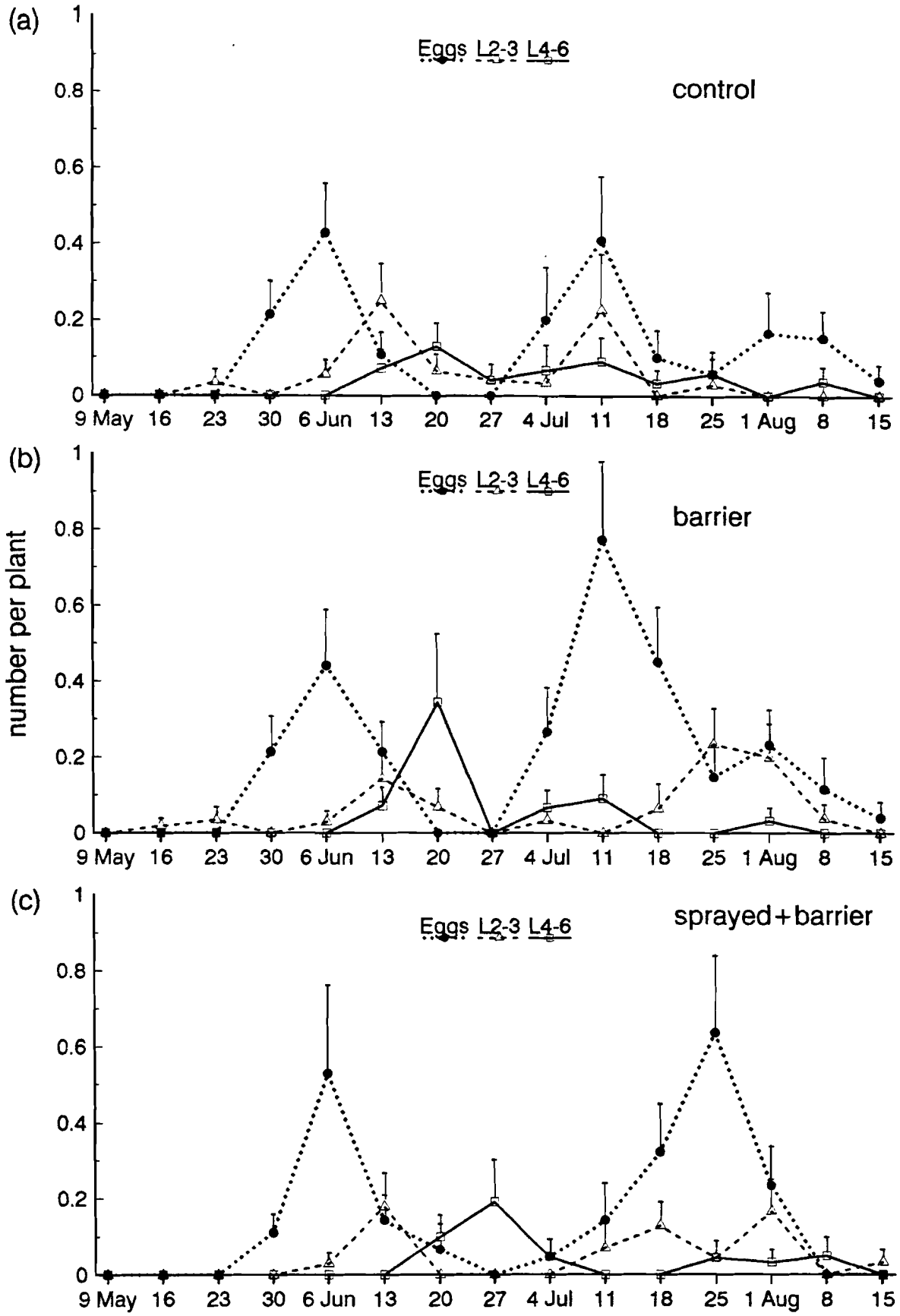

Figure 11.3. Seasonal densities of *H. armigera* stages in control, barrier and sprayed+barrier plots. Kibos, long rains 1990.

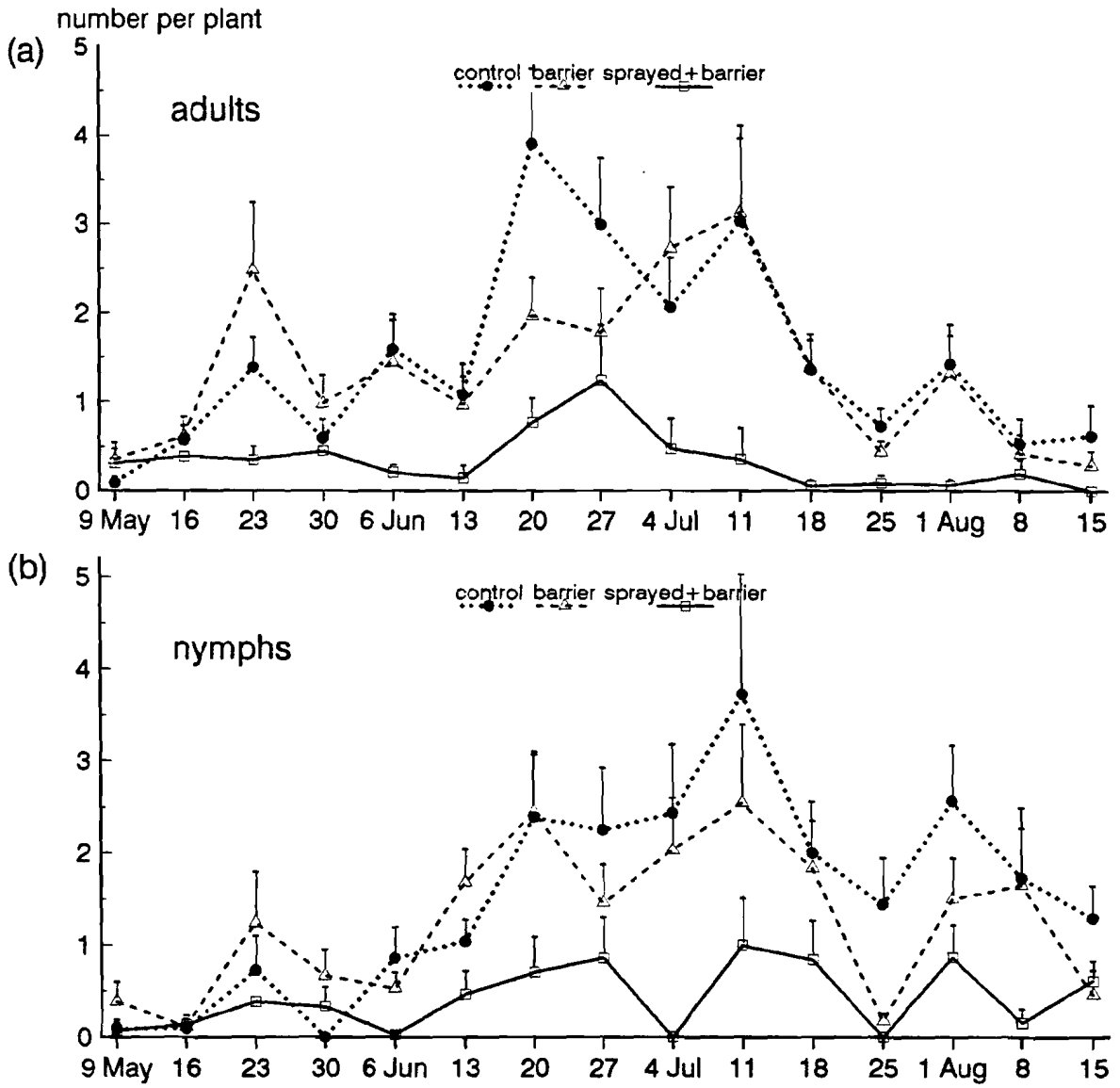

Figure 11.4. Seasonal densities of (a) *Orius* spp. and other anthocorids adults and (b) *Orius* spp. and other anthocorids nymphs, in control, barrier and sprayed+barrier plots. Kibos, long rains 1990.

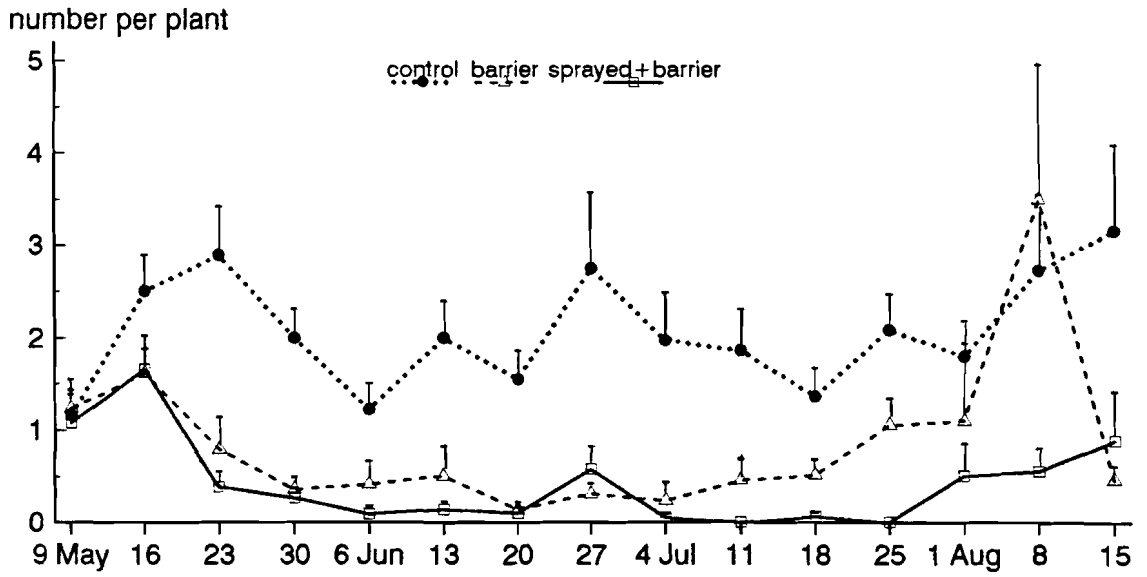

Figure 11.5. Seasonal densities ants in control, barrier and sprayed+ barrier plots. Kibos, long rains 1990.

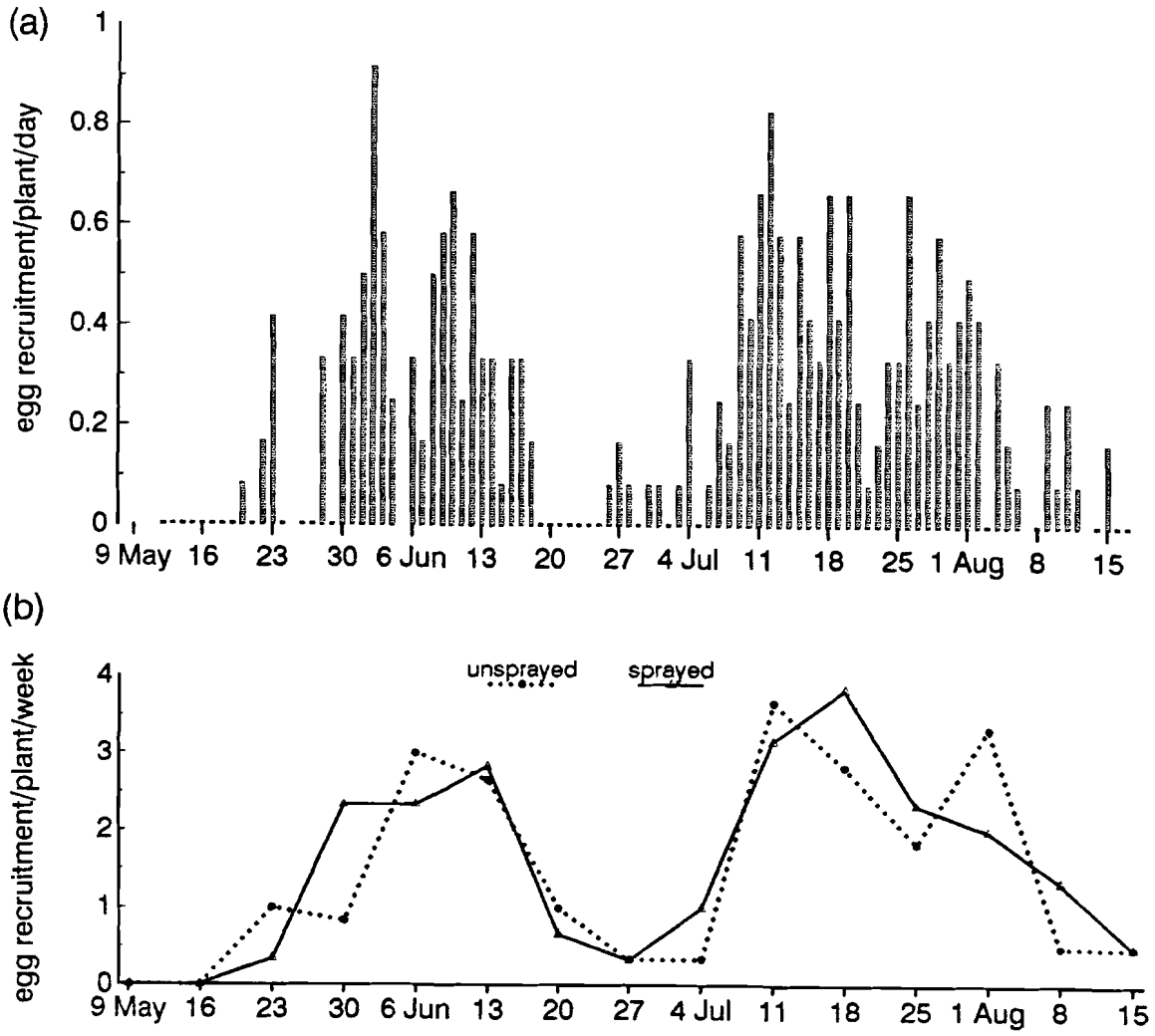

Figure 11.6. *H. armigera* Egg recruitment on cotton during the season; (a) daily recruitment per plant; (b) weekly recruitment per plant for plants in sprayed and unsprayed plots. Kibos, long rains 1990.

Mortality from eggs to L2-3 was high (92-97%) and could not be attributed to natural enemies. During the first generation, mortality from L2-3 to L4-6 was relatively low in the barrier and sprayed+barrier treatments, which indicates the role of ants, but the recruitment estimate of L4-6 was not different between the three treatments.

In the second generation, mortality from L2-3 to L4-6 was considerably higher than during the first generation.

Table 11.2 compares the egg recruitment (N_r) with the estimate N_s from Southwood's method. Clearly, egg recruitment is largely underestimated if based on N_s.

Table 11.2. Measured egg recruitment[a] N_r, compared with the estimate with Southwood's method (N_s).

	control	barrier	sprayed
N_r	22.5	22.5	22.5
N_s	3.1	4.8	3.7

[a] per plant over one crop season.

The discrepancy between N_r and N_s could be explained by (1) mortality that occurred during a particular stage (intra-stage mortality), or due to (2) sampling errors discussed below. Intra-stage mortality can be calculated as follows. If survival during the stage is assumed to be constant, the following relation exists between N_r and N_s (Sawyer & Haynes 1984; Van Driesche *et al.* 1989).

$$N_s/N_r = (S-1)/\ln S$$

S is determined by iteration. According to this equation, mortality within the egg stage is 99.93% in the control, 99.04% in the barrier, and 99.76% in the sprayed+barrier treatments, which seem unrealistically high. In other words, intra-stage mortality alone can not explain the discrepancy between N_r and N_s. However, the above equation, and Southwood's method alike, are only valid if young eggs are sampled with the same accuracy as older eggs, which is not true for *H. armigera* (Section 5).

Higher larval mortality in the second generation on cotton corresponds with a separate study on predator-excluded cotton (Section 13), and suggests a relation with the age of the crop. In the latter study, the establishment of *H. armigera* cohorts in the absence of predators decreased as the crop matured. Preferred feeding sites of *H. armigera* are the young squares (see Section 4). Although squares are still present in older cotton (Section 6), the plant grows in size and the availability of squares decreases. This suggests the role of host plant quality in population regulation of *H. armigera*.

Conclusions

The experimental design of this study provides an unambiguous measure of irreplaceable mortality due to predation. Although overall mortality of eggs and larvae was high, the irreplaceable role of predation appeared to be negligible. Differences in predator numbers between the treatments do not seem to affect the life-table. However, simultaneous field cage studies on cotton showed a strong impact of the local natural enemy complex on *H. armigera* cohorts; larval levels were 4.5-6.5 times higher in exclusion cages than in control cages (Section 13). Moreover, the egg exposures on cotton indicated a substantial impact of anthocorids.

Possibly, mortality rates in exclusion trials are higher than in the control, but the levels are obscured by the high natural mortality i.e. not due to predation. Total mortality is too high to detect the role of predation.

Another explanation could be that, although predator densities were considerably lower in the exclusion treatments, the predators present could have been relatively effective because of reduced competition.

Furthermore, it is noteworthy that the numbers of eggs introduced per plant in the cage study were many times higher than the local infestation level as observed in this section. The fact that predation is much higher in the cages than in this field trial might be due to a strong density response of predators. Hence, at high infestation levels of *H. armigera*, predator efficacy would be higher than in present study. Also in the cage study, all *H. armigera* are in the same stage, which might influence the effectiveness of different groups of natural enemies.

Finally, the low concentration of triazophos could have affected *H. armigera*, being an additional mortality factor in the sprayed treatment.

This study suggests that it is important to measure the impact of predators in the context of overall mortality, with all other natural mortality factors acting on a natural population of *H. armigera*. This gives the role of irreplaceable predation relative to other mortality factors. Exclusion trials that concentrate on one prey stage, or use artificial prey densities, may be misleading because they may not measure irreplaceable mortality.

12. Stage-specific predation on a field population of *Helicoverpa armigera* on cotton. II. Mwea Tebere

This experiment, parallel to that described in the last section, was run at Mwea Tebere in the long rains 1990 to measure the impact of crawling predators (especially ants) and flying predators (especially anthocorids) on the population dynamics of *H. armigera*.

Materials and methods

Experimental field plot
Cotton (variety UKA 59/240, spacing 100x30 cm) was planted in a plot of 1.4 ha at KARI's National Fibre Research Centre (NFRC), Mwea Tebere, in a layout similar to that described in the last section (Figure 11.1), although once again the treatments were allocated in a randomised latin square. Bean (variety GLP 2, spacing 50x100 cm) was planted between the plots and around the outside of the trial. The three treatments were as described in Section 11.

Meteorological data was obtained from the KARI NFRC Mwea Tebere.

Sampling methods
Weekly sampling of 30 plants per treatment was carried out as described in Section 2.2. Data were pooled for each week.

Recruitment
Larval and egg recruitment were estimated as described in Section 11.

Egg mortality
A separate experiment was set up from 28 June until 4 July, to estimate *H. armigera* egg mortality at that stage. This coincided with the week that predators numbers first increased significantly.

Four cages of 0.5mm nylon mesh (LxWxH 1.5x1.0.5x1.5) were each placed over five cotton plants from which all eggs of *H. armigera* and predators had been removed, the former manually following visual inspection, the latter by shaking the cotton plant to dislodge mobile predators. Two cages were placed in the barrier plots and the other two in the control. Fifteen three day old moths (males and females) were then released into each cage at dusk on 28 June. The moths were allowed to oviposit for two nights after which they were removed early on the morning of 30 June. The position of each egg on the plants was marked with liquid paper. A maximum of 12 eggs per plant was allowed and any excess was removed. In each treatment, one cage was then removed and the other left in position. The fate of the *H. armigera* eggs was then determined after a period of 96 hours, when the remaining eggs were taken to the laboratory and held to check for eclosion and parasitism. There was no rain during the experiment.

Results

The incidence of *H. armigera* stages in the three experimental conditions is shown in Figure 12.1. The population of *H. armigera* was low throughout the season. Considering the three treatments as a whole, oviposition was low, but more or less continuous throughout the season. The larval population is generally low, but by late in the season the trend is reasonably clear: the control plot has fewest larvae, while the sprayed+barrier has most.

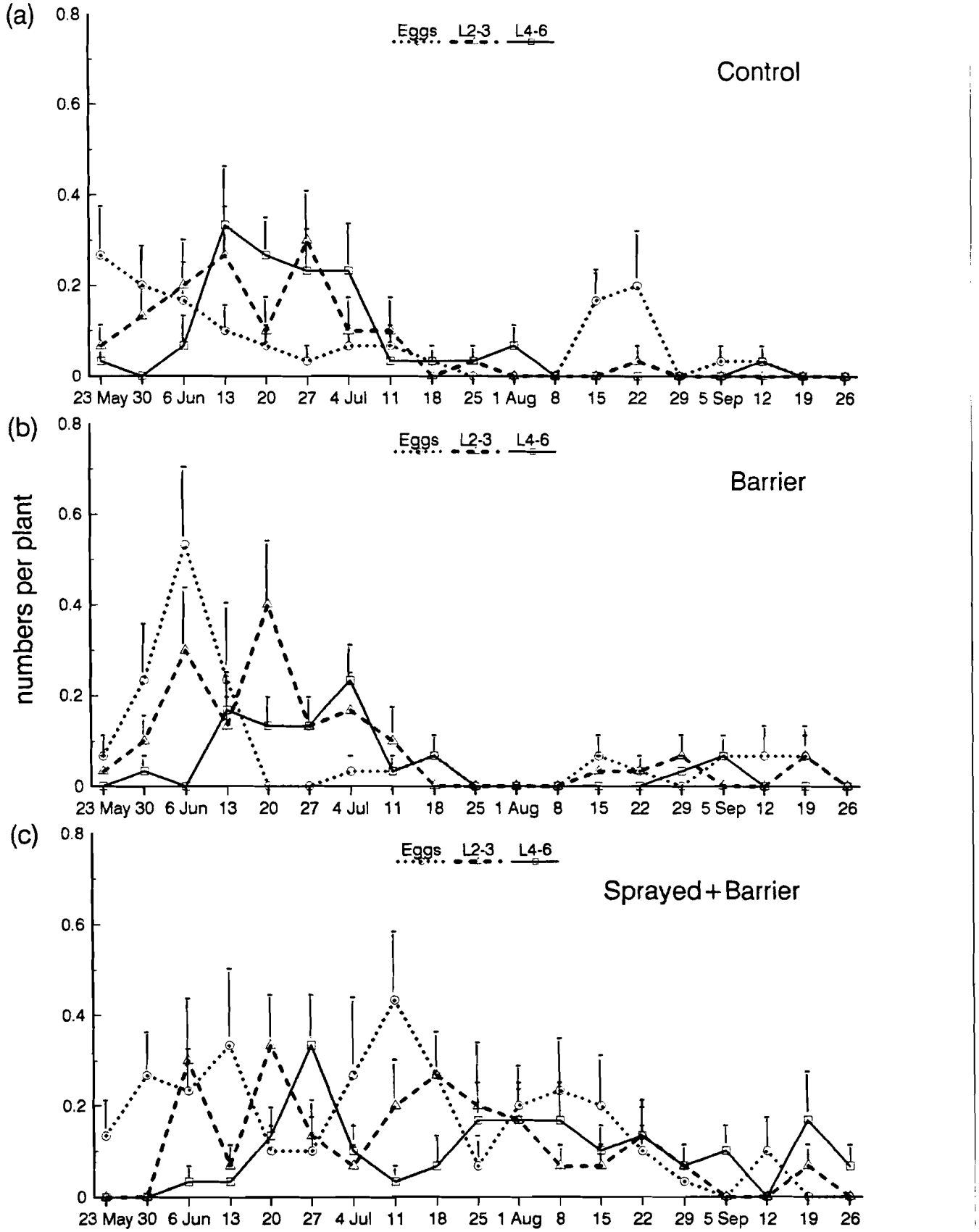

Figure 12.1. Seasonal densities of *H. armigera* stages in (a) control; (b) barrier; (c) sprayed + barrier plots. Mwea Tebere, long rains 1990.

The incidence of the predators of *H. armigera* in the three experimental treatments is shown in Figure 12.2. In the control plots, the population of the predators remained low until the beginning of July when *Orius* spp. nymphs and *Pheidole* sp. ants increased, before declining as the season progressed.

Ants were not observed on cotton plants in the barrier plots, showing that the barriers were successful. The population of *Orius* spp. nymphs and adults in the barrier plots followed a similar pattern to the control plot. Apart from a few *Orius* spp. observed at the beginning of the season, predators were absent from the sprayed+barrier plots.

Oviposition by *H. armigera* through the season is shown in Figure 12.3(a) as a daily rate and in Figure 12.3(b) as a weekly rate. Egg recruitment was sporadic throughout the season, and eggs were almost always present on the cotton plants, albeit in very low numbers.

The fate of the egg cohorts of *H. armigera* after 96 hours is shown in Table 12.1. There was no egg parasitism.

Table 12.1. The fate of egg cohorts of *H. armigera* exposed for 96 hours on cotton in the field in barrier and control plots with and without a covering nylon mesh cage. Mwea Tebere, long rains season, 1990.

Plot/Treatment	number exposed	% sucked	% eaten	% disappeared	total % mortality
BARRIER WITH CAGE	45	8.9	0	13.3	22.2
BARRIER WITHOUT CAGE	56	19.6	1.8	19.6	48.1
CONTROL WITH CAGE	56	19.6	5.4	8.9	33.9
CONTROL WITHOUT CAGE	46	23.9	8.7	32.6	65.2

Discussion:

In this study on the role of natural enemies on the incidence of *H. armigera*, both crawling and flying predators had access to the cotton plants in the control plots, *Orius* spp. had access to the barrier plots, but neither predator group survived in the sprayed+barrier plots. Thus the roles of these two groups of predators can be separated.

These predators are implicated in maintaining the *H. armigera* populations at low levels late in the season. This is supported by the sudden increase in the population of both *Orius* spp. and *Pheidole* sp. ants at the beginning of July, when the *H. armigera* population started to decline to low levels. In the absence of predators (sprayed+barrier plot), *H. armigera* larvae persisted in larger numbers throughout the season.

The total number of *H. armigera* eggs and larvae recovered from the plots from the beginning of July (when predators appeared) to the end of the season was 39, 40 and 136 from the control, barrier and sprayed+barrier plots respectively. Based on these figures, there were 71% fewer *H. armigera* when anthocorids and ants were present, and also 71% fewer *H. armigera* when anthocorids were present but not ants, implying that ants caused far less mortality than anthocorids.

In the egg exposure experiments the presence of the cages which exclude flying predators, leads to reduced predation by sucking predators, i.e. *Orius* spp. This effect was strongest in the barrier plots, emphasising the important regulatory role played by flying predators (*Orius* spp.). However, the largest mortality is due to disappearance in the control with neither barrier nor cage.

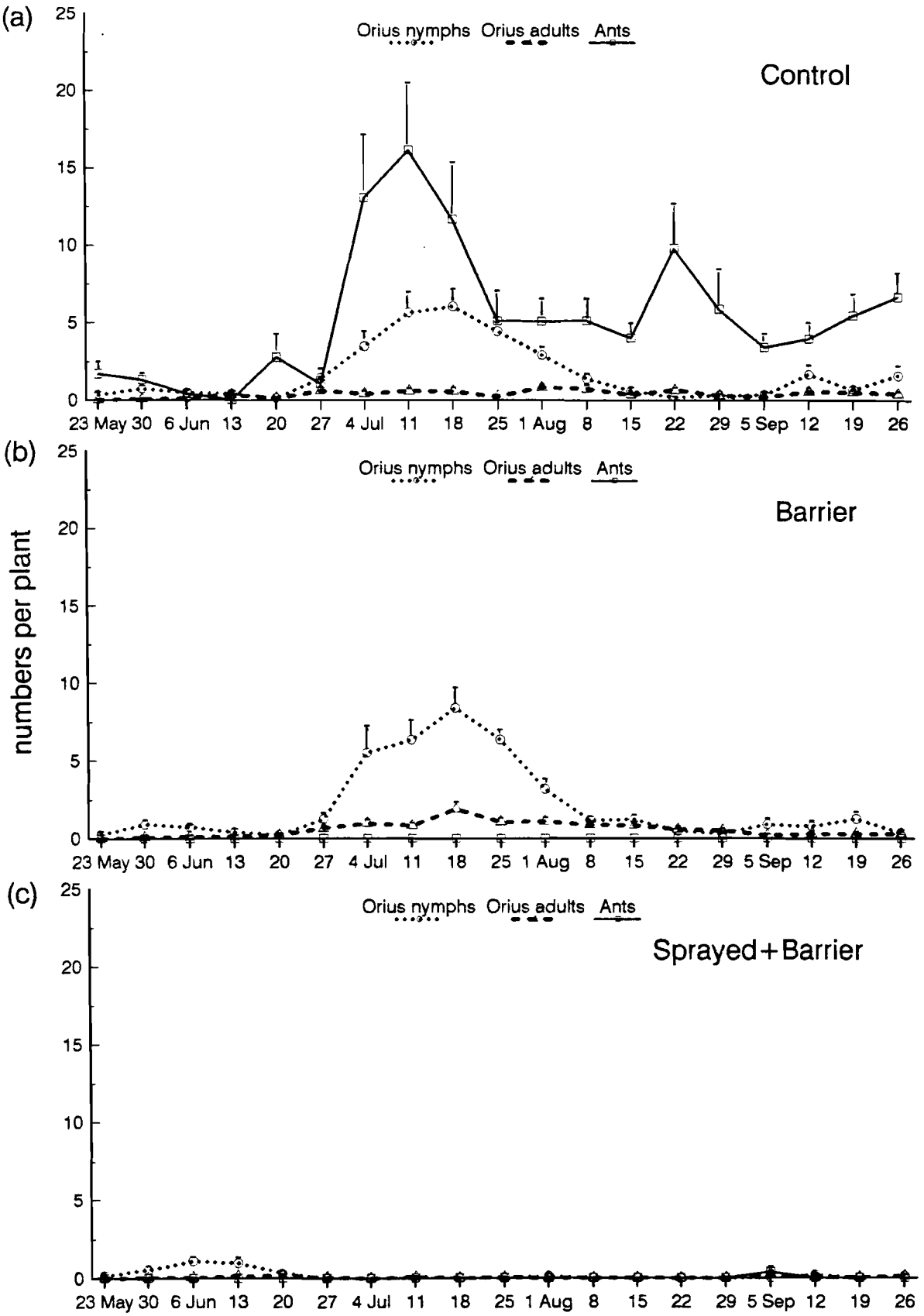

Figure 12.2. Seasonal densities of predators in (a) control; (b) barrier; (c) sprayed+barrier plots. Mwea Tebere, long rains 1990.

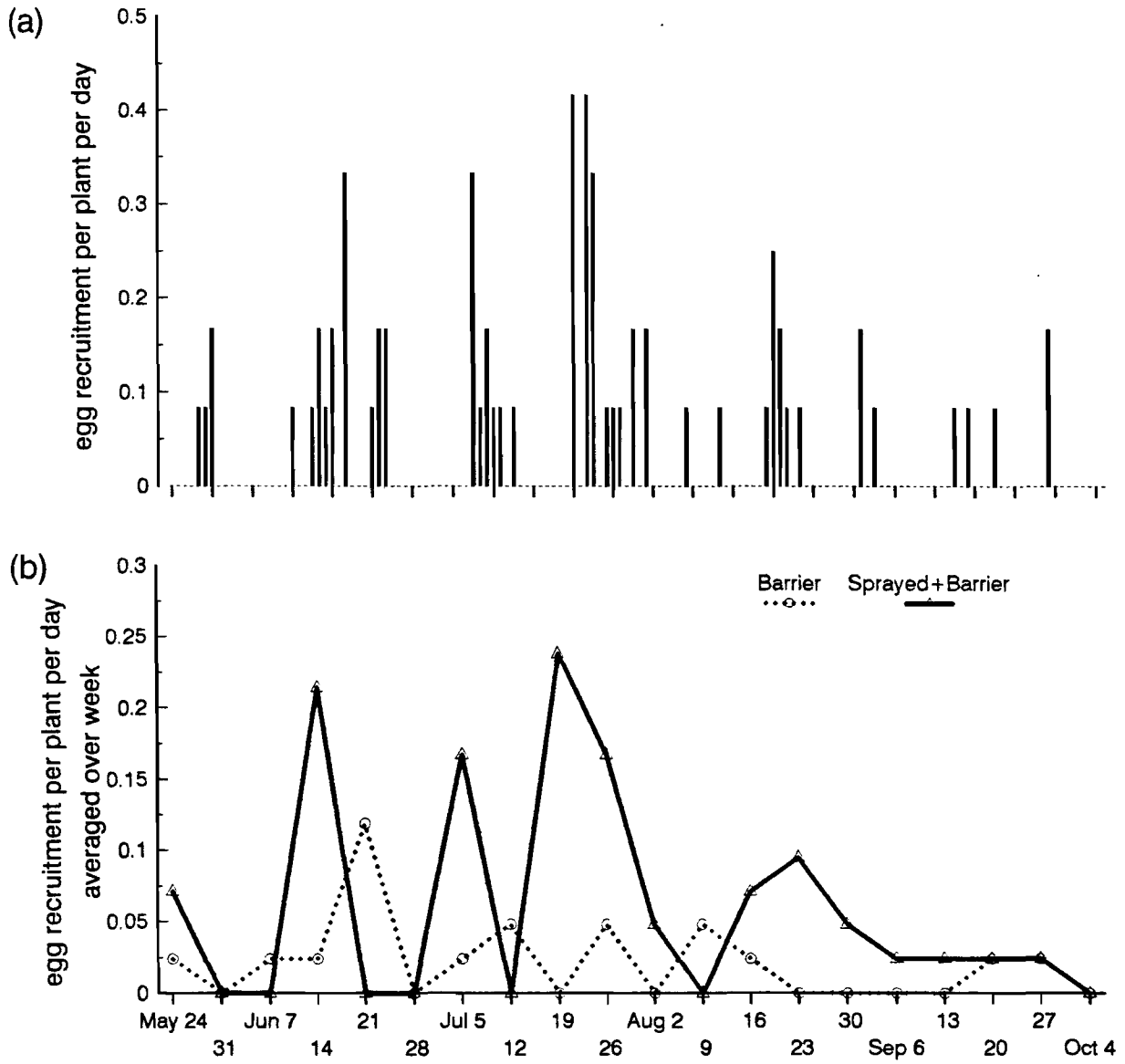

Figure 12.3. *H. armigera* egg recruitment on cotton during the season; (a) daily recruitment per plant; (b) weekly average daily recruitment per plant for plants in sprayed and unsprayed plots. Mwea Tebere, Central province, long rains 1990.

13. Cage studies on the impact of natural enemies on a cohort of *Helicoverpa armigera* on cotton

Introduction

The predator exclusion trials of the previous chapter are dependent on field infestation levels of *Helicoverpa armigera*. As shown in Sections 11 and 12, larval levels can be low, making it difficult to quantify the impact of natural enemies. Field cage experiments overcome this problem because of a smaller and more controllable environment. By introducing a known cohort of *H. armigera* into the cages, the impact of natural enemies on this cohort can be measured more quickly and more directly than in the trials above. Moreover, because of this small environment and the short experimental period, natural enemies can be excluded more effectively and with less side-effects on the pest.

The objective of this study was to measure the impact of natural enemies on *H. armigera*, and to compare the results of this experiment with that of the field trials of the previous section.

Materials and methods

The study was conducted at KARI's Cotton Research Sub-centre, Kibos, Nyanza Province. Cages (LxWxH, 4x2x1.8 m) were constructed using 8 bamboo poles connected with a top frame of metal wire, and covered with 0.5 mm nylon mesh. Cages were randomly assigned as exclusion cages or control cages. Exclusion cages had the bottom margin of the net buried 10 cm in the soil to keep predators out. Ants, which managed to enter the cage through the soil, were kept off the plants by a band of insect trap adhesive (tanglefoot), put on the base of every plant. Care was taken to avoid branches touching the nylon netting or the ground, and where necessary, parts of branches were cut off, and a similar number of branches was cut off in the control cages to keep the plants constant in each treatment. For the control cages, the lower margin of the net was lifted 30 cm above the ground to allow entry of local populations of natural enemies. Outside the control cages, any plants closer than 0.8 m to the cage were removed, in order not to encourage *H. armigera* larvae to leave the cage.

Eggs of *H. armigera* were obtained from the culture, and field-collected moths. Eggs were deposited on blue tissue paper which was cut into approximately 0.3-1 cm^2 pieces, such that each piece contained 3-8 viable (2-day old) eggs. Pieces of tissue paper were randomly allocated between the cages.

The tissue pieces per cotton plant were put inside the squares or, in the absence of squares, inside the flowers.

Larvae of *H. armigera* and possible predators were sampled 14 days after the inoculation. This was just before the cohort of *H. armigera* had reached their sixth instar, the most active stage that could leave the plants in the control cages. All plants in the cages were sampled, checking every individual plant part. Fruiting plant parts were counted and damage was recorded.

Trial 1 was conducted during the 1989/90 short rains. A 20x20 m plot of cotton BPA-75 was planted on 18th October 1989, at 90x30 cm spacing. In February 1990 four field cages, 2 predator exclusion and 2 controls, were set up in the plot. Exclusion cages in trial 1 were made predator-free by removing predators by hand; nymphs and adults of all potential predators (mainly predatory bugs, coccinellids, ants, cotton stainer, cotton seed bug and spiders) were removed daily starting four days prior to the experiment. It was particularly difficult to find all nymphs of anthocorids. Aphids were not removed.

Trials 2, 3 and 4 were conducted during the 1990 long rains. A 60x10 m plot of cotton BPA-75 was planted on 14th February 1990, at 90x30 cm spacing. Eight cages, four exclusion cages and four

controls, were set up in the plot. Four days prior to the inoculation, the plants in the exclusion cages were sprayed with cypermethrin (0.31 kg a.i. per ha.), a rapid action insecticide, to remove predators. One day after spraying, all predators had died.

For trial 3, the eight cages were transferred to cover new plants. Again, plants were sprayed and four days later inoculated with eggs. Because of very low levels of *H. armigera* during trial 3 and thus very little impact on the crop, cages were not transferred for trial 4, but new eggs were inoculated on the same plants as in trial 3.

Results and discussion

H. armigera

The results show obvious differences in *H. armigera* levels between the treatments; levels are 6.5 times higher in the exclusion treatment of the first trial (Table 13.1), and a factor 4.5 higher in the second trial (Table 13.2). In the third and fourth trials, very low levels of *H. armigera* established, even in the exclusion cages with virtually no predators (Table 13.3-13.4).

Table 13.1. Numbers of *Helicoverpa armigera*[a] and predators, and numbers of damaged and normal fruiting plant parts, in predator exclusion cages and open control cages. Cotton, 119 d after planting, February 1990, Kibos.

	Exclusion		Control		
	mean[b]	s.e.	mean[b]	s.e.	[c]
H. ARMIGERA					
Total larvae	2.567	0.335	0.400	0.132	**
PREDATORS					
Ants	0.133	0.079	5.300	1.554	**
Orius spp. adults	0.233	0.104	2.633	0.417	**
Orius spp. nymphs	1.967	0.382	4.200	0.733	n.s.
Others	1.300	0.333	0.500	0.134	n.s.
FRUITING PLANT PARTS					
Normal squares	0.186	0.076	3.250	0.376	**
Damaged squares	0.070	0.052	0.167	0.081	n.s.
Normal flowers	0.023	0.023	0.292	0.023	n.s.
Damaged flowers	0	0	0	0	
Normal bolls	1.070	0.192	1.583	0.273	n.s.
Damaged bolls	2.093	0.255	0.896	0.202	**
Total normal parts	2.465	0.333	4.604	0.494	**
Total damaged parts	2.246	0.322	1.063	0.241	**

[a] 14 days after inoculation

[b] per plant, with 22 plants sampled per cage

[c] DMRT, 95%

Table 13.2. Numbers of *Helicoverpa armigera*[a] and predators, and numbers of damaged and normal fruiting plant parts, in predator exclusion cages and open control cages. Cotton, 119 d after planting, June 1990, Kibos.

	Exclusion		Control		
	mean[b]	s.e.	mean[b]	s.e.[c]	
H. ARMIGERA					
Total larvae	2.70	0.24	0.576	0.120	**
PREDATORS					
Ants	0.027	0.019	1.394	0.188	**
Orius spp. adults	0.351	0.091	0.929	0.144	**
Orius spp. nymphs	0.500	0.09	0.586	0.111	n.s.
Others	0.595	0.136	0.646	0.093	n.s.
FRUITING PLANT PARTS					
Normal squares	5.256	0.383	6.831	0.333	n.s.
Damaged squares	3.952	0.331	2.000	0.156	**
Normal flowers	0.723	0.133	1.052	0.132	n.s.
Damaged flowers	1.253	0.242	0.364	0.078	**
Normal bolls	1.711	0.223	3.701	0.223	**
Damaged bolls	1.711	0.205	1.259	0.139	n.s.
Total normal parts	7.699	0.541	11.58	0.510	**
Total damaged parts	6.916	0.548	3.623	0.244	**

[a] 14 days after inoculation
[b] per plant, with 22 plants sampled per cage
[c] DMRT, 95%

Table 13.3. Numbers of *Helicoverpa armigera*[a] and predators, in predator exclusion cages and open control cages. Cotton, 163 d after planting, July 1990, Kibos.

	Exclusion		Control		
	mean[b]	s.e.	mean[b]	s.e.	[c]
H. ARMIGERA					
Total larvae	0.383	0.082	0.083	0.083	n.s.
PREDATORS					
Ants	0.217	0.095	2.467	0.492	**
Orius spp. adults	0.017	0.017	2.375	0.355	**
Orius spp. nymphs	0.016	0.016	4.500	0.580	**
Others	0.083	0.083	0.633	0.156	**

[a] 14 days after inoculation
[b] per plant, with 22 plants sampled per cage
[c] DMRT, 95%

Table 13.4. Numbers of *Helicoverpa armigera*[a] and predators, and numbers of damaged and normal fruiting plant parts, in predator exclusion cages and open control cages. Cotton, 174 d after planting, August 1990, Kibos.

	Exclusion mean[b]	s.e.	Control mean[b]	s.e.	[c]
H. ARMIGERA					
Total larvae	0.552	0.097	0.009	0.009	**
PREDATORS					
Ants	0.010	0.010	1.094	0.203	**
Orius spp. adults	0.031	0.018	0.660	0.184	**
Orius spp. nymphs	0.021	0.015	0.660	0.158	**
Rest	0	0	0.160	0.047	**
FRUITING PLANT PARTS					
Normal squares	2.255	0.245	2.396	0.270	n.s.
Damaged squares	1.796	0.213	1.822	0.207	n.s.
Normal flowers	0.684	0.108	0.921	0.132	n.s.
Damaged flowers	0.878	0.123	0.703	0.118	n.s.
Normal bolls	5.867	0.454	5.010	0.399	n.s.
Damaged bolls	3.806	0.305	3.337	0.304	n.s.
Total normal parts	8.806	0.596	8.832	0.539	n.s.
Total damaged part	6.480	0.466	5.861	0.456	n.s.

[a] 14 days after inoculation

[b] per plant, with 22 plants sampled per cage

[c] DMRT, 95%

Table 13.5 shows the mortality of *H. armigera* during the experiment in the predator exclusion cages, based on the number of inoculated viable eggs per plant and the number of larvae per plant 14 days after inoculation. Mortality is considerably higher in the last two trials, and may be related to the age of the crop. A separate study on cotton showed that the second generation of *H. armigera* suffered higher mortality than the first generation, and this mortality was not attributable to natural enemies (Section 11). This may have important implications for IPM strategies to be developed. This mortality factor, which is related to crop age and which is not due to natural enemies, could be due to failure of larvae to establish on the plants, e.g. because of a lack of favourable feeding sites. Preferred feeding sites of young larvae are the squares and the soft growing parts of cotton (see Section 4).

Predators

Predator densities given in Table 13.1-13.4 were measured at the end of the experiment (i.e. 16 d after spraying). However, during the experiment, predator densities in the exclusion cages were lower than that, especially at the beginning of the experiment just after spraying predators were virtually absent, when the *H. armigera* cohort was in its vulnerable egg and early larval stages.

Fruiting plant parts

Although the experiments lasted for only 14 days, there was in this time an effect of predator exclusion on the fruiting plant parts in trial 1 and 2. There was no effect on the fruiting plant parts in trial 4, when the crop was maturing, but larval levels were low.

Table 13.5. Natural mortality of *H. armigera* in predator exclusion cages.

date	days after planting	plants per cage	viable eggs at inoculation	larvae 14 d after inoculation	% mortality
February 1990	119	22.3	6.6-17.5	2.67	61-85
June 1990	119	21.1	7.1-18.9	2.7	62-86
July 1990	163	26.8	5.6-14.9	0.38	93-97
August 1990	174	25.6	5.9-15.6	0.55	91-97

Conclusions

This study shows that in the absence of natural enemies, *H. armigera* were 4-6 times as numerous, and there was a corresponding increase in damaged plant parts.

The impact of predators was much higher in this study than in the field trial of Section 11, and possible reasons why this impact was not observed in the field trial have been discussed in that section.

In conclusion, this study shows natural enemies can have a high impact on *H. armigera*, and are important in controlling the pest. However, such exclusion studies should always be evaluated in the context of life-table studies of the pest, in order to evaluate what the observed impact means under local field conditions.

14. Predation and parasitism of egg cohorts of *Helicoverpa armigera* on sunflower and cotton.

Introduction

In the studies of Sections 5 and 11 it appears that mortality of *Helicoverpa armigera* mostly occurs during the early developmental stages, i.e. during the egg stage, or somewhere between the egg stage and the young larval stages (L2-3). Life-tables, however, do not answer exactly where mortality occurs, or what the different mortality factors contribute.

With the exception of parasitism and pathogens, the impact of factors such as predation or disappearance of eggs remain largely unknown from field samples in life-table studies.

Placement of marked cohorts of eggs on plants in the field provides a useful tool for measuring the impact of different mortality factors during the development period of the egg. This method also provides a better measurement of egg parasitism than through field samples, because the percent parasitism values do not have to be corrected for sample errors (see van den Berg *et al.* 1988).

This so-called prey-enrichment method applies to sessile stages such as eggs, although there have been studies where larvae were tethered to plants (Weseloh 1982).

In this section we present the fate of egg cohorts exposed on sunflower and cotton. Studies on sunflower were conducted at Kakamega, studies on cotton were conducted at Kibos and Mwea Tebere.

Materials and methods

Prey enrichment
Egg cohorts were laid by moths on sunflower or cotton plants which had been manually cleared of eggs. Just before dawn, 6-12 moths (from light trap catches and culture; sexes mixed) were released in each of the 0.5 mm mesh diameter nylon cages (LxWxH, 0.7x1x1.5 m) covering a row of 3 cotton plants inside the control plots. Next morning at 8 a.m., the newly deposited eggs were marked by putting a small dot of liquid paper at a distance of 0.5-1 cm from the egg, away from the base of the plant. The number of eggs per plant ranged from 1 to 20. When more than 20 eggs were laid per plant, the surplus was removed. Marked eggs were left for 48 hours, and then the fate of the eggs was recorded. Predation by sucking predators could be recognised by a characteristic collapse of the egg. Eggs were recorded as disappeared even when remains of the egg were found which was characteristic for chewing predators. It is unknown how many eggs had dropped (e.g. by leaves touching each other). Remaining eggs were reared individually in ventilated tubes for emergence of parasitoids.

Egg development period
We measured the development period of eggs under field conditions, on sunflower at Kakamega and on cotton at Kibos. In June 1990, eggs were laid by moths on sunflower plants and cotton using the same methods as above. Eggs were numbered and checked regularly, starting from 3.5 days after oviposition until all viable eggs emerged. At Kakamega, the eggs were checked at regular intervals as shown in Figure 14.1. At Kibos, the interval at which eggs were checked ranged from 1.5 hour at peak emergence to 6 hours towards the end of the experiment.

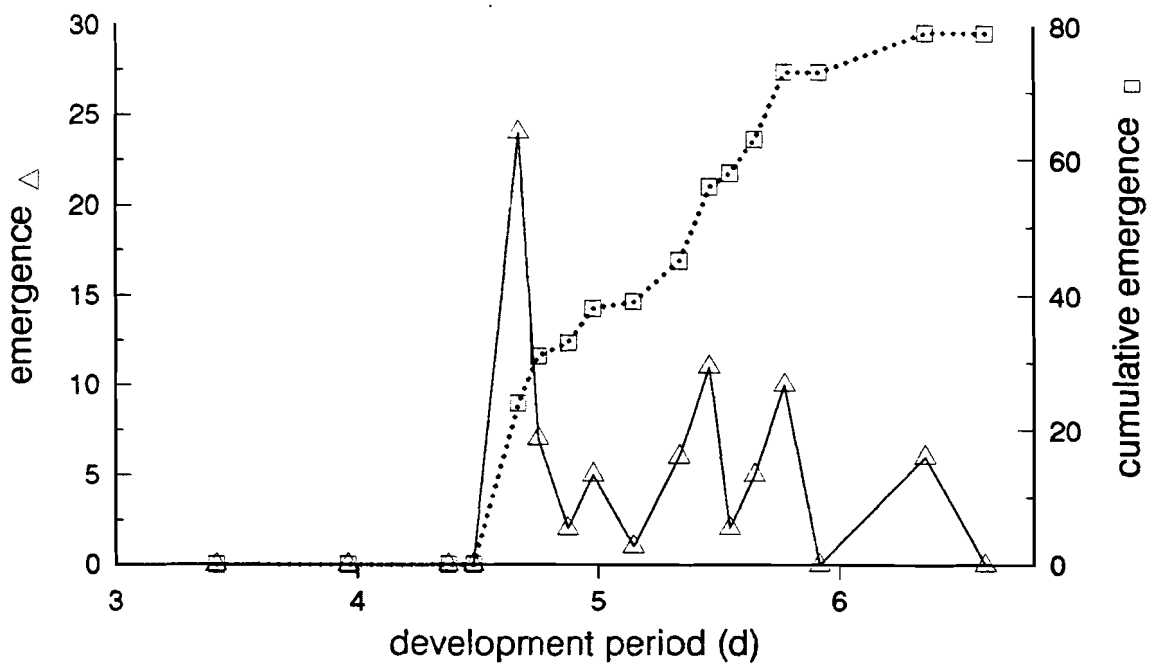

Figure 14.1. Development period of a cohort of eggs of *H. armigera* on sunflower in the field. Kakamega 1990.

Results and discussion

Table 14.1 shows the fate of eggs on sunflower in Kakamega. Sucked eggs were not recorded separately at Kakamega, but were included under the heading "predation and disappearance". Predation and disappearance within 48 hours ranged from 14 to 42 %. Parasitism was nil. At Kakamega, the egg development period is 5.2 days (Figure 14.1), which means that eggs are normally exposed to mortality factors for a period 2.5 times longer than in this experiment. Therefore, it is anticipated that the impact of predation and disappearance of eggs over such a longer period will be higher than measured here. However, young eggs are more attractive to parasitoids, and the same may be true for predators.

At Kibos, predation by sucking predators was recorded separately. Predation by sucking predators could be recognised by characteristic collapsed egg chorion. The only common sucking predators at Kibos were anthocorids of the genus *Orius* spp. Predation events were observed regularly in the field, both by anthocorid adults and nymphs.

Table 14.2 shows the fate of eggs on cotton at Kibos. Each of the factors disappearance, parasitism and predation by sucking predators had a considerable impact on the eggs. The combined impact of these factors over 48 hours could be as high as 78%. Again, this only involves mortality during the first two days of the egg stage, and does not include mortality of older eggs, egg infertility and mortality during or after emergence. At Kibos, the development period of eggs of *H. armigera* is 4.2 days.

Table 14.1. Fate of egg cohorts of *H. armigera* exposed on sunflower in the field, Kakamega.

date	n[a]	disappeared[b]	parasitism[c]
1 June 89	95	32.6	0.0
15 June 89	38	42.1	0.0
17 June 89	99	14.1	0.0
25 June 89	66	13.6	0.0
9 July 89	104	22.1	0.0
1 December 89	64	26.6	0.0
23 July 90	54	20.4	0.0

[a] number of eggs exposed
[b] due to predation and other causes, including sucked eggs
[c] percent parasitism of remaining eggs

Table 14.2. Fate of egg cohorts of *H. armigera* exposed on cotton in the field. Kibos 1989/90.

date	n[a]	% sucked[b]	% disappeared[c]	% parasitism[d]	total % mortality
6 June 1989	114	12.3	27.2	21.0	52.2
5 July 1989	52	15.4	11.5	11.5	35.4
18 July 1989	89	40.4	12.4	9.1	57.1
17 July 1990	85	64.7	8.2	19.0	78.1
24 July 1990	60	55.0	13.3	0.0	68.3

[a] number of eggs exposed
[b] eggs consumed by predators with sucking mouth parts; Orius spp. were the only common sucking predators
[c] due to predation and other causes
[d] percent parasitism of remaining eggs

Figure 14.2 shows that there is no correlation between the density of anthocorids and the level of sucked predation (by anthocorids). This is surprising, and suggests that the effectiveness of anthocorids is influenced by other factors (e.g. weather conditions, alternative food, plant size). Therefore, it might be difficult to predict the level of predation from *Orius* densities.

Table 14.3 shows the predators with sucking mouthparts, and the parasitoids that attack the eggs of *H. armigera* in western Kenya.

The impact of predation and parasitism on egg of *H. armigera* is higher on cotton in Kibos than on sunflower in Kakamega.

In conclusion, this study shows natural enemies can have a high impact on eggs of *H. armigera*, and are thus likely to be important in controlling the pest. However, such studies should always be evaluated in the context of life-table studies of the pest, in order to understand what the observed impact of natural enemies means in terms of irreplaceable mortality of *H. armigera*.

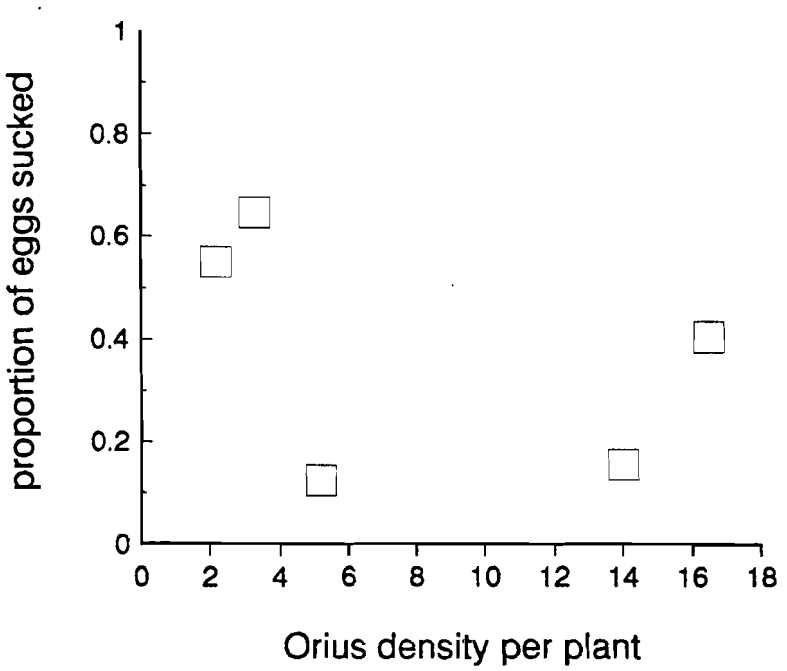

Figure 14.2. Relation between density of *Orius* spp. (including other anthocorids) and the level of sucking predation. Kibos, 1989-90.

Table 14.3. Predators and parasitoids attacking eggs of *H. armigera* in western Kenya, 1989-90.

TRICHOGRAMMATIDAE

Trichogrammatoidea armigera Nagaraja
Trichogrammatoidea eldanae Viggiani
Trichogrammatoidea lutea Girault
Trichogrammatoidea simmondsi Nagaraja
Trichogramma sp.

ANTHOCORIDAE

Orius albidipennis (Reuter)
Orius tantillus (Motschulsky)
Orius thripoborus (Hesse)
Orius sp. A (nr. *thripoborus*)
Orius sp. C
Blaptostethus sp.
Cardiastethus exiguus (Poppius)
Cardiastethus sp.

15. Stage-specific predation of a field population of *Helicoverpa armigera* on sunflower.

Introduction

Studies in Section 5 have shown that natural mortality of *H. armigera* stages in sunflower can be very high, but varies from season to season. The role of parasitoids and pathogens is small. Predation is likely to be an important mortality factor, with ants and anthocorids as the most important predator groups, but its effect has to be evaluated in exclusion trials. The present study uses glue barriers to exclude ants and other crawling predators, and a combination of glue barriers and a selective insecticide to exclude, both, crawling and flying predators. The study is designed such that stage-specific mortality can be estimated for each treatment. Recruitment of the generation of larvae was estimated using Southwood's method, whereas for eggs the actual daily influx was measured.

The objectives were (1) to assess the level of predation, and the prey stages at which predation occurs, by ants and by anthocorids on a natural population of *H. armigera*; and (2) to evaluate the role of irreplaceable mortality due to predation in the overall mortality of *H. armigera* stages.

Materials and methods

Experimental field plot
A 1.4 ha field was selected that had previously been grown with maize. The plot was separated from sprayed plots by at least 100 m. Sunflower (var. Comet, spacing 75x30 cm) was planted on 16 March 1990. The experimental design was a 3x3 latin square (3 treatments and 3 replicates) of 9 individual plots (Figure 15.1), with a plot size of 20x20 m, and a distance between plots of 20 m. This was to reduce the movement of arthropods between treatments, because sprayed plots could act as a 'sink' for natural enemies. The area between plots was initially planted with beans (GLP-2, spacing 45x15 cm), which are fast-maturing, and were already harvested before sampling of sunflower began. Afterwards, the area between the plots was kept clear of weeds, so as to create a barrier for natural enemies.

Ant barriers were put on all plants in the barrier and sprayed+barrier treatments. A ring of tanglefoot insect trap adhesive was placed around the stem of each plant at about 15 cm above the ground. To prevent crawling predators from gaining access to plants via weeds, plots were kept clear of weeds. Control plots were weeded accordingly. Starting from 22 June 1990, flower heads in the sprayed+barrier treatment were sprayed weekly with a low dosage of triazophos (0.071 kg a.i. per ha), using a knapsack sprayer (see Section 11).

Sampling methods
Sampling was conducted weekly from monday to friday, during the morning hours (7.30-11.00 a.m.) to avoid the hottest time of the day. Plants were selected with a random number table, to select row numbers and plant numbers in a row. The sampling procedure is described in Section 5. Weekly, 30 plants were sampled per treatment. The average time spent sampling per plant was approx. 25 minute, depending on the plant age. Data were pooled per week. Sampling started 7 May 1990 and continued until 25 July 1990, just before harvest.

H. armigera eggs and larvae were taken to the laboratory, and held for emergence of parasitoids (Section 2.2).

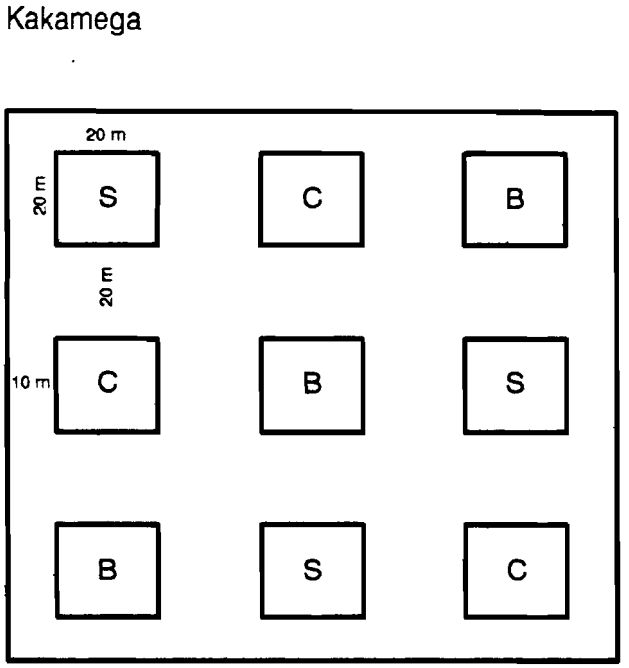

Figure 15.1. Layout of predator evaluation field plot, Kakamega long rains 1990.

Estimation of recruitment

For larvae, recruitment was estimated by Southwood's method, dividing the graphical area of the stage concerned by its development period (see Section 5). The development periods depend on the temperature. Temperature-dependent development of *H. armigera* has been studied in detail by Twine (1977). Derived from his data, Figure 15.2 shows the regressions for the relevant sets of instars. In addition, two data points for eggs, obtained from the field in western Kenya, are shown. The mean weekly temperature values at Kakamega are shown in Figure 15.3. Temperature-driven development rates are now calculated for every week using the regression equations from Figure 15.2, and recruitment estimates derived accordingly. The first instar was excluded from recruitment estimates, because of undersampling of this small stage.

Egg recruitment

As discussed in Section 5, Southwood's method estimates, correctly speaking, not the number that enter a stage, but the number somewhere at the median of a stage, which is the resultant of the actual recruitment (Nr), minus the mortality that has already acted on the stage. For calculations of generational mortality, it is particularly important to measure true recruitment of the first stage into the system, the eggs. Therefore, we measured the actual influx of eggs.

For assessment of egg recruitment, the method described in Section 11 was used. Twelve randomly-selected plants were checked every morning for eggs laid during the previous night, and any eggs laid were recorded and removed. Plants were used for 7 consecutive days, after which new plants were selected. The plants were selected with a random number table, 6 plants in unsprayed barrier plots, and 6 plants in sprayed barrier plots, in order to evaluate the effect of spraying on oviposition.

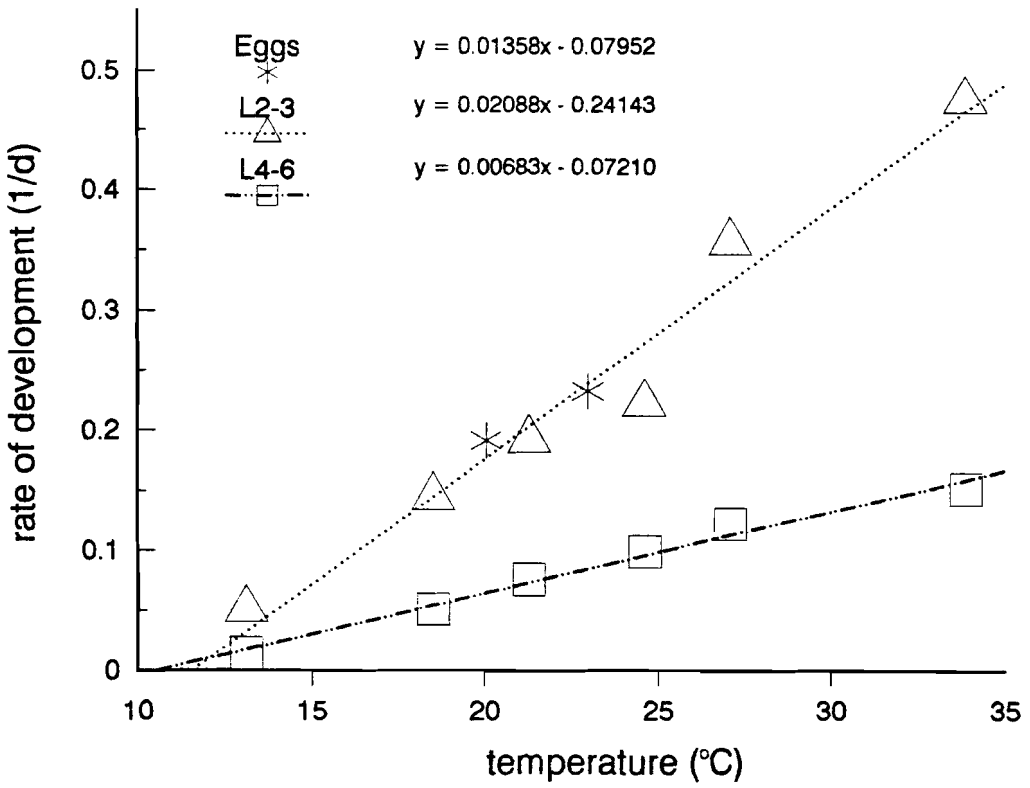

Figure 15.2. Relationship between the rate of development of *H. armigera* stages and temperature. For eggs, data were collected in western Kenya, 1990; for L2-3 and L4-6, data were derived from Twine (1977).

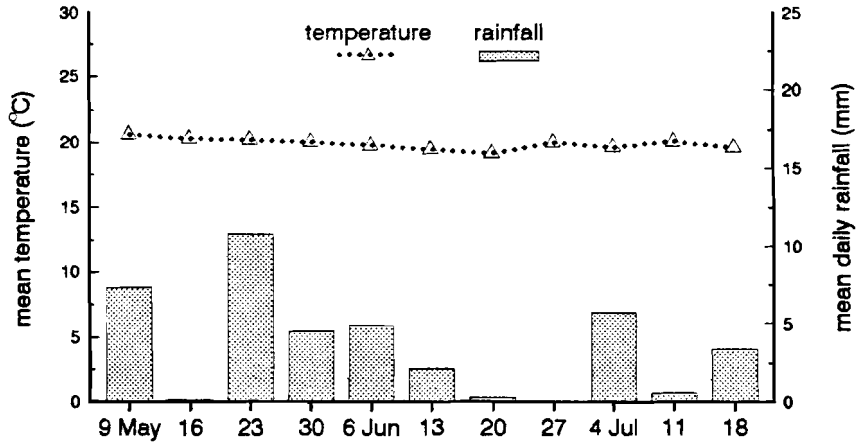

Figure 15.3. Mean temperature and mean daily rainfall during the sample season, pooled per week. Kakamega, long rains 1990.

Results

Figure 15.4 shows the levels of *H. armigera* stages in the three treatments. Only one generation occurred during the season.

Mortality was low, relative to previous trials at the same location (Section 5). Egg and L2-3 densities were slightly lower in control than in barrier and sprayed+barrier plots, suggesting a moderate effect of ant predation. At this time anthocorid levels were still low, and selective spraying to exclude them did not start before 20th June. There was no difference in L4-6 levels between treatments. Figure 15.5 shows the levels of predators in the three treatments. Because initially, the occurrence of anthocorids was low (compare with Section 5), spraying started from 22 June. Therefore, data for barrier and sprayed-barrier treatments were pooled up to this date, and were only separated after 20 June. The daily recruitment of eggs is shown in Figure 15.6. Total egg recruitment during the season was 9.7 eggs per plant; spraying had no deterrent effect on oviposition by moths; recruitment in unsprayed and sprayed plots was 8.3 and 11.0 respectively. Table 15.1 shows the recruitment and mortality of the different stages for each treatment. Recruitment of larvae was based on Southwood's method.

Discussion

Although egg and L2-3 recruitment was slightly lower in the control plots than in the exclusion treatments, there was no difference in L4-6-recruitment between the treatments. Possibly in the exclusion treatments, other mortality factors which are density dependent (e.g. cannibalism) compensated for the impact of predation during the early stages.

Table 15.2 compares the egg recruitment (Nr) with the estimate of egg recruitment using Southwood's method (Ns). As in Section 11, egg recruitment is largely underestimated if based on Ns. Possible explanations were discussed in Sections 5 and 11.

Table 15.1. Recruitment (l_x) (number per plant) and percent mortality (100 q_x) of *H. armigera* in three treatments. Kakamega, 1990.

	control		barrier		sprayed	
x	l_x	100 q_x	l_x	100 q_x	l_x	100 q_x
Eggs[a]	9.67	54.7	9.67	34.5	9.67	39.7
L2-3[b]	4.37	46.7	6.33	58.0	5.83	63.3
L4-6[b]	2.33		2.65		2.14	
Total mortality		75.9		72.6		77.9

[a] Direct measurement of recruitment

[b] Estimate of recruitment, using Southwood's method

Table 15.2. Measured egg recruitment[a] N_r, compared with the estimate with Southwood's method (N_s).

	control	barrier	sprayed
N_r	9.7	9.7	9.7
N_s	1.4	1.6	2.4

[a] per plant over one crop season.

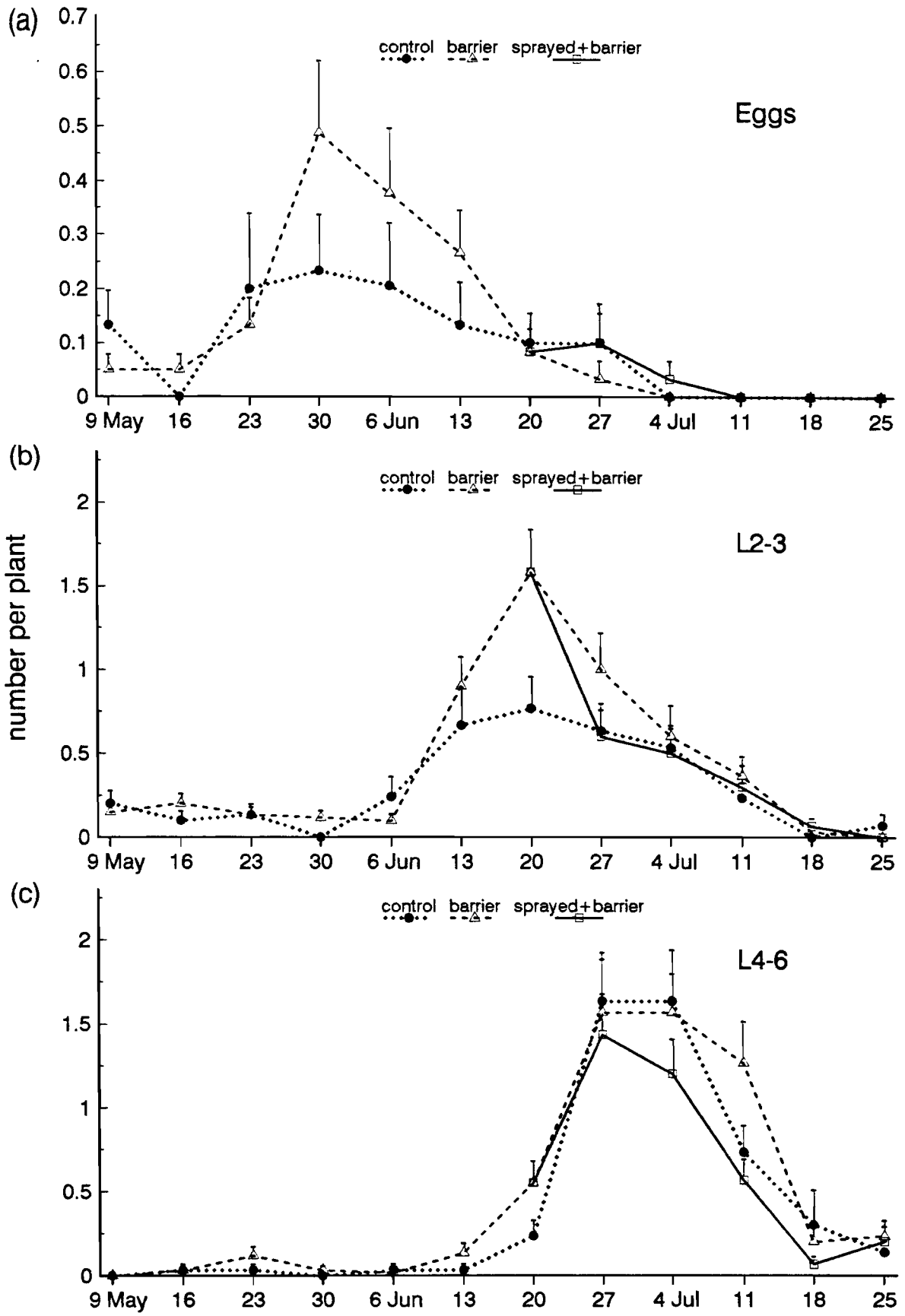

Figure 15.4. Seasonal densities of *H. armigera* stages in control, barrier and sprayed+barrier plots. Kakamega, long rains 1990.

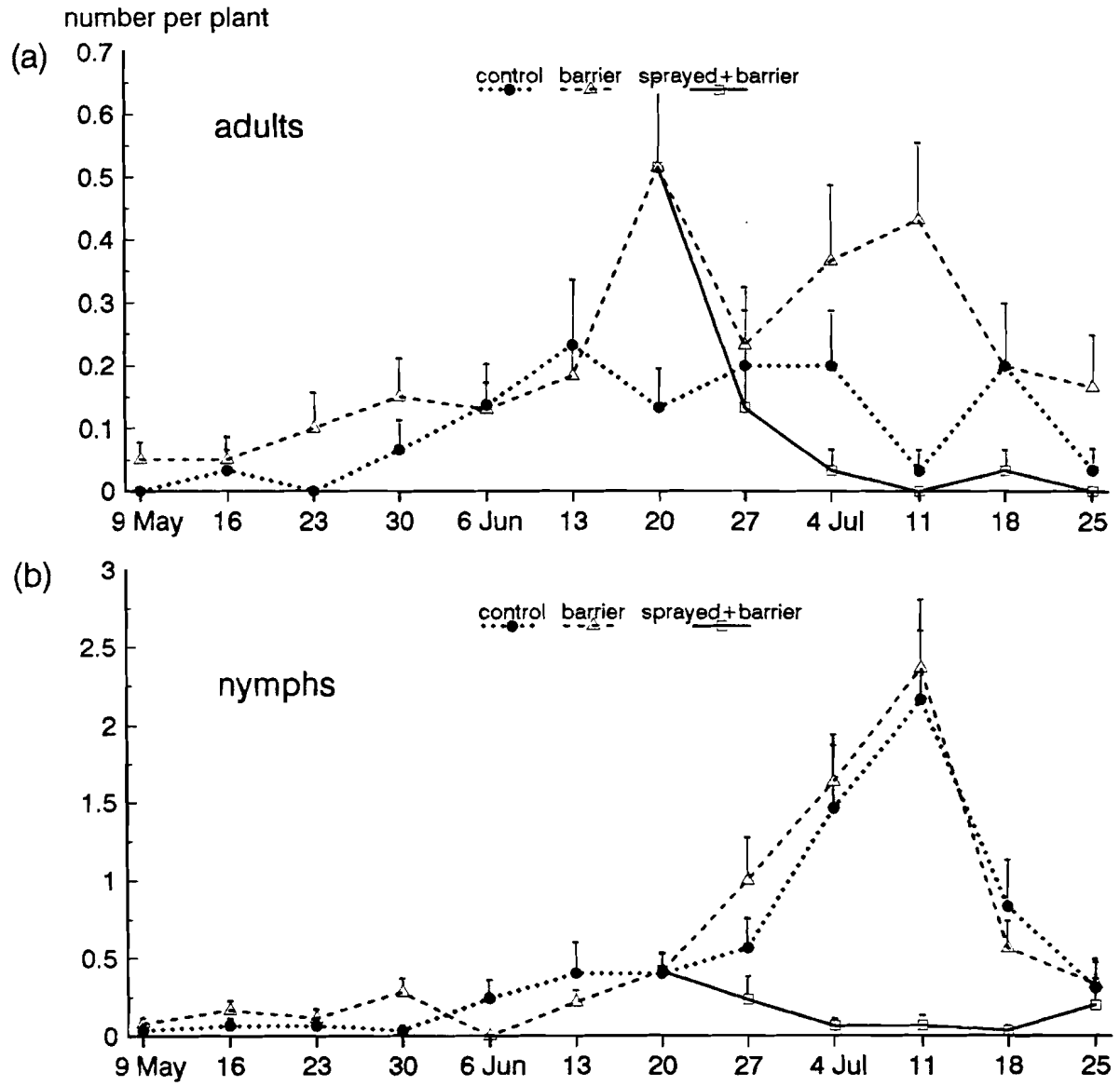

Figure 15.5. Seasonal densities of (a) *Orius* spp. adults; (b) *Orius* spp. nymphs, in control, barrier and sprayed+barrier plots. Kakamega, long rains 1990.

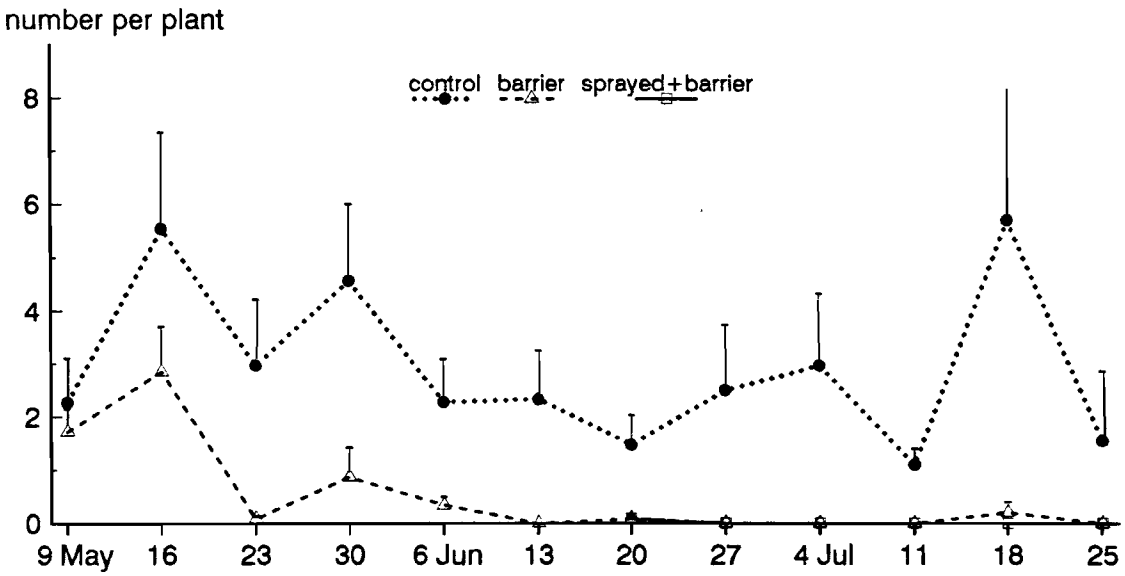

Figure 15.6. Seasonal densities of ants in control, barrier and sprayed+ barrier plots. Kakamega, long rains 1990.

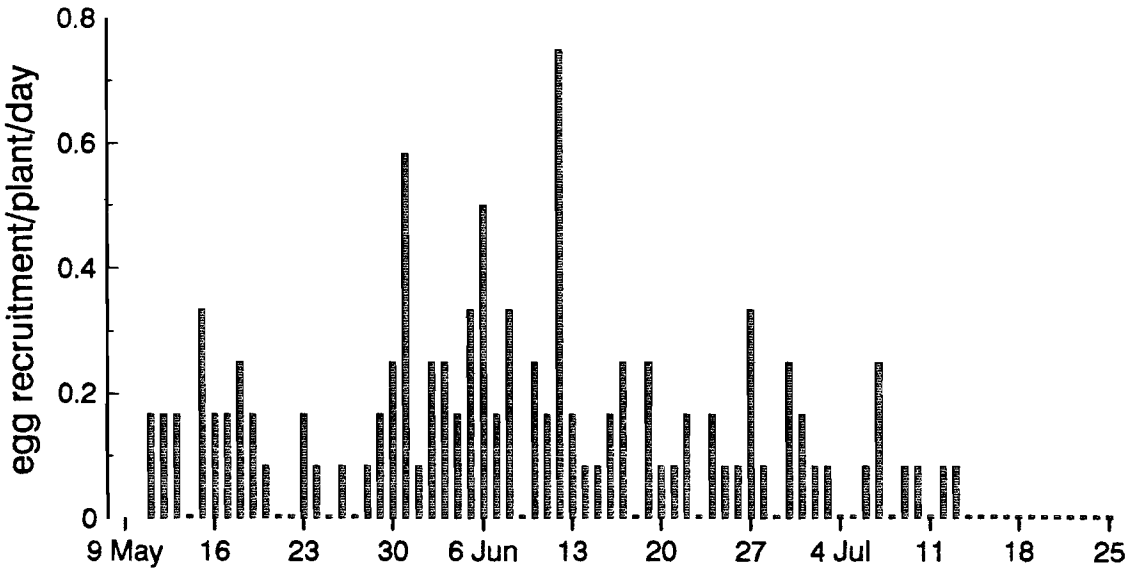

Figure 15.7. Egg recruitment (per day per plant) on sunflower during the season. Kakamega, long rains 1990.

16. The impact of ant communities on *Helicoverpa armigera* dynamics on sunflower in farmers' fields.

Introduction

Previous sections have suggested that agricultural lands in Kenya have an important ant community, sometimes consisting of several species, sometimes of one dominant species. Ant communities may be very local in their occurrence, and so may be their impact on *H. armigera*.

At agricultural research stations, the history of experimental field plots may have an adverse effect on the ant communities (e.g. due to previous pesticide experiments). Therefore, we conducted exclusion trials on farmers' fields, in order to assess the impact of local ant communities on *H. armigera* populations. We selected the crop sunflower, because of the potential importance of ants on this crop, and because ants can be excluded effectively from this crop.

Materials and methods

Mwea Tebere
During the short rains 1989-90, a small-scale trial was set up at Mwea Tebere (Central Province), consisting of six small plots (7x4 m) of sunflower (Hungarian White, spacing 30x75 cm). Ant barriers were put on all plants in the barrier treatments. A ring of tanglefoot insect trap coating was placed around the stem of each plant about 15 cm above the ground. To prevent crawling predators from climbing the plants, plots were kept clear of weeds, and dried-up sunflower leaves on the lower part of the plant were removed. Control plots were maintained similarly. The ant-barriers were set up just after the main oviposition peak of *H. armigera*. Therefore, only the impact of ants on larvae could be measured. Sampling was conducted between 8 a.m. and 1 p.m., and 10-15 plants were sampled per treatment per occasion. Sampling of *H. armigera* concentrated on the flower heads only, which is their preferred feeding site (see Section 4). Flower heads were dissected to detect larvae burrowed in the plant tissue. Ants were recorded from all plant parts. Sampling started on 6 January 1990, with five weekly sampling occasions until 1 February 1990, just before harvest.

During the long rains of 1990, more exclusion experiments were set up in sunflower plots at two farmers' fields, about 5 km from Mwea Tebere National Fibre Research Centre. At each of the two fields, six 10x10 m plots were planted with sunflower (Hybrid 894) at a spacing of 30x75 cm at the beginning of the 1990 long rains season. When the plants were about a foot high, the stems of plants in three plots (3 replicates) were covered by a band of tanglefoot insect glue about 3 cm from the ground (barrier). Plants in the other three plots (control) were not interfered with. There were three replicates and each plot and replicate was separated by a 1.5 m gap. Treatments were assigned to plots randomly and the entire trial was surrounded by two guard rows of maize (Katumani). DAP fertiliser was used at planting and normal agronomic practices were followed. One plot was at the farm of Mr. Githinji Kigamba (Farmer 1) and the other at Mr. Muriuki Thuo (Farmer 2).

Lugari
During the long rains 1990, 0.25 ha experimental plots of sunflower (Hybrid 7000, spacing 75x30 cm) were planted at each of two farmers' fields at Lugari (Farmer 1, Farmer 2), Western province. The sites were 5 km apart. the plots were divided into 8 plots (14x20 m), 2 treatments (control, barrier) with 4 replicates. Time of planting: 18 April 1990.

Ant barrier were in place before flowering. Plots were kept clear of weeds, and dried-up sunflower leaves on the lower part of the plant were removed. Weekly, 20 randomly selected plants were sampled per treatment, and *H. armigera* stages and predators were recorded.

Recruitment of larvae was estimated using Southwood's method. The first instar was excluded from recruitment estimates, because of under-sampling of this small stage. Recruitment of eggs was estimated by the graphical area of eggs, not divided by the development period of eggs as in Southwood's method, but by the age up to which eggs can be traced from the field (as discussed in Section 5). This is because eggs turn brown during development, and are thus difficult to detect against the dark leaf background.

Results

Mwea Tebere

In the first trial at Mwea Tebere, *Pheidole* sp. was very common in the control plots, but was totally excluded from the barrier plots. Figure 16.1 shows 3.5-4x higher levels of larvae in barrier plots than in control plots. The ant barrier were put after the main egg peak, therefore the data exclude the impact of *Pheidole* on eggs.

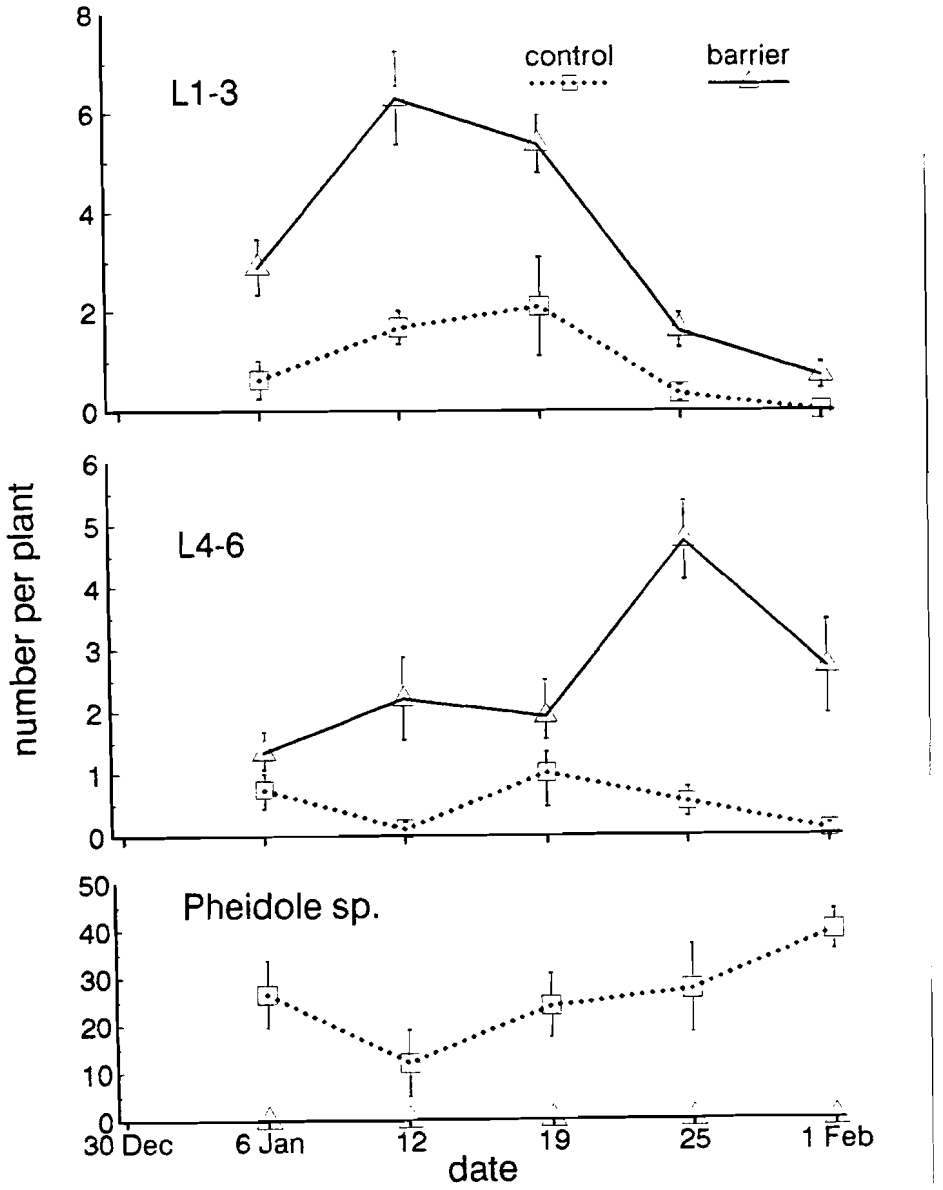

Figure 16.1. Seasonal densities of (a) instars 1 to 3; (b) instar 4 to 6 of *H. armigera*; (c) *Pheidole* sp. ants, in control and barrier plots. Mwea Tebere, short rains 1989-90.

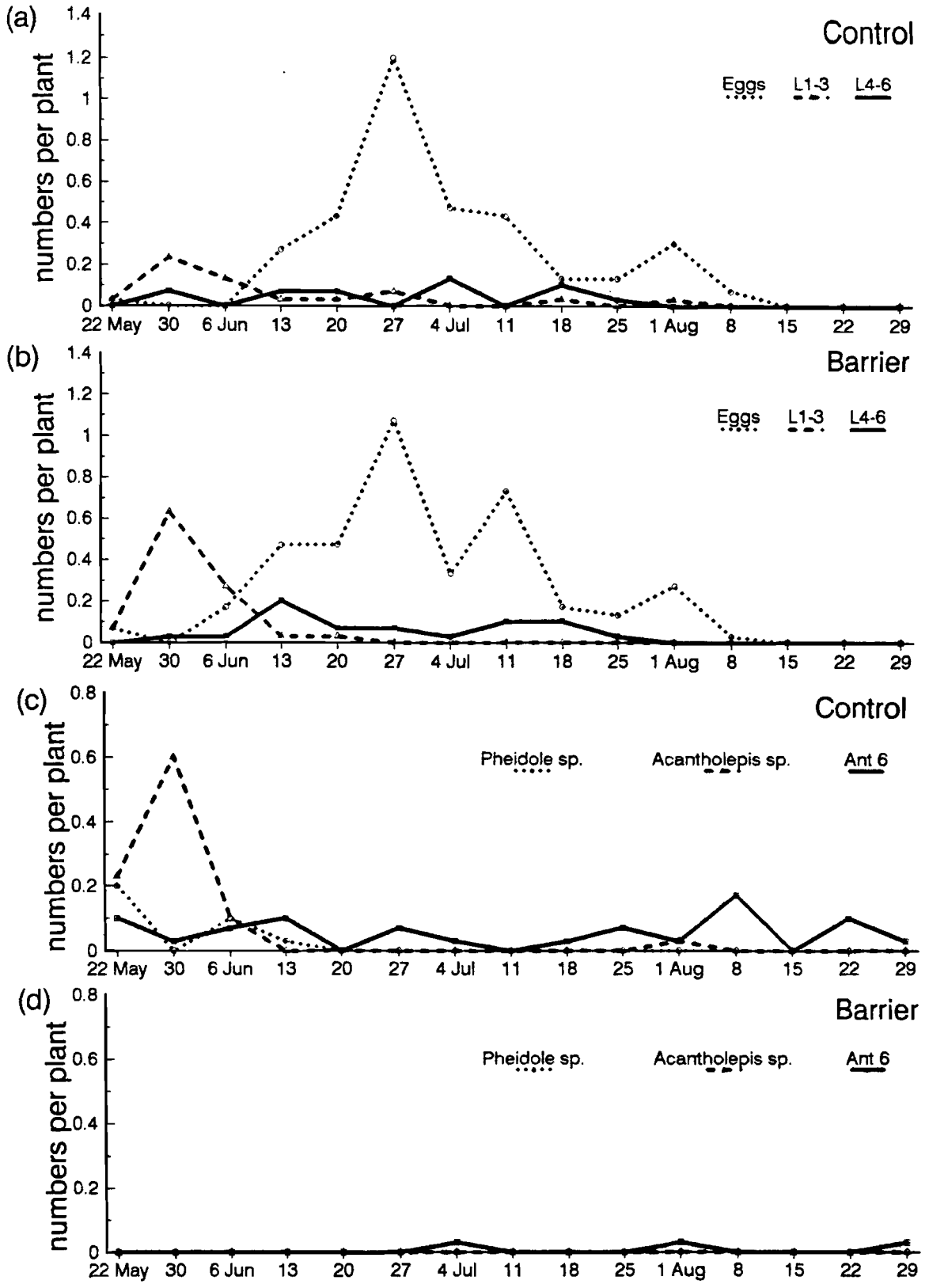

Figure 16.2. Seasonal densities of *H. armigera* egg and larvae in (a) control; (b) barrier plots and of natural enemies in (c) control and (d) barrier plots of sunflower. Farmer 1, Mwea Tebere, long rains 1990.

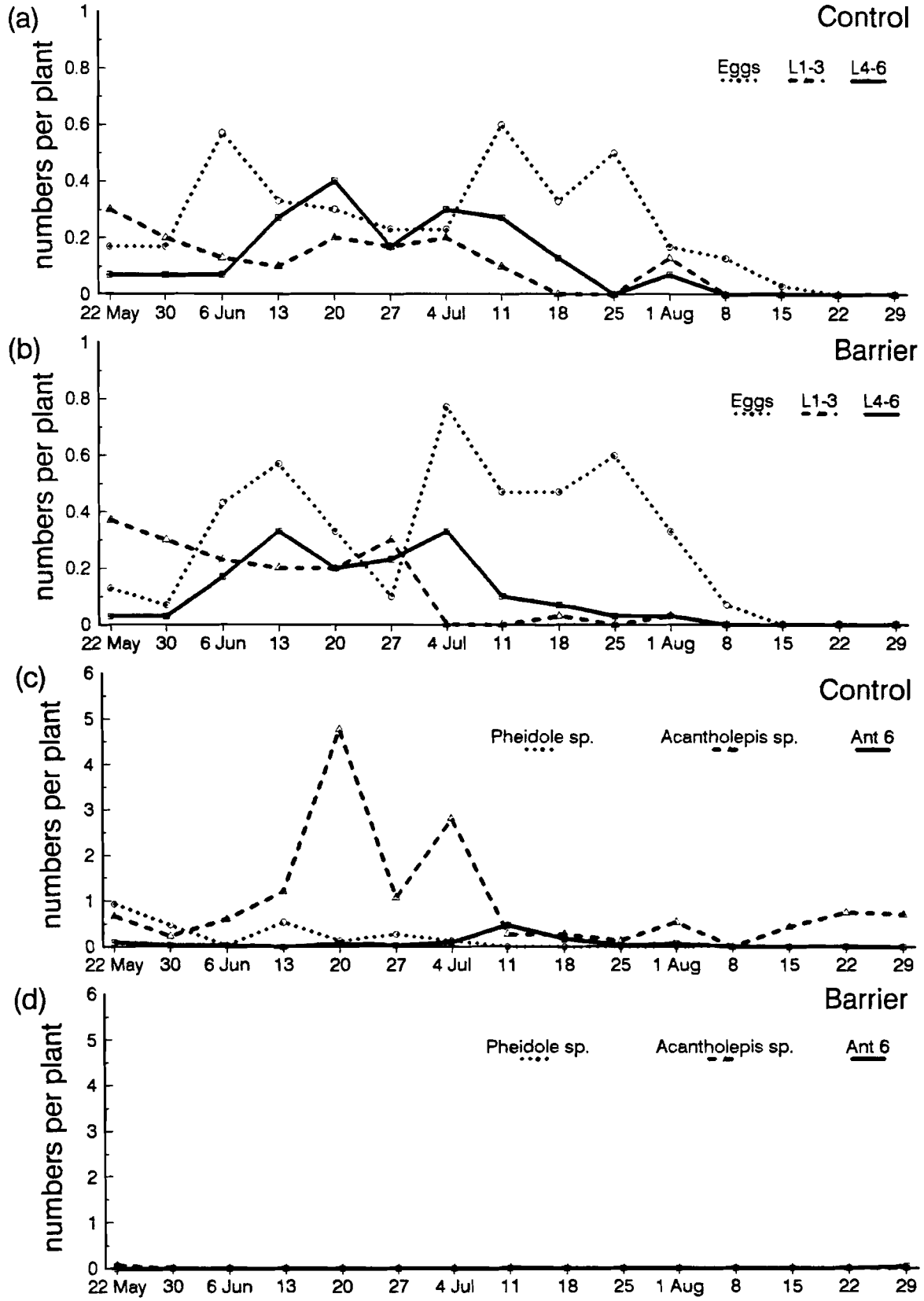

Figure 16.3. Seasonal densities of *H. armigera* eggs and larvae in (a) control and (b) barrier plots, and of predators in (c) control and (d) barrier plots of sunflower. Farmer 2, Mwea Tebere, long rains 1990.

Results of the 1990 long rains are shown in Figures 16.2 and 16.3. Ant densities at these two farmers' fields were much lower than those of Figure 16.1. Especially at Farmer 1, ants were almost absent (Figure 16.2c). Consequently, there was no visible difference in *H. armigera* levels between the control and the barrier treatments at this site (Figure 16.2a,b). At Farmer 2, moderate to low levels of ants were found (Figure 16.3c, *Acantholepis* sp. was the most common ant), but surprisingly, excluding them had no effect on *H. armigera* (Figure 16.3b).

Lugari

Figure 16.4 shows the levels of *H. armigera* and predators at Farmer 1 in Lugari. Figure 16.5 shows the levels at Farmer 2 in Lugari. Ants were less common than in Figure 16.1. Although larval levels were generally higher in the barrier treatments compared to the control treatments, the impact of ants was lower than in Figure 16.1.

Table 16.1 shows the recruitment and mortality of *H. armigera* eggs and larvae at the two sites in Lugari. Recruitment estimates based on graphical areas of stages (e.g. Southwood's method) are, correctly speaking, not the number that enter the stage, but the number somewhere during the media of the stage, which is the resultant of the recruitment minus the mortality that has already acted on the stage. Consequently, if the l_x for eggs is lower in the control treatment than in the barrier treatment (as for Farmer 1, Table 16.1), this could indicate egg predation by ants. At Farmer 1, the ultimate level of L4-6, which is the most damaging stage, is a factor 1.8 higher in the barrier treatment. At Farmer 2 this factor is 1.5.

Table 16.1. Recruitment[a] (l_x) (number per plant) and percent mortality (100 q_x) of *H. armigera* in two treatments at two farmer's fields. Lugari, 1990.

	control		barrier	
x	l_x	100 q_x	l_x	100 q_x
FARMER 1				
Eggs[a]	13.94	73.2	20.82	77.3
L2-3	3.73	63.3	4.72	47.3
L4-6	1.37		2.49	
FARMER 2				
Eggs[a]	12.25	73.6	8.75	58.3
L2-3	3.24	77.3	3.65	69.7
L4-6	0.74		1.10	

[a] Recruitment estimate corrected for undersampling of eggs older than 1 day.

Conclusion

Ants can be very important in controlling *H. armigera* on sunflower, but ant communities differ greatly from site to sites, and so does their impact on *H. armigera*.

By sampling ants, it could ultimately be possible to predict the capacity of ants to keep *H. armigera* in check, but this requires more research on their interactions with *H. armigera*.

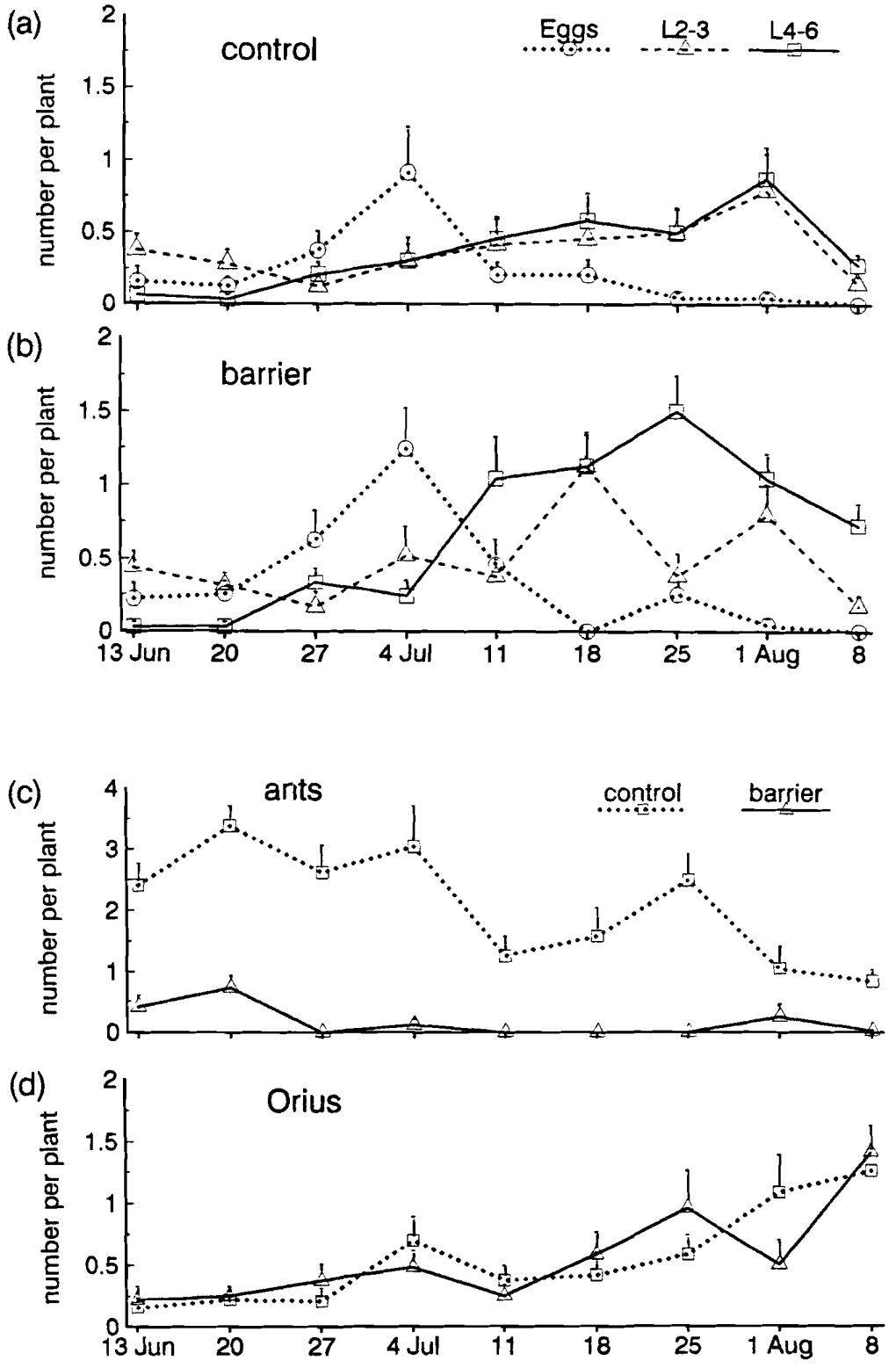

Figure 16.4. Seasonal densities of *H. armigera* stages in (a) control plots; (b) barrier plots, and of (c) ants, and (d) *Orius* spp. in control and barrier plots. Farmer 1, Lugari, long rains 1990.

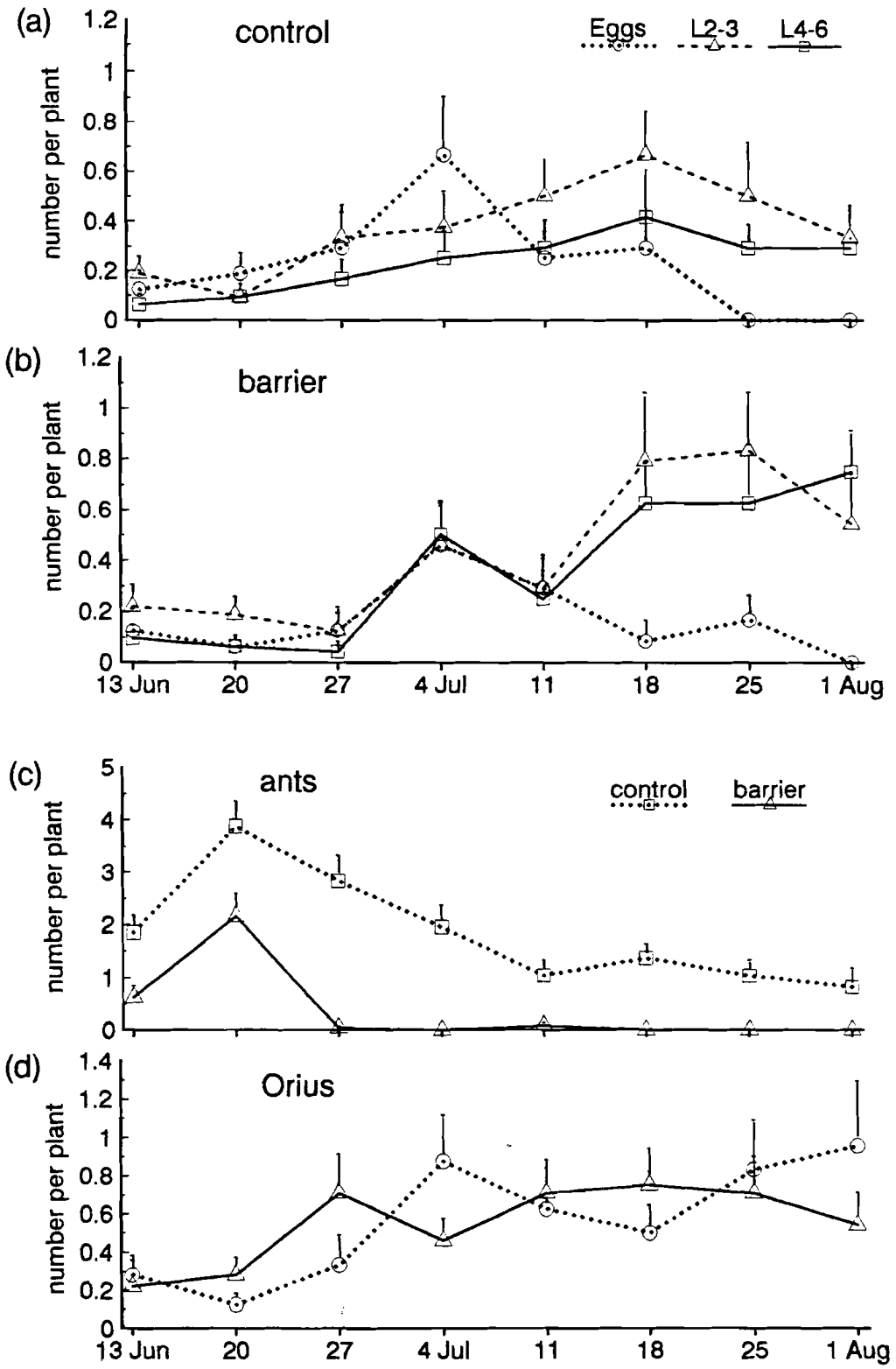

Figure 16.5. Seasonal densities of *H. armigera* stages in (a) control plots; (b) barrier plots, and of (c) ants, and (d) *Orius* spp. in control and barrier plots. Farmer 2, Lugari, long rains 1990.

17. General Discussion

Life-table studies in this report show that natural mortality of *H. armigera* is generally high, with highest mortality usually occurring during the egg and young larval stages. This study allowed comparison of the life-tables of *H. armigera* on different crops. There were some differences in mortality rates between the crops, as discussed above, especially with respect to the young development stages.

Oviposition by *H. armigera* moths is restricted to the stage of pollen shed or flowering of the crops, which is a relatively short period. Oviposition on cotton and pigeon pea is extended over a long period, which is why total egg recruitment during the season is higher than on the other crops.

Attraction of *Orius* adults is also related to the stage of pollen production of the crops. Build-up of nymphs show large differences from season to season, and may be related to rainfall and host plant conditions.

Although predator levels are similar on sunflower, maize and sorghum, there are strong differences in the microhabitat association between the predators and prey. *Orius* spp. are much more closely associated with *H. armigera* on sorghum than on maize and sunflower. On the other hand, ants are more closely associated with *H. armigera* on maize and sunflower than on sorghum. On cotton, all predators are strongly associated with the microhabitat of eggs of *H. armigera*, but less so for larvae. These differences between crops may partly explain the differences in the life-tables.

The occurrence of *H. armigera* and predators shows strong differences between sites (Section 9). Generally, *H. armigera* was more common in Makueni, Mwea Tebere, Kakamega and Kisii, than in Kibos and at the coast. Ants were most common in Mwea Tebere, and anthocorids were most common in the western sites.

Cotton
Evaluation of the role of predators on cotton shows that predators are capable of reducing *H. armigera* larval levels by a factor 4.5 to 6.5 in the field cage study. Furthermore, the impact of *Orius* spp. in egg exposure studies was 12-65% within 48 hours. This suggests that predators have an important role in controlling *H. armigera* on cotton. However, in addition to these traditional exclusion studies, we set up large trials where we combined life-table studies and predator exclusion, using natural populations. Despite obvious differences in the densities of the two major predator groups, *Orius* spp. and ants, in the three treatments, there was no or little effect on the life-table. This was probably because the background mortality (i.e. not due to predators) was extremely high, and could have obscured the impact of predators. This shows the importance of extending traditional predator exclusion studies to life-table studies (for each of the treatments) under local conditions.

Sunflower
Depending on the location, ants can have an important role in controlling *H. armigera* on sunflower. In farmers' fields they reduced natural populations by a factor of up to 4. In the trial in Kakamega, densities of ants were relatively low; we observed some effect of ants on the young stages of *H. armigera*, but this effect was compensated in the older stages probably due to intra-specific competition of *H. armigera* larvae. The other group of potential predators, *Orius* spp., showed some impact on egg cohorts exposed to the field. In Figure 17.1, the occurrence of *Orius* spp. is plotted against the survival of *H. armigera* eggs obtained from the life-table studies on sunflower, maize and sorghum. There seems to be a relationship: survival is always low when *Orius* are abundant, but survival can be high when *Orius* are rare. The large variation at low *Orius* densities shows that other mortality factors are involved. This indicates that *Orius* spp. are important in controlling *H. armigera* when *Orius* are abundant. However, their effectiveness on sunflower is somewhat limited by (1) the fact that *Orius* populations normally build up after the period of oviposition (Section 5), and (2) by poor association of *Orius* spp. with the microhabitat of *H. armigera* eggs (Section 4). This was confirmed in the predator evaluation trial at Kakamega. We

started spraying in the sprayed+barrier treatments only after the main oviposition peak, simply because *Orius* spp. were not common; *Orius* exclusion had no effect on *H. armigera*.

This project has shown that *H. armigera* suffers high mortality during its development, but there is much variation between sites and between seasons. In some trials we have demonstrated that predators play an important role in overall mortality. In other trials, either background mortality was very high, obscuring the impact of predators, or predator densities were low. On cotton, *Orius* spp. and ants are effective predators, and in times of high infestation levels of *H. armigera* they may be a major mortality factor. On sunflower, ants are the most effective predators and can be capable of controlling *H. armigera*. In western Kenya, the contribution of parasitism was moderate, in the other sites parasitism was negligible.

Maize has been suggested as a trap crop for *H. armigera* (e.g. Rens 1977), but our results are somewhat contrdictory; maize is preferred in Central Kenya (p. 80), but not in Western Kenya (p. 95). Moreover the attraction to maize becomes negligible by the end of tasselling. Cotton has a much longer period when it is suitable for oviposition, and so would continue to be attractive long after the maize. Thus maize may not be effective as a trap crop with cotton.

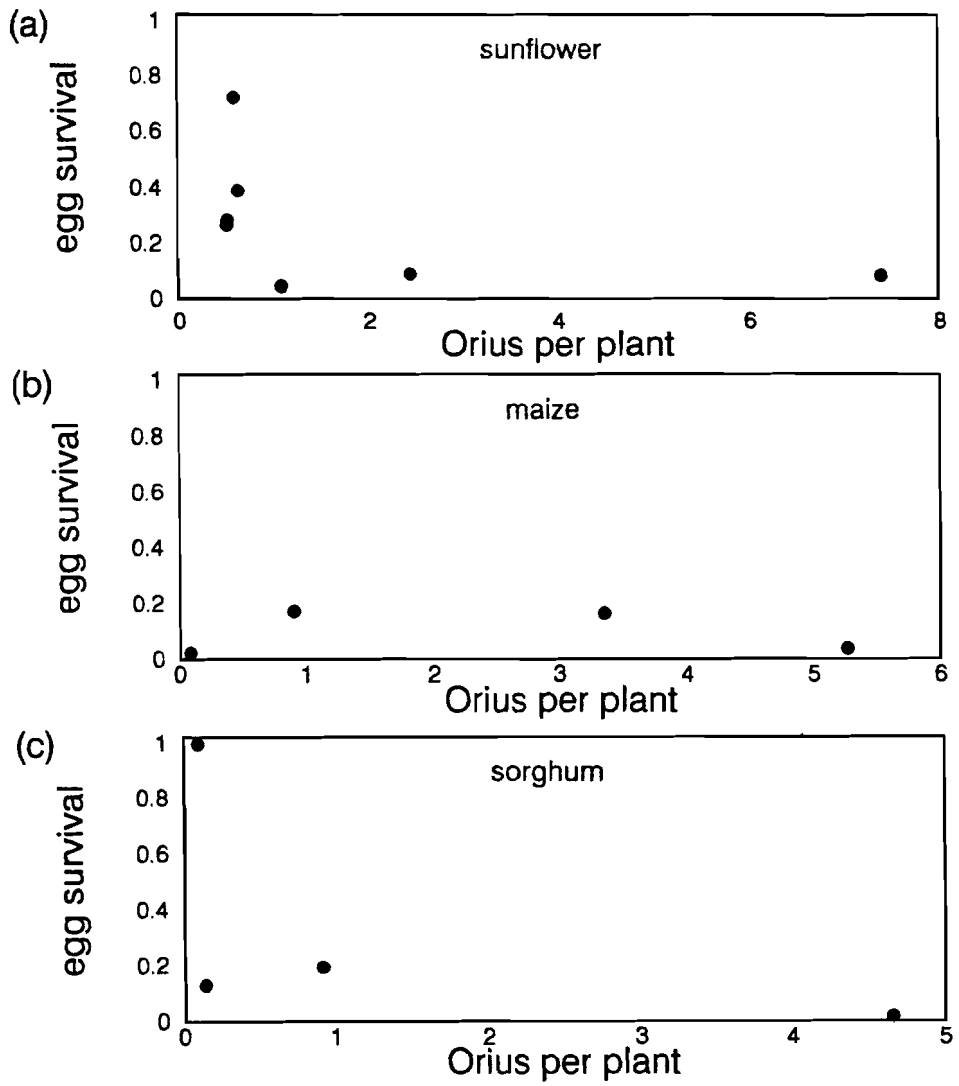

Figure 17.1. Relation between egg survival and the occurrence of *Orius* spp. (average density during the period of availability of eggs in the field). Each point represents a site during a season. Western Kenya, 1988-90.

Implications of the results or findings for achieving the objectives of the project

The research results reported above have substantially met the project objectives, although the emphasis accorded to specific questions has been modified as the project proceeded.

The project objectives and how they have been met are as follows:

The basic objective is a better understanding of the role of natural enemies in the population dynamics of H. armigera *in smallholder food and cash crops in Kenya, with a view to developing IPM strategies for its control in Africa.*

The studies reported above, lead to a better understanding of the role of natural enemies in the population dynamics of *H. armigera* in Kenya. Thus, we now know that predators, especially the ants *Myrmicaria* sp. and *Pheidole* sp. and anthocorids, can have substantial impact. IPM strategies for *H. armigera* should be based upon conserving and enhancing these indigenous predators, as discussed in the next section. Parasitoids and pathogens are not important at the population levels which we studied, and the possibility of introducing exotic parasitoids to fill this apparently empty niche in Kenya should also be explored.

Specific questions posed include:
(1) How does the incidence of parasitoids, predators and pathogens vary with season and crop?

The observations reported in Sections 4-9 comprehensively address this issue for seven varied sites in Kenya.

(2) What determines the specificity of natural enemies to H. armigera *on particular crops?*

This question was framed in the light of observations from Tanzania that parasitoids showed clear crop preferences, whereas we have focused our study on the predators once it became apparent that they were the predominant natural enemy group in Kenya. The observations on phenology and distribution in Sections 4-9, do not show any clear pattern of crop specificity for the major groups of predators. At some sites, or in some seasons, certain crops do seem to be less attractive than others, but we attribute this to temporary circumstances, such as the crop stage, availability of alternative prey, etc. Further analysis can be done on our data to follow this up.

(3) What is the relative importance of the parasitoids, predators and pathogens and what role, if any, do they play in the regulation of the population of H. armigera?

This question is answered by our regular observations described in sections 4-10 which show that predators are the only common natural enemy group in our plots, and the manipulative experiments described in Sections 11-16, which separate out the effects of the two main groups of predators: ants and anthocorids.

(4) To what extent do natural enemies move around, within and between crops, and how important is this to H. armigera *population dynamics?*

As in question 2, this question was framed on the basis of observations on parasitoids in Tanzania, and has not been a major feature of our investigation. Ants, with subterranean nest sites in or near the field sites would collect food from the whole of their foraging area, responding to local concentrations of food. Anthocorids probably do move around between crops, in response to plant

stage, but since we have not been able to attempt identification of the different species until near the end of the project, this question has had to be deferred.

(5) How is the contribution of natural enemies to H. armigera *mortality influenced by the application of* Bacillus thuringiensis *(BT) and other insecticides?"*

This question was addressed through collaborative field trials at Kakamega and Kibos, involving the University of Wales College Cardiff (UWCC), KARI and IIBC staff. These were funded partly through the present project, but mostly through an ODA funded project with UWCC, and this work is reported under that project.

Priority tasks for follow-up

Based on this study of the ecology and natural mortality factors of *H. armigera* in different crop ecosystems, there appears to be scope for developing measures that can enhance the degree of biological control, in order to reduce the application of insecticides. Of the crops studied, cotton is most promising in this respect, because of (1) the seriousness of the *H. armigera* problem in this crop, (2) the potentially high impact by natural enemies, and (3) the amount of insecticides already used in cotton.

We therefore recommend a project with four specific questions, all of which aim at enhancing the degree of control of *H. armigera* in cotton, utilising its natural enemies.

1. Can exotic parasitoids fill an empty niche, improving the level of biological control of H. armigera*; and which parasitoid is most promising?*

Although natural biological control has an important role in the population dynamics of *H. armigera* in Kenya, it is mostly predators that are important. Parasitoids of *H. armigera* are under-represented in Kenya, apart from egg parasitoids. Parasitoids that attack the larvae of *H. armigera* are rare, and if they are found they do not have a significant impact on the pest. This in contrast to other regions such as East Asia, Southern Europe and the Americas, where high larval parasitism of *H. armigera* or closely related species does occur. Thus, there appears to be scope for improving the overall level (and the reliability) of biological control by introducing exotic larval parasitoids to fill an empty niche. This is without any cost to the farmer. Four parasitoids stand out as promising candidates: *Campoletis chlorideae* Uchida, *Glabromicroplitis croceipes* (Cresson), *Hyposoter didymator* (Thunberg) and *Apanteles kazak* Telenga.

2. How can natural enemies be encouraged to build up in numbers early in the season?

Phase II of the project has demonstrated the important role of predatory insects in controlling *H. armigera*. In a newly planted crop, predators need time to invade the field and to build up in numbers. As has been documented for other crop ecosystems, *H. armigera* in cotton invades the field earlier than its natural enemies, resulting in crucial damage to the young crop. If farmers apply insecticides at this stage, natural enemies, which might otherwise have built up and controlled the pest, are killed, and the farmers will have to continue spraying.

Studies are required on how to enhance (1) attraction of natural enemies to the crops early in the season, and (2) the build-up of their populations, by cropping practices or other cultural methods.

3. Can Bacillus thuringiensis *or* H. armigera *Nucleur Polyhedrosis Virus (NPV) be an integral part in a control strategy?*

In case natural enemies are not effective or have not yet built up in numbers high enough to control the pest, action has to be taken against *H. armigera*, with an insecticide that kills the pest but does not affect the natural enemies.

The new strain of *Bacillus thuringiensis* of the University of Wales, Cardiff (UWCC), tested in Kenya during collaborative effort trials with IIBC and KARI during Phase II, are promising in this respect. Further evaluation of the *H. armigera* NPV would also be relevant.

4. How can the effect of chemical pesticides on natural enemies in cotton be reduced?

Even if *H. armigera* is controlled by *Bacillus thuringiensis*, other pests of cotton can remain a problem, thus requiring chemical pesticides. Pests that follow *H. armigera* in importance are Cotton Stainer, *Dysdercus* spp., and Cotton Seed Bug, *Oxycarenus* spp., both appearing later in

the season, after the *H. armigera* peak. The negative effect of insecticides on natural enemies can be limited by the choice of pesticide, threshold spraying and timing of spraying (based on pest and natural enemy densities), but requires further study.

After development of an effective and appropriate strategy to manage the African Bollworm in cotton, the next step would be extension to the farmers, through the Ministry of Agriculture.

Publications produced during Phase I and Phase II of the project

Phase I

Cock, M.J.W.; Waage, J.K.; van den Berg, H. (1988) The population ecology of *Helicoverpa armigera* in smallholder crops in Kenya, with emphasis on its natural enemies. Final Report, Phase I: April 1987 - March 1988. CIBC Report, 18 pp.

van den Berg, H.; Nyambo, B.T.; Waage, J.K. (1990) Parasitism of *Helicoverpa armigera* in Tanzania: analysis of parasitoid-crop associations. *Environmental Entomology* 19, 1141-1145.

van den Berg, H.; Waage, J.K.; Cock, M.J.W. (1988) *Natural enemies of* Helicoverpa armigera *in Africa: - a review*. Ascot, U.K.; C.A.B International, 81pp.

Phase II

Cock, M.J.W.; van den Berg, H.; Oduor, G.I.; Onsongo, E.K. (1989) The population ecology of *Helicoverpa armigera* in smallholder crops in Kenya, with emphasis on its natural enemies. First Annual Report, Phase II: April 1988 - March 1989. CIBC Report, 74 pp.

Titles of planned publications

Beneficial organisms in pest control: an illustrated guide to the natural enemies of the African Bollworm. CABI, Wallingford.

Microhabitat selection and spatial distribution of *H. armigera* and its predators in smallholder crops.

Seasonal dynamics of *H. armigera* and its natural enemies in Western Province, Kenya: Life-table construction for a system consisting of three crops.

Natural mortality of *H. armigera* on smallholder crops in Kibos, Nyanza Province, Kenya.

The occurrence of *H. armigera* and its major predators in Kenya: A comparison of sites.

Stage-specific mortality by predators of a field population of *Helicoverpa armigera* on cotton. I. Kibos.

Stage-specific mortality by predators of a field population of *Helicoverpa armigera* on cotton. II. Mwea Tebere.

Cage studies on the impact of natural enemies on cohorts of *H. armigera* on cotton.

Predation and parasitism of egg cohorts of *H. armigera* on sunflower and cotton.

Stage-specific mortality by predators of a field population of *Helicoverpa armigera* on sunflower.

Ant predation on *H. armigera* on sunflower in farmers fields.

8 ACKNOWLEDGEMENTS

This research project was carried out with funding from the ODA (UK) under ODA-NRE Project R4365B, and administered by the Natural Resources Institute (NRI) under Extra Mural Contract EMC X044. Grateful acknowledgement is made for this. The liaison officer at NRI was Dr A B S King, and interactions with him, and feedback from him, have been particularly helpful.

Research was mounted in close collaboration with the Kenya Agricultural Research Institute (KARI). We would like to acknowledge with thanks the co-operation and support received from the Director, KARI, Dr C Ndiritu, and his predecessor, Dr B N Majisu. Similarly the support and guidance of KARI's Deputy Director, Crops Soils and Water (and C.A.B International Liaison Officer for Kenya), W W Wapakala, and his successor, J K Rutto, have been invaluable. The IIBC Kenya Station is hosted by KARI's National Agricultural Research Centre (NARC) at Muguga, and we would like to thank the Director, Dr B W Ngundo, and his successor, Dr A Kilewe, for their hospitality, advice and support. The co-ordination of KARI's collaboration on this project was managed by the Head of the Division of Entomology and Biocontrol, NARC, Dr A M Mailu, and his successor, C W Kariuki, and we thank them for their assistance throughout the project.

The research described in this report was carried out at several of KARI's Research Stations, and it is a particular pleasure to thank most warmly the Directors of the stations and their staff for their co-operation and the interest which they have shown in the project: Dr A B Orodho (Director), L Akanga, N O Aluodi, Regional Research Centre, Kakamega; the late P K Kusewa (Director), Mrs J Songa, E N Migwa, National Dryland Farming Research Centre, Katumani; A Mambiri (Director), B Wabuko, Cotton Research Sub-Centre, Kibos; Y W K Malinga (Director), M Kariuki, Regional Research Centre, Kisii ; E C Ikitoo (Director), C Waturu, S Njoka, National Fibre Research Centre, Mwea Tebere; W Gitonga (Director), S T Macharia, Regional Research Sub-Centre, Msabaha; A Aziz (Director), K Mwangi, K Kamina, D Karuri, Regional Research Centre, Mtwapa.

We also thank the IIBC and KARI staff who have worked in such a committed manner on the project: P C Ng'ang'a, A M Momanyi, E A Chandi, B M Mutulili, B M Kasivu, A L Majisu, B Musau, J W Obiero, C Muasa, and A Ndambuki. A full list of staff and collaborators is given in Annex 1.

The project has enjoyed the support of the International Institute of Entomology, in providing information and literature, as well as identifications and taxonomic research. We would like to thank the Director, Dr K M Harris, and IIE staff: R G Booth (Coccinellidae, Tenebrionidae), Z Boucek (Eurytomidae, Pteromalidae), M L Cox (Curculionidae), C J Hamilton (Information), R Madge (Carabidae, Staphylinidae), A Polaszek (Scelionidae, Trichogrammatidae, taxonomic research), G M Stonedahl (Anthocoridae, Lygaeidae, Nabidae, Reduviidae, taxonomic research), and A K Walker (Braconidae, Ichneumonidae, and taxonomic research) and their colleagues at the Natural History Museum: B Bolton (Formicidae), S J Brooks (Chrysopidae, Hemerobiidae), W R Dolling (Coreidae), T Huddlestone (taxonomic research), J S Noyes (Encyrtidae), and N P Wyatt (Syrphidae, Tachinidae, and taxonomic research).

Finally, we have also enjoyed the support of the International Institute of Biological Control Headquarters at Silwood Park, and we would like to thank the Director, Dr D J Greathead, and Deputy Director, Dr J K Waage. Apart from having to produce the project accounts, Mrs P J Briggs has without complaint arranged the ordering and freight of equipment for the project, for which she merits our special thanks.

Annex 1.

Staff and collaborators

A1.1. List of project staff

At the various field sites, KARI officers collaborated with IIBC staff on the African Bollworm project. The following is a list of all officers and technical staff who undertook maintenance of the plots and sampling at the sites quoted. Dr A M Mailu, at that time Head of the Division of Entomology and Biocontrol, NARC, KARI, co-ordinated the KARI involvement in the project.

IIBC KENYA STATION AT
MUGUGA: NATIONAL AGRICULTURAL RESEARCH CENTRE (NARC)

M.J.W. Cock*	IIBC Principal Investigator
H. van den Berg*	IIBC entomologist, based at Kakamega seasons 1-4
G.I. Oduor*	KARI NARC entomologist seconded to IIBC
E.K. Onsongo*	KARI NARC entomologist seconded to IIBC, based at Kibos seasons 2 and 4
P. Chege*	IIBC technologist
A. Momanyi*	KARI NARC technician seconded to IIBC
E. Chandi*	IIBC technician, based at Kakamega season 1, Kibos season 2, Msabaha season 3, Mwea Tebere season 4
B. Mutulili*	IIBC technician, based at Kakamega seasons 2-4
B. Musau*	KARI NARC technician seconded to IIBC, based at Kakamega seasons 3-4
A. Majisu	KARI NARC technician seconded to IIBC, based at Kakamega seasons 1-3, and Kibos season 4
B. Kasivu	KARI NARC technician on secondment to IIBC, based at Mwea Tebere seasons 1-3
J. Obiero*	KARI NARC subordinate seconded to IIBC
C. Muasa*	KARI NARC subordinate seconded to IIBC
A. Ndambuki*	KARI NARC subordinate seconded to IIBC

KAKAMEGA REGIONAL RESEARCH CENTRE (KRRC)

L. Akanga	KARI KRRC technical assistant
N.O. Aluodi	KARI KRRC technical assistant

KIBOS COTTON RESEARCH SUB-CENTRE (KCRSC)

A. Mambiri+	KARI KCRSC Sub-centre Director
B. Wabuko▪	KARI KCRSC technical assistant

KISII REGIONAL RESEARCH CENTRE (KRRC)

Y.W.K. Malinga+	KARI KRRC Centre Director
M. Kariuki▪	KARI KRRC technical assistant

MAKUENI REGIONAL RESEARCH SUB-CENTRE OF
KATUMANI: NATIONAL DRYLAND FARMING RESEARCH CENTRE (NDFRC)

Mrs J. Songa+	KARI NDFRS entomologist
E.N. Migwa▪	KARI NDFRS Makueni Sub-centre Officer-in-charge

MSABAHA REGIONAL RESEARCH SUB-CENTRE (MRRS)

W. Gitonga+	KARI MRRS entomologist, Sub-centre Officer-in-charge
S.T. Macharia▪	KARI MRRS technical assistant

MTWAPA REGIONAL RESEARCH CENTRE (MRRC)

K. Mwangi+	KARI MRRC entomologist
K. Kamina▪	KARI MRRC technical assistant
D. Karuri▪	KARI MRRC technical assistant

MWEA TEBERE NATIONAL FIBRE RESEARCH CENTRE (MTNFRC)

C. Waturu+.	KARI MTNFRC entomologist
S. Njoka+	KARI MTNFRC entomologist

* Salaries funded by project
\+ Provide general co-ordination at field sites
▪ Provide day-to-day management of field site

A1.2. Summaries of information on collaborating KARI research stations

The following information summaries are updated from Cock *et al.* (1988) in light of KARI (1989).

KAKAMEGA REGIONAL RESEARCH CENTRE (formerly Western Agricultural Research Station)

Centre mandate: Sorghum/millet improvement and production programme; rice improvement and production.
Centre director: Dr A B Orodho
Crops on centre: Maize, beans, sorghum, oil crops, horticulture, citrus, papaya, potato, onion etc.
Local crops: Small farmers mostly grow maize and beans intercropped with no rotation. Little or no pesticides.
Rains: 1845 mm (unimodal, February - December); Ecozone II. Locally recognised as long rains late January/February - June; short rains August - November.
Seasons: Harvest December and June - July; land preparation immediately afterwards.
Elevation: 1590 m.

KIBOS COTTON RESEARCH SUB-CENTRE

Sub-centre mandate: Cotton and cotton systems.
Centre director: Mr A M Mambiri
Crops on centre: Cotton and some intercrop systems.
Local crops: Maize and beans usually intercropped; also cassava and sweet potato.
Rains: 1287 mm (unimodal, September - July); Ecozone III. Locally recognised as long rains March - June, short rains August - October; usually poorly defined but long rains reliable.
Seasons: Planting cotton at beginning of long rains (March), harvest August - September for about one month in 3 pickings; after harvest plants cut and burnt, and land left fallow for rest of year as short rains inadequate. Land preparation December - January.
H. armigera: No. 1 pest on cotton; recommended to use insecticides (Pyrethroids) 2 months after planting and then every 2 weeks until bolls mature, i.e. 5 - 6 sprays. In practice farmers economise with sub-standard doses and less frequent sprays.
Elevation: 1184 m.

KISII REGIONAL RESEARCH CENTRE

Centre mandate: Improvement and production of sorghum, maize, groundnut, cotton, rainfed rice, cassava and breeding livestock.
Centre director: Dr Y W K Malinga
Crops on centre: Maize, soya, beans, potato, cabbage, bananas, onion, tomato, groundnut.
Local crops: Small farmers: maize and beans predominate, mostly as intercrop; cash crops coffee, tea, pyrethrum.
Rains: Rainfall 1845 mm (unimodal, February - December); Ecozone II. Locally recognised as long rains: late February to late May or early June; short rains - late August to early November.
Seasons: Harvest January and August and prepare land immediately afterwards.
H. armigera: Not considered common.
Elevation: 1590 m.

MAKUENI AGRICULTURAL RESEARCH SUB-CENTRE (Sub-centre of Katumani National Dryland Farming Research Station)

Sub-centre mandate: Improvement of dryland crops: maize, cassava, pigeon pea, sorghum, millet.
Officer-in-charge: Mr E.N. Migwa
Local crops: Maize-beans intercrop predominates, but also pigeon pea, cotton and cassava.
Rains: Rainfall 730 mm. Long rains March - May; short rains October - December but erratic.
Seasons: Land preparation just before rains in January - February and September - October; planting at the beginning of the rains and harvest in May - June (beans) and June - July (maize) for long rains and January - February for short rains.
H. armigera: Third most important pest on pigeon pea.
Elevation: 1145 m.

MSABAHA AGRICULTURAL RESEARCH SUB-CENTRE (Sub-Centre of Mtwapa Regional Research Centre)

Sub-centre mandate: All crops in area, especially cassava, maize, cotton, legumes (pigeon pea, cowpea, green gram).
Centre director: Mr W Gitonga
Local crops: Small farmers grow maize, cowpea, green gram, pigeon pea, simsim, cassava about equally; some tomato under irrigation; cotton as cash crop.
Rains: mm (unimodal, April - November); Ecozone II. Locally interpreted as long rains April to mid June and short rains October - November.
Seasons: Maize and cassava planted at start of long rains; the former is harvested towards the end of the rains and replanted with simsim or green gram which is harvested December. Pigeon pea also planted in April for harvest in September. Land preparation: burn and plant - no tillage. Cotton is planted in April, harvested at the end of October and replanted with legumes.
Elevation: 20 m.

MTWAPA REGIONAL RESEARCH CENTRE (formerly Coast Research Station)

Centre mandate: Development of improved varieties of cashewnuts, coconuts, maize, cassava, sesame and breeding of cattle.
Centre director: Mr Abubakar Aziz
Crops on centre: Coconut, cashew, root and tuber crops.
Local crops: Maize, cassava, simsim and to lesser extent cowpea and tomato.
Rains: Rainfall 1267 mm (unimodal, April - November); Ecozone II. Locally interpreted as long rains May to July followed by showers and the short rains October to the beginning of December.
Seasons: Maize planted April - May and harvested July; simsim planted end of July and harvested September/October and harvested December giving three crops a year. Maize is intercropped with cassava (one year cycle), cowpea etc. Simsim is often inter-planted rather than clear the land.
H. armigera: Mainly on tomato and cotton, very few farmers use pesticides.
Elevation: 21 m.

MWEA TEBERE NATIONAL FIBRE RESEARCH CENTRE

Centre mandate: Improvement of cotton and kenaf.
Centre director: Mr E C Ikitoo
Crops on centre: cotton and kenaf.
Local crops: Maize-beans intercrop, with lesser amounts of french beans, rice, cotton, and some tomato.
Rains: 887 mm (bimodal, March - May, October - November); Ecozone IV.
Seasons: Maize and bean planted at beginning of rains and harvested in January - February (short rains) and June - July (long rains). French bean and rice grown throughout the year under irrigation. Pesticides extensively used on french bean against thrips and *H. armigera*. Cotton planted mainly in October - November.
H. armigera: *H. armigera* and tetranychid mites are the most serious pests of cotton.
Elevation: 1140 m.

Annex 2.1.

A taxonomic study of *Palexorista* spp. (Diptera: Tachinidae)

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Department of Entomology, Natural History Museum, Cromwell Road, London SW7 5BD, UK

Introduction

The purpose of this study is to clarify which species of *Palexorista* parasitise the African Bollworm, *Helicoverpa armigera* (Hbner), and based on this to clarify their host ranges. In the majority of cases *P. laxa* (Curran) is known to be the parasitoid species concerned, but records also exist for other members of the genus. Similarly, there are records of *P. laxa* from many other hosts apart from *H. armigera*, although many of these have been questioned (Crosskey 1967).

In Phase I of the IIBC project, *Palexorista* was selected for further studies to be organised by Dr K M Harris (Director, International Institute of Entomology) and Dr L A Mound (Keeper of Entomology, Natural History Museum.

Species of *Palexorista* are superficially very similar in appearance, and few can be identified reliably using external characters alone; examination of male genitalia is often necessary to confirm identifications. Crosskey (1967) clarified the identification of the Oriental species with the help of characters of the male genitalia. Earlier keys relied on external characters only, for example that by Mesnil (1949), which included the species now placed in *Palexorista* in *Drino*, subgenus *Prosturmia*. Although external characters, such as head shape, width of frons and relative lengths of antennal segments, can undoubtedly be useful, keys that rely on them carry a greater risk of producing unreliable identifications. Misidentifications of *palexorista* have inevitably occurred and have resulted in a distorted picture of the host ranges of many species. Meanwhile, the Afrotropical species still require a revision; 29 valid species are listed by Crosskey *et al.* (1980), but there are several additional undescribed species.

Diagnosis

Palexorista belongs to the tribe Sturmiini, which is characterised by the inner margin of the lower squama having an angular rather than rounded posterior angle, resulting in its inner margin lying closely adjacent to the outer margins of the thorax and scutellum for its entire length; also, the hind tibia has a dense and comb-like row of antero-dorsal setae. Another character often present in Sturmiini and shown by *Palexorista* is the fascicle of dense hair on the ventral surface of the fourth abdominal tergite in males; other characters typical of this genus are: head with at least two pairs of reclinate upper-frontal setae, ocellar setae weak, eyes almost bare, parafacials setulose on their upper part, and four sternopleural bristles.

Most records of *Palexorista* spp. from *Helicoverpa* spp. are either of *P. laxa* or of other closely related species that are very similar in appearance. the most distinctive character of *P. laxa* is its broad frons, that measures 0.32 - 0.34 of head width at the vertex of the male, and likewise 0.35 - 0.37 of head width in the female. Other species, however, have the frons almost as wide, especially *P. imberbis*. The species of *Palexorista* recorded as parasitising *Helicoverpa* spp. can however be separated with care even using external characters:

1. Occiput with additional row of black setulae behind occipital row. (Palaearctic region only; recorded from *H. armigera* in Italy). ***inconspicua* (Meigen)**

   Occiput with at most isolated black setulae behind occipital row. **2**

2. Parafacials broad, twice the width of the third antennal segment. Median pair of thoracic vittae broad, as wide as distance between acrostichal and dorso-central setae. (South Africa and Mozambique; very doubtful whether this parasitises *Helicoverpa* spp.). ***idonea* Brauer & Bergenstamm**

   Parafacials much less than twice width of the third antennal segment. Median pair of thoracic vittae narrow, much less than width between acrostichals and dorso-centrals. **3**

3. Male: genitalia with cerci very narrow and pointed, strikingly narrower than the broad surstyli. Third antennal segment 2.0 - 2.2 x as long as second. (North Africa and Middle East; Canary Is.; Djibouti. Very doubtful whether this parasitises *Helicoverpa* spp.). ***imberbis* (Wiedemann)**

   Male: genitalia with cerci only slightly narrower than surstyli. Third antennal segment 2.6 - 3.0 x as long as second. (Widespread in Afrotropical region; also India, Peninsular Malaysia. Parasitises *Helicoverpa* spp. especially *H. armigera*). **laxa (Curran)**

Material

All specimens in the NHM identified as *P. laxa* and any other *Palexorista* reared from *Helicoverpa* spp. were checked. The result of this was that all the *Palexorista* specimens reared from *Helicoverpa* spp. proved to be *P. laxa*, with the possible exception of a male from Botswana labelled "reared from *Heliothis* on *Abutilon*". The genitalia of this specimen had been dissected and presumably mounted on a slide, but unfortunately this slide is not in the NHM collection. Notes accompanying the specimen state that it is possibly a new species but obviously very close to *P. laxa*, with significant differences in the genitalia in the shape of the surstyli and cerci. Externally it is clearly very similar to *P. laxa*, with a very broad frons but with an unusually angular head profile due to greater forward projection of the frons.

The most frequent host of *P. laxa* is *H. armigera*, but I have seen a few specimens that have been reared from other species of *Helicoverpa*, in both the Afrotropical and Oriental regions. A specimen from Botswana was reared from *H. scutuligera*, one from India from *H. peltigera* (Schiffermller) and another from peninsular Malaysia from *H. assulta* (Guenée). Two specimens were reared from *H. zea* (Boddie) in laboratory culture in the USA, the population of parasitoids used having originated in India. There were also five specimens from India that had been reared from *Adisura stigmatica* (also Noctuidae) but apart from these, no material of *P laxa* could be found from hosts other than *Helicoverpa* spp. There are, however, clearly occasional exceptions to the general rule.

Published records of *P. laxa* parasitising hosts other than *Helicoverpa* spp. are from several species of noctuids, including *Spodoptera* spp., Lasiocampidae, Arctiidae, Pyralidae and Sphingidae. Most of these should be considered to be at least very suspect, since to date there have been no fully authenticated records of *P. laxa* from any host other than *Helicoverpa*, and the strong likelihood is that most are misidentifications. Many such records were published by Cuthbertson & Munro (1941), at a time when characters to separate species of *Palexorista* were very poorly known. Similar doubts must be applied to records of *Palexorista* species other than *P. laxa* parasitising *Helicoverpa* spp. For example Parsons (1940) considered *P. inconspicua* to be an important biological control agent of *H. armigera* in South Africa, but nowadays it is realised that this species is exclusively Palaearctic. Additionally he mentions *P. imberbis* as a variety of *P. inconspicua* though it is now realised that the former species is largely Palaearctic and reports of it from the southern Afrotropical Region in fact usually refer to *P. laxa*, which therefore seems the likely

identity of his *P. inconspicua*. The only likely instance of *P. inconspicua* parasitising *H. armigera* ia a record from italy where *P. laxa* is unlikely to occur. *P. inconspicua* is mostly a parasitoid of sawflies (Tenthredinoidea), especially Diprionidae, but a few records also exist from a variety of Lepidoptera hosts.

Acknowledgements

This research was funded by the UK Overseas Development Administration through the International Institute of Biological Control's ODA-NRE Project R4365B: "The Population Ecology of *Helicoverpa armigera* in Smallholder Crops in Kenya with Emphasis on its Natural Enemies". It was supervised by Dr K M Harris (International Institute of Entomology).

References

Cock, M.J.W.; Waage, J.K.; van den Berg, H. (1988) The population ecology of *Helicoverpa armigera* in smallholder crops in Kenya, with emphasis on its natural enemies. Final Report, Phase I: April 1987 - March 1988. CIBC report, 18pp.

Crosskey, R.W. (1967) A revision of the Oriental species of *Palexorista* Townsend (Diptera: Tachinidae, Sturmiini). *Bulletin of the British Museum (Natural History)* **21**, 37-97.

Crosskey, R.W. *et al.* (1980) *Catalogue of the Diptera of the Afrotropical region*. British Museum (Natural History), 1437pp.

Cuthbertson, A.; Munro, H.K. (1941) Some records of tachinid parasites and their hosts in southern Africa. *Transactions of the Rhodesian Science Association* **38**, 88-118.

Mesnil, L.P. (1949) Essai de revision des espèces du genre *Drino* Robineau-Desvoidy. Sturmiinae oeufs macrotypes. *Bulletin Institute Sciences Naturelles Belgiques* **35**(42), 1-38.

Parsons, F.S. (1940) Investigations on the cotton bollworm, *Heliothis armigera* Hbn. (*obsoleta* Fabr.). Part II The incidence of parasites in quantitative relation to bollworm populations in South Africa. *Bulletin of Entomological Research* **31**, 89-109.

Annex 2.2.

Egg parasitoids of *Helicoverpa armigera* in Kenya

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Introduction

This report summarises the identifications of the families Scelionidae and Trichogrammatidae (Hymenoptera) which were provided by the IIE (International of Entomology) Identification Services for samples received in 1989 and 1990 from the IIBC *Helicoverpa* Project in Kenya.

Summary of Identifications

Table A2.2.1 summarises all identifications provided for the project during 1989-1991. Seven species of egg parasitoids were collected, six trichogrammatids and one scelionid, *Telenomus ullyetti* Nixon. Of the Trichogrammatidae, two belong to the genus *Trichogramma* and four to *Trichogrammatoidea*. The taxonomy of African *Trichogramma* is in such a confused state currently that no species-level identifications were possible. Notes on the taxa identified are provided below:

Scelionidae

1. *Telenomus ullyetti* Nixon

Recorded from sorghum (Makueni). This species is well-known as a widespread parasitoid of *H. armigera* in Africa (Parry-Jones, 1937). Records from *Scirpophaga* sp. (Descamps 1956), *Chilo diffusilineus* and *Thopeutis* sp. (Feijen & Schulten 1981) are based on misidentifications (Polaszek & Kimani 1990). These records also appear in van den Berg *et al.* (1988).

Trichogrammatidae

2. *Trichogrammatoidea armigera* Nagaraja

In the present survey, recorded only from sorghum at Kakamega and Makueni. Not recorded from Africa by Pintureau & Babault (1986). Originally described from from *Helicoverpa armigera* from India (Nagaraja 1978). Known also from eggs of *Heliocheilus albipunctella* from Senegal (IIE A19571). Introduced into the Cape Verde Islands during the 1980s, but apparently failed to establish (A. van Harten, personal communication).

3. *Trichogrammatoidea eldanae* Viggiani

In the present survey, recorded from cotton (Kibos) and sorghum (Kisii, Kibos). Described from Eldana saccharina (Pyralidae) in Ivory Coast (Viggiani 1979) and also known from Heliochellus sp. (Pintureau & Babault 1986).

4. *Trichogrammatoidea lutea* Girault

Recorded from cotton (Kibos) and sunflower (Kakamega). According to my own records this species is a very widespread, polyphagous parasitoid known also from eggs of the following Lepidoptera genera in Africa: *Appana*, *Chilo*, *Panotima*. Other unconfirmed records are *Diparopsis* and *Platyedra* (IIE specimens), and the following records from the literature, summarised by

Pintureau & Babault (1986): *Anomis, Crytophlebia, Earias, Helicoverpa.* Some of these records may be based on misidentifications.

5. *Trichogrammatoidea simmondsi* Nagaraja
Recorded from cotton (Kibos) and sunflower (Kakamega) during this survey. Known also from Chilo sp. (Pyralidae) and Diopsis sp. (Diptera) in Ghana (Nagaraja 1978) and Diopsis sp. in Malawi (Feijen & Schulten 1981).

6. *Trichogramma* sp. near *bournieri* Pintureau & Babault
A single sample recorded form sorghum (Makueni). Although I have examined paratypes of *T. bournieri*, these are not in sufficiently good condition for the genitalia to be examined, *T. bournieri* was described from *Chilo partellus* in the Comoro Islands, and has been successfully reared on *Ephestia kuehniella*.

7. *Trichogramma* sp.
Collected from maize and sunflower (Kakamega). Until further taxonomic studies are carried out on the African *Trichogramma* spp., very little can be said about this genus. The most recent review (Pintureau & Babault 1986) is far from complete, and does not contain any keys to species.

General discussion and recommendations

In Kenya, the eggs of the polyphagous pest *Helicoverpa armigera* are attacked by at least seven distinct species of egg parasitoids. Most of these species are known to be polyphagous, with the exception of the scelionid *Telenomus ullyetti*. An assessment of the value of these egg parasitoids as naturally-occurring regulators of *H. armigera* populations is outside the scope of this report. However, given the abundance of certain of the *Trichogrammatoidea* species, their importance in natural control of *H. armigera* populations seems to be beyond doubt.

The role of *Trichogramma* species especially requires further study, and the value of any assessment of the role of species of this genus in *H. armigera* control depends largely on future elucidation of the taxonomy of this genus in Africa.

Several other species of Trichogrammatidae are known to attack eggs of *H. armigera* in Africa, albeit north of the Sahara. These are the following: *Trichogramma bourarachae* Pintureau & Babault, *T. cacoeciae* Marchal and *T. cordubensis* Cabello & Vargas (Pintureau & Babault 1986).

Future studies on species of egg parasitoids as natural enemies, or potential classical biological control agents, of *H. armigera* in Africa will be greatly facilitated when several taxonomic problems within the Trichogrammatidae are solved.

Acknowledgements

This research was funded by the UK Overseas Development Administration through the International Institute of Biological Control's ODA-NRE Project R4365B: "The Population Ecology of *Helicoverpa armigera* in Smallholder Crops in Kenya with Emphasis on its Natural Enemies".

References

Descamps, M. (1956) Insects nuisibles au riz dans le Nord Cameroun. *L'Agronomie Tropicale* **11**, 732-755

Feijen, H.R.; Schulten, G.M. (1981) Egg parasitoids of rice pests in Malawi, East Africa. *International Rice Research Newsletter* **6**, 17-18.

Nagaraja, H. (1978) Studies on Trichogra matoidea (Hymenoptera: Trichogrammatidae). *Oriental Insects* **12**, 489-530.

Parry-Jones, E. (1937) The egg parasit of the cotton boll worm, *Heliothis armigera*, Hubn. (*obsoleta*, Fabr.) in Southern Rhoc sia. The British South Africa Co. Publication No.6a.

Pintureau, B.; Babault, M. (1986) Systen ique des espèces africaines des genres *Trichogramma* Westwood et *Trichogrammatoid* Girault. pp. 97-120 in Voegele, J.; Waage, J.; van Lenteren, J. (*eds*) *Trichogramma d other egg parasites*. Les colloques de l'INRA **43**, 91-96.

Polaszek, A.; Kimani, S.W. (1990) *Telenor* species (Hymenoptera; Scelionidae) attacking eggs of pyralid pests (Lepidoptera) in A ca: a review and guide to identification. *Bulletin of Entomological Research* **80**, 57-7

van den Berg, H.; Waage, J.K.; Cock, M. W. (1988) Natural enemies of Helicoverpa armigera in Africa: - a review. Ascot, U.K.; CAI nternational, 81 pp.

Viggiani, G. (1979) Description of *Tricho mmatoidea eldanae* n. sp. (Hym. Trichogrammatidae), parasite of *Eldana saccharina* lk. (Lep. Pyralidae) in Ivory Coast, with notes on *Trichogrammatoidea nodicornis* estw.). *Bolletino del Laboratorio di Entomologia agraria "Filippo Silvestri" Portici* **36**, 108- 11.

Table A2.2.1. A summary of the identific tions of egg parasitoids attacking *Helicoverpa armigera* in Kenya, reared during the IIBC African B 'lworm Project.

FAMILY	GENUS	SPECIES	ST PLANT				LOCALITY	IIBC CODE(S)	IIE CODE(S)
			COTTON	MAIZE	SORGHUM	SUNFLOWER			
Scelionidae	*Telenomus*	*ullyetti*			X		Makueni	HvdB90/12, 13	A21046
Trichogrammatidae	*Trichogrammatoidea*	*armigera*			X		Kakamega, Makueni	HvdB90/16, 17, 38, 39, 40	A21046, A21327
	Trichogrammatoidea	*eldanae*	X		X		Kibos, Kisii	HvdB89/19, 50, 52, 53;	A20218, A20584
	Trichogrammatoidea	*luzea*	X			X	Kakamega, Kibos	HvdB89/59; HvdB90/32, 34-37, 52, 54, 55, 57, 58	A20584, A21327
	Trichogrammatoidea	*simmondsi*	X			X	Kakamega, Kibos	HvdB89/54,56; HvdB90/22-31,51,56	A20584, A21327
	Trichogrammatoidea	spp (not determined)*	X		X		Kakamega, Kibos, Makueni	HvdB89/20,22,51 HvdB90/18,19	A20218, A20584
	Trichogramma	sp. near *bournieri*			X		Makueni	HvdB90/14,15,18	A21046
	Trichogramma	spp (not determined)*				X	Kakamega	HvdB90/41-50, 53	A21327

Annex 2.3.

Anthocorid predators of *Helicoverpa armigera*

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Introduction

This report summarises the identifications of the family Anthocoridae which were provided by the IIE identification Services for samples received in 1989 and 1990 from the IIBC African Bollworm Project in Kenya. Recommendations for further taxonomic research on this group are given at the end of the report.

Summary of Identifications

Table A2.3.1 gives a summary of the identifications provided for seven samples collected from cotton and sunflower primarily in July and August, 1989-1990. The vast majority of specimens represented in these samples belong to the genus *Orius* Wolff. Six species of *Orius* were distinguished, with *O. thripoborus* (Hesse) represented in four of the seven samples, and found in the highest numbers. *Orius albidipennis* (Reuter) also was found in four samples but in much lower numbers, and *O. tantillus* (Motschulsky) was represented in two samples. Three additional species of *Orius* were distinguished, but none of these could be identified to the species level. *Orius* sp. A (nr. *thripoborus*) was represented in two collections, while *Orius* sp. B (females only) and *Orius* sp. C were each found in a single collection. The females of *O. albidipennis* and *O. tantillus* could not be adequately distinguished. The numbers of these specimens are reported in Table A2.3.1 in the column headed "*Orius* spp. (mixed females)". Two other genera of Anthocoridae were represented in a single sample collected at Kibos in August 1989 on cotton. One species, *Cardiastethus exiguus* (Poppius) was represented in relatively high numbers, but *Blaptostethus* sp. and *Cardiastethus* sp. (not *exiguus*) were much less common.

Based on the samples submitted, it is clear that *Orius* is an abundant predator, at least on cotton and sunflower in Kenya. Of the species represented, *O. thripoborus* is most prevalent, with *O. albidipennis* and *O. tantillus* also occurring in reasonable numbers. Samples collected on sunflowers at Kibos, Muguga and Mwea Tebere contained two additional species of *Orius* (sp. A and sp. B) not found in the other samples taken from sunflower. The Mwea Tebere sample, which contained the highest number of specimens of *Orius* sp. A, was collected in January. This suggests the possibility of a seasonal fluctuation in the species composition of *Orius* on sunflower. Obviously, regular sampling on each individual crop would be required to determine species composition and the population structure of the various *Orius* species involved.

Recommendations for Further Taxonomic Research.

Orius is a large and taxonomically complex genus, with over 35 species described from south of the Sahara in Africa. Many of these species are known only from the original descriptions and one to several type specimens in museum collections. There are no comprehensive taxonomic studies or keys to species of this genus for any part of Africa or mainland tropical Asia.

Orius spp. are common predators in agricultural situations throughout the Old World subtropics, and their possible role in controlling pest populations has become a subject of increasing interest

in recent years. The inability to obtain accurate species level determinations is evidenced by the vast majority of studies that report these predators simply as *Orius* spp. Even after considerable effort, only three of the six taxa recognised in the present study could be identified to species level, and one of these, *O. thripoborus* must be considered tentative until type material can be obtained for comparison.

In my opinion, a comprehensive revisionary study of African *Orius* is needed before even common species in agricultural situations can be identified with reasonable certainty. Such a project would involve the acquisition and study of a vast number of museum specimens, including all available type material, and would take approximately two years to complete. Some consideration would also have to be given to Asian taxa, as a number of *Orius* species are known to be broadly distributed in the Old World tropics. My work completed to date on funds provided from the African Bollworm Project has laid the groundwork for a broader study of this group, and I am currently investigating possible sources of funding to continue research on African *Orius*. If research on the biological control aspects of *Orius* is to continue in conjunction with the African Bollworm Project, I would recommend that a proposal for additional funds for taxonomic research be submitted with the next project renewal.

Acknowledgements

This research was funded by the UK Overseas Development Administration through the International Institute of Biological Control's ODA-NRE Project R4365B: "The Population Ecology of *Helicoverpa armigera* in Smallholder Crops in Kenya with Emphasis on its Natural Enemies".

Table A2.3.1. A summary of the Anthocoridae found in association with *Helicoverpa armigera* in Kenya.

				Orius albidipennis (Reuter)		*Orius tantillus* (Motschulsky)		*Orius thripoborus* (Hesse)		*Orius* sp. A (nr *thripoborus*)		*Orius* sp. B		*Orius* sp. C		*Orius* spp. (mixed females)	*Blaptostethus* sp.		*Cardiastethus exiguus* (Poppius)		*Cardiastethus* sp.	
Locality	Date	Host	IIE No.	M	F	M	F	M	F	M	F	M	F	M	F		M	F	M	F	M	F
Mwea-Tebere	Jan. 89	Sunflower	20701							3	4											
Muguga	Aug. 89	Sunflower	20701										9									
Kibos	Aug. 89	Sunflower ?	21046							4												
Kibos	Aug. 89	Cotton	-	6		20		2								*58	1	3	11	48	1	3
Kakamega	July 90	Sunflower	21327	3		3		25	23							*20						
Kibos	July 90	Cotton	21327	14	15			80	58													
Lugari	July 90	Sunflower	21327	2	11			23	67					2	5							

* - albidipennis/tantillus

Annex 3.

Predation studies on anthocorids

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Introduction

Anthocorids are polyphagous predators of soft bodied prey such as thrips, mites, aphids and lepidopteran eggs. They also feeds on pollen in times of scarcity (Askari & Stern 1972; Stoltz & Stern 1978; McCaffrey & Horsburgh 1986). Some species are even able to complete their development on a diet of pollen alone (Kiman & Yeargan 1985; Salas-Aguilar & Ehler 1977).

Experiments during the previous seasons showed that anthocorids are abundant predators in all crops, and may have an important effect on the egg mortality of *H. armigera*. To measure the role of the importance of the anthocorids on egg mortality, an egg exposure experiment was carried out in the field. To test whether the presence of alternative prey might have an effect on the predation by anthocorids, a laboratory experiment was carried out.

Material and methods

Field experiment

Experiments were carried out on sunflower in Kakamega from 14-22 February 1991. To exclude ants and other crawling predators from this experiment, all plants were banded with insect-glue two weeks before the start of the experiment. Just before dawn, 5-12 moths from the culture were released in each of the 0.5 mm nylon mesh covered cages (LxWxH, 1.5x1x2.5 m) enclosing a row of 4-6 sunflower plants. Next morning at 7.30 a.m., the newly deposited eggs were marked by putting a small dot of liquid paper on the plant at a distance of 0.5-1 cm distal to the egg. The positions and the numbers of eggs were recorded. The total number of eggs per plant ranged from 1 to 20. Marked eggs were left for 48 hours, and then the fate of the eggs was recorded. Predation by anthocorids could be recognized by a characteristic collapse of the egg. Also 20 plants were sampled to determine the population density of the anthocorids (as described in section 5 of the main report).

Lab experiment

Experiments were carried out in a CE room (Temperature 27 ± 1°C; RH 60-80%; L:D 12H:12H). Field-collected anthocorid females were starved for 2 hours prior to the experiment. One anthocorid was released in a 9 cm diameter petri dish on a sunflower leaf disc placed on wet cotton-wool. Ventilation was provided by a hole 3 cm in diameter in the lid covered with fine-mesh nylon screen. Also placed on the leaf discs were, according to the treatment:

A 20 fresh *H. armigera* eggs
B 20 fresh *H. armigera* eggs + a spider mite (*Tetranychus lombardini* complex) infested bean leaf (50-100 mites)
C 20 fresh *H. armigera* eggs + 20-30 aphids (*Rhopalosiphum maidis*)

24 and 48 hours after inoculation, the number of predated eggs was counted.

Results and discussion

Field experiment
The results of the egg exposure experiment are presented in Table A3.1-A3.2. A graphic presentation of Table A3.2 is given in Figure A3.1.

Table A3.1. Fate of *H. armigera* eggs in egg exposure studies on sunflower during two plant stages, Kakamega, short rains 1990-91.

	sucked[a]		missing		N
plant stage	**average**	**s.e.**	**average**	**s.e.**	
budding	18.9	6.9	7.6	2.9	19
flowering	11.0	2.6	10.6	4.3	30
total	11.5	2.6	13.0	3.4	60

[a] Anthocorids were the only sucking predators.

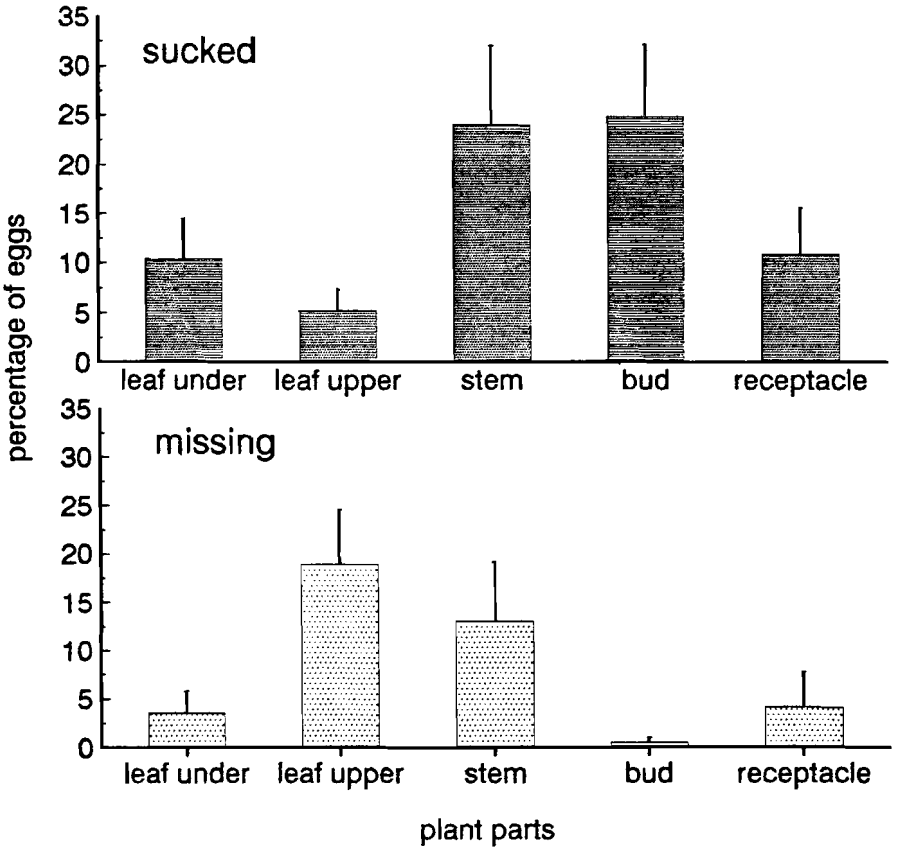

Figure A3.1. Fate of *H. armigera* eggs on different plant parts in egg exposure studies on sunflower, Kakamega, short rains 1990-91.

The predation of *H. armigera* eggs by anthocorids on budding plants is greater than on flowering plants, even though the anthocorid population is higher during the flowering period (see section 5). This could be explained by the abundance of thrips and other soft bodied insects and the presence of pollen in the receptacle of flowering plants, which may serve as alternative food sources. The anthocorids are mostly concentrated in this part of the plant (see section 4). Therefore, the lower egg predation on flowering plants could be due to the availability of alternative food sources.

Table A3.2. Fate of *H. armigera* eggs on different plant parts in egg exposure studies on sunflower, Kakamega, short rains 1990-91. Analysis of variance shows significant effects of plant part on predation ($p = 0.03$), and disappearance of eggs ($p = 0.02$).

	sucked[a]		missing		N
plant parts	**average**	**s.e.**	**average**	**s.e.**	
underside leaf	10.4	4.2	3.6	2.3	26
upperside leaf	5.2	2.2	19.0	5.7	36
stem	24.0	8.5	13.1	6.4	23
bud	24.8	7.6	0.5	0.5	21
receptacle	10.9	4.8	4.2	3.7	21

[a] Anthocorids were the only sucking predators.

Table 2 shows that the level of predation varies according to plant parts on which eggs were laid. Predation was high on the stem and bud, and lower on the receptacle and upperside of the leaf. The explanation for this could be that eggs laid on the bud and the stem are easily accessible, while the eggs laid on the receptacle are more difficult to find. Eggs that are laid on the leaves are far removed from the flower, and the anthocorids will have to travel greater distances to reach them.

More eggs are missing from the stem and the upperside of the leaf, than any other plant part. The reason for this could be that eggs laid on these plant parts are more exposed to rain and wind and will therefore disappear more easily.

Lab experiment
The results of this experiment are presented in Table A3.3.

Table A3.3 shows that in the presence of alternative prey, fewer *H. armigera* eggs are eaten the first day, but there is no difference in predation on the second day. This shows that even in the abundance of alternative prey, *H. armigera* eggs are still eaten, although at a reduced rate. The presence of alternative food sources will help to build-up anthocorid populations. It was subsequently found that a large proportion of the *H. armigera* eggs were infertile and this may have affected the results, especially during the second day of the experiment since the quality of the eggs deteriorated.

Table A3.3. The predation of *H. armigera* eggs by anthocorids with and without alternative prey, during the first and second day after introduction of the eggs. Analysis of variance shows significant effects of the presence of alternative prey on the first day ($p = 0.04$), and on the second day ($p = 0.03$).

	first day		second day		
prey	**average**	**s.e.**	**average**	**s.e.**	**N**
Eggs	2.7	0.8	1.7	0.5	19
Eggs + mites	1.2	0.4	1.0	0.4	18
Eggs + aphids	1.0	0.3	2.1	0.5	23

Acknowledgement

This study was carried out under the IIBC African Bollworm Project, as a student attachment from the Wageningen Agricultural University.

References

Askari, A.; Stern, V.M. (1972) Biology and feeding habits of *Orius tristicolor* (Hemiptera: Anthocoridae). *Annals of the Entomological Society of America* 65, 96-100.

Kiman, Z.B.; Yeargan, K.V. (1985) Development and reproduction of the predator *Orius insidiosus* (Hemiptera: Anthocoridae) reared on diets of selected plant material and arthropod prey. *Annals of the Entomological Society of America* 78, 464-467.

McCaffrey, J.P.; Horsburgh, R.L. (1986) Biology of *Orius insidiosus* (Hemiptera: Anthocoridae): a predator in Virginia apple orchards. *Environmental Entomology* 15, 984-988.

Salas-Aguilar, J.; Ehler, L.E. (1977) Feeding habits of *Orius tristicolor*. *Annals of the Entomological Society of America* 70, 60-62.

Stoltz, R.L.; Stern, V.M. (1978) The longevity and fecundity of *Orius tristicolor* when introduced to increasing numbers of the prey *Frankliniella occidentalis*. *Environmental Entomology* 7, 197-198.

Annex 4.

Surveys of predators in farmers' fields in western Kenya

During the short rains of 1989-90, some surveys were conducted in farmers' fields in western Kenya for predators of *Helicoverpa armigera*.

Crop stages varied from site to site, some crops being in their vegetative stage, while others were already ripening. The crops might not have been in the stages most attractive to predators. The observed predator levels were lower than those during the flowering stages in our experimental trials (see Sections 5 and 6) and this may be attributable to the crop stages.

In conclusion, these limited surveys only show that the common predators are found all over the area. More detailed and more regular surveys would be required to compare the predator densities in farmers fields with those at our experimental sites.

Table A4.1. The occurrence of *Orius* spp. and ants in farmers' fields in western Kenya, short rains 1989-90.

Crop	District	No. of farms	No. of plants	Orius nymphs	Orius adults	Myrmicaria sp.	Camponotus sp.	Pheidole sp.
Cotton	Kisumu	6	48	4.52	0.94	0.02	0.85	1.46
Maize	Kakamega	6	31	0.42	0.16	0.39	0.06	0
Sorghum	Kakamega	6	34	0.24	0.18	0.76	0.21	0

Annex 5.

Details of field sites.

Crop	Variety	Spacing	Planting date	Weeding dates 1st	2nd	3rd	Gapping date
Kakamega *short rains 1988/89*							
Sunflower	Comet	30 x 75	6-10-88	17-10	10-11	15.12	17-10
Maize	H511	30 x 75	6-10-88	17-10	10-11	15.12	17-10
Sorghum	E525-HR	15 x 75	6-10-88	17-10	10-11	15.12	17-10
Bean	GLP-2	10 x 50	6-10-88	17-10	10-11	15.12	17-10
Kakamega *long rains 1989*							
Sunflower	Comet	30 x 75	6-4-89	26-4	18-5	-	20-4
Maize	H614	30 x 75	29-3-89	20-4	22-5	1-7	-
Sorghum	E525-HR	15 x 75	6-4-89	27-4	16-5	-	-
Kakamega *short rains 1989/90*							
Sunflower	Comet	30 x 75	27-9-89	18-10	23-11	4-12	-
Maize	H511	30 x 75	29-9-89	17-10	24-11	1-12	-
Sorghum	E525-HR	15 x 75	28-9-89	25-10	22-11	-	-
Kakamega *long rains 1990*							
Sunflower	Comet	30 x 75	22-3-90	12-4	15-5	30-5	20-4
Maize	H614	30 x 75	2-4-90	20-4	17-5	2-7	-
Sorghum	E525-HR	15 x 75	4-4-90	21-4	11-5	-	-
Kakamega *long rains 1990 (predator evaluation trial)*							
Sunflower	Comet	30 x 75	29-3-90	17-4	2-5	7-6	12-4
Bean	GLP-2	10 x 50	28-3-90	18-4	30-4	-	-
Kibos *long rains 1989*							
Cotton	BPA-75	30 x 90	5-3-89	3-4	3-5	17-5	4-4
Maize	H-511	30 x 75	29-3-89	17-4	3-5	17-5	-
Sorghum	Serena	15 x 60	29-3-89	17-4	3-5	17-5	-
Kibos *long rains 1990*							
Cotton	BPA-75	30 x 90	20-3-90	5-4	20-4	11-5	6-4
Maize	H-511	30 x 75	20-3-90	5-4	20-4	11-5	6-4
Sorghum	E525-HR	15 x 60	21-3-90	5-4	20-4	11-5	6-4
Kibos *long rains 1990 (predator evaluation trial)*							
Cotton	BPA-75	30 x 90	16-3-90	3-4	20-4	8-5	9-4
Bean	GLP-2	10 x 45	17-3-90	-	-	-	-
Kisii *short rains 1988/89*							
Sunflower	Comet	30 x 75	7-10-88	22-11	10-12	29-12	31-10
Maize	H511	30 x 75	6-10-88				
Sorghum	Serena	15 x 75	6-10-88				
Bean	GLP-2	15 x 45	21-10-88				

Annex 5. (continued)

Crop	Variety	Spacing	Planting date	Weeding dates 1st	2nd	3rd	Gapping date
Kisii *long rains 1989*							
Sunflower	Comet	30 x 75	20-2-89	13-3	3-4	16-5	-
Maize	H511	30 x 75	20-2-89				
Sorghum	Serena	15 x 75	20-2-89				
Mwea Tebere *short rains 1988/89*							
Cotton	UKA 59/240	30 x 100	19-10-88	4-11	25-11	27-12	4-11
Maize	Katumani	30 x 75	19-10-88				
Sunflower	Hungarian	30 x 75	19-10-88				
Bean	Mwezi Moja	10 x 50	8-11-88				
Mwea Tebere *long rain 1989*							
Cotton	UKA59/240	30 x 100	24-3-89	17-4	26-4	-	17-4
Maize	Katumani	30 x 75	4-4-89				
Sunflower	Hungarian	30 x 75	4-4-89				
Bean	GLP-2	10 x 50	4-4-89				
Mwea Tebere *short rains 1989/90*							
Cotton	UKA59/240	30 x 100	12-10-89	3-11	2-12	-	26-10
Maize	Katumani	30 x 75	12-10-89				
Maize/Bean	Katumani		12-10-89				
Sunflower	Hybrid 894	30 x 75	12-10-89				
Bean	Mwezi Moja	10 x 50	7-11-89				
Mwea Tebere *long rains 1990*							
Cotton	UKA59/240	30 x 100	27-3-90	17-4	26-4	-	17-4
Maize	Katumani	30 x 75	6-4-90				
Sunflower	Hybrid 894	30 x 75	6-4-90				
Makueni *short rains 1988/89*							
Cotton	UKA59/240	45 x 90	12-10-88	14-11	29-11	-	14-11
Maize	Katumani	30 x 90	12-10-88				
Bean	Mwezi Moja	20 x 50	12-10-88				
Pigeon pea	60/80	50 x 75	12-10-88				
Sorghum	1576	15 x 75	12-10-88				
Makueni *long rains 1989*							
Cotton	UKA59/240	45 x 90	5-4-89	14-4	6-5	15-6	14-4
Maize	Katumani	30 x 90	5-4-89				
Bean	Mwezi Moja	20 x 50	5-4-89				
Pigeon pea	60/80	50 x 75	5-4-89				
Makueni *short rains 1989/90*							
Cotton	UKA59/240	45 x 90	24-11-89	7-12	18-12	30-12	7-12
Maize	Katumani	30 x 90	24-11-89				
Sunflower	Hybrid 894	30 x 75	24-11-89				
Pigeon pea	60/80	50 x 75	24-11-89				
Sorghum	Serena	15 x 75	24-11-89				

Annex 5. (continued)

Crop	Variety	Spacing	Planting date	Weeding dates 1st	2nd	3rd	Gapping date
Msabaha *short rains 1988/89*							
Cotton	UKA59/240	45 x 90	4-11-88	6-12	25-12	15-1	15-11
Maize	Coast comp.	30 x 75	4-11-88				
Cowpea	"Local"	45 x 45	4-11-88				
Sorghum	Serena	15 x 60	4-11-88				
Msabaha *long rains 1989*							
Cotton	UKA59/240	45 x 90	26-4-89	12-5	7-7	-	26-4
Maize	Coast Comp.	30 x 75	26-4-89				
Cowpea	"Local"	45 x 45	26-4-89				
Sorghum	Serena	15 x 60	26-4-89				
Msabaha *short rains 1989/90*							
Cotton	UKA59/240	45 x 90	11-10-89	13-11	10-1	-	11-10
Maize	Coast Comp.	30 x 75	11-10-89				
Cowpea	"Local"	45 x 45	11-10-89				
Sorghum	Serena	15 x 60	11-10-89				
Mtwapa *short rains 1988/89*							
Sorghum	Serena	15 x 60	17-11-88	20-12	8-1	1-2	
Cotton	UKA59/240	45 x 90	17-11-88				
Maize	Coast Comp.	30 x 75	17-11-88				
Cowpea	"Local"	45 x 45	17-11-88				
Pigeon pea	Munyenzeni	60 x 90	17-11-88				
Finger millet	"Local"	15 x 30	17-11-88				
Bean	Mwezi Moja	15 x 30	17-11-88				
Mtwapa *long rains 1989*							
Sorghum	Serena	15 x 60	25-4-89	15-5	16-6	10-7	-
Cotton	UKA59/240	45 x 90	25-4-89				
Maize	Coast Comp.	30 x 75	25-4-89				
Cowpea	"Local"	45 x 45	25-4-89				
Pigeon pea	Munyenzeni	60 x 90	25-4-89				
Finger millet	"Local"	15 x 30	25-4-89				
Tomato	Moneymaker	60 x 90	25-4-89				

References

Abate, T. (1988) Experiments with trap crops against African bollworm, *Heliothis armigera*, in Ethiopia. *Entomologia Experimentalis et Applicata* **48**, 135-140.

Carroll, C.R.; Risch, S.J. (1983) Tropical annual cropping systems: ant ecology. *Environmental Management* **7**, 51-57.

Coaker, T.H. (1959) Investigations on *Heliothis armigera* (Hb.) in Uganda. *Bulletin of Entomological Research* **50**, 487-506.

Cock, M.J.W.; Waage, J.K.; van den Berg, H. (1988) The population ecology of *Helicoverpa armigera* in smallholder crops in Kenya with emphasis on its natural enemies. Final Report, Phase I: April 1987 - March 1988. CIBC report, 18pp.

Cock, M.J.W.; van den Berg, H.;Oduor, G.I.; Onsongo, E.K. (1989) The population ecology of *Helicoverpa armigera* in smallholder crops in Kenya with emphasis on its natural enemies. First Annual Report, Phase II: April 1988 - March 1989. CIBC report, 74pp.

Ewing, K.P.; Ivy, E.E. (1943) Some factors influencing bollworm population and damage. *Journal of Economic Entomology* **36**, 602-606.

Fitt, G.P. (1989) The ecology of *Heliothis* species in relation to agroecosystems. *Annual Review of Entomology* **34**, 17-52.

Fletcher, R.K.; Thomas, F.L. (1943) Natural control of eggs and first instar larvae of *Heliothis armigera*. *Journal of Economic Entomology* **36**, 557-560.

Goodenough, J.L. *et al.* (26 authors) (1986) Efficacy of entomophagous arthropods. pp 75-91 in Johnson, S.J.; King, E.G.; Bradley, Jr., J.R. (*eds*) Theory and tactics of *Heliothis* population management: I. Cultural and biological control. *Southern Cooperative Series Bulletin* **316**, 161pp.

Hogg, D.B.; Nordheim, E.V. (1983) Age-specific survivorship analysis of *Heliothis* spp. populations on cotton. *Researches on Population Ecology* **25**, 280-297.

Huddleston, T.; Walker, A.K. (1988) *Cardiochiles* (Hymenoptera: Braconidae), a parasitoid of lepidopterous larvae, in the Sahel of Africa, with a review of the biology and host relations of the genus. *Bulletin of Entomological Research* **78**, 435-461.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) (1982) *Proceedings of the International Workshop on* Heliothis *Management, 15-20 November 1981, ICRISAT Center, Patancheru, A.P., India*. Patancheru, A.P., India; ICRISAT, 418 pp.

Jayaraj, S. (1982) Biological and ecological studies of *Heliothis*. *In* ICRISAT *Proceedings of the International Workshop on* Heliothis *Management, 15-20 November 1981, ICRISAT, Patancheru, India*. Patancheru, India; ICRISAT, pp. 17-28

Joyce, R.J.V. (1982) A critical review of the role of chemical pesticides in *Heliothis* management. *In* ICRISAT *Proceedings of the International Workshop on* Heliothis *Management, 15-20 November 1981, ICRISAT, Patancheru, India*. Patancheru, India; ICRISAT, pp. 173-188

KARI (Kenya Agricultural Research Institute) (1989) *Kenya Agricultural Research Institute*. Government Printer, Nairobi, 30 pp.

Khaemba, B.M.; Mutinga, M.J. (1982) Insect pests of sunflower (*Helianthus annuus* L.) in Kenya. *Insect Science and its Application* **3**, 281-286.

King, E.G.; Jackson, R.D. (*eds*) (1989) *Proceedings of the workshop on biological control of* Heliothis*: increasing the effectiveness of natural enemies, 11-15 November 1985, New Delhi, India.* New Delhi, India; Far Eastern Regional Office, U.S. Department of Agriculture, 550 pp.

King, E.G.; Powell, J.E.; Smith, S.W. (1982) Prospects for utilisation of parasites and predators for management of *Heliothis* spp. *In* ICRISAT *Proceedings of the International Workshop on* Heliothis *Management, 15-20 November 1981, ICRISAT Center, Patancheru, A.P., India.* Patancheru, A.P., India; ICRISAT, pp. 103-122.

Muthamia, J.B. (1971) *Cotton pests and their control.* Entomology Section, Department of Agriculture, Kenya.

Nyambo, B.T. (1986) Studies in the bollworm, *Heliothis armigera* Hubner, the key cotton pest in Tanzania, as a basis for improved integrated pest management. Ph.D. thesis, University of London, 444pp.

Nyambo, B.T. (1990) Effect of natural enemies on the cotton bollworm, *Heliothis armigera* Hübner (Lepidoptera: Noctuidae) in Western Tanzania. *Tropical Pest Management* **36**, 50-58.

Parsons, F.S. (1940a) Investigations on the cotton bollworm, *Heliothis armigera* Hübn. (*obsoleta* Fabr.). Part II. The incidence of parasites in quantitative relation to bollworm populations in South Africa. *Bulletin of Entomological Research* **31**, 89-109.

Parsons, F.S. (1940) Investigations on the cotton bollworm, *Heliothis armigera* Hübn. Part III. Relationship between oviposition and the flowering curves of food-plants. *Bulletin of Entomological Research* **31**, 147-177.

Parsons, F.S.; Ullyett, G.C. (1934) Investigations on the control of the American and red bollworms of cotton in South Africa. *Bulletin of Entomological Research* **25**, 349-381, Plate XI.

Pearson, E.O. (1958) *The insect pests of cotton in tropical Africa.* London, U.K.; Empire Cotton Growing Corporation & Commonwealth Institute of Entomology, 355pp.

Reed, W. (1965) *Heliothis armigera* (Hb.) (Noctuidae) in Western Tanganyika. I. Biology, with special reference to the pupal stage. II. Ecology and natural and chemical control. *Bulletin of Entomological Research* **56**, 117-125, 127-140.

Rens, G.R. (1977) Interrelations and control of insects, attacking cotton and food crops, with particular reference to *Heliothis armigera*. *In* De Lima, C.P.F. (*ed*) *Advances in medical, veterinary and agricultural entomology in eastern Africa.* Proceedings of the First East African Conference on Entomology and Pest Control, December 6-10, 1976, Nairobi, Kenya. Nairobi, Kenya; East Africa Literature Bureau (Kenya), pp. 80-84.

Ridgeway, R.L.; Lingren, P.D.; Cowan, C.B. Jr.; Davis, J.W. (1967) Populations of arthropod predators and *Heliothis* spp. after applications of systemic insecticides to cotton. *Journal of Economic Entomology* **60**, 1012-1016.

Roome, R.E. (1975) Activity of adult *Heliothis armigera* (Hb.) (Lepidoptera: Noctuidae) with reference to the flowering of sorghum and maize in Botswana. *Bulletin of Entomological Research* **65**, 523-530.

Sawyer, A.J.; Haynes, D.L. (1984) On the nature of errors involved in estimating stage-specific survival rates by Southwood's method for a population with overlapping stages. *Researches on Population Ecology* **26**, 331-351.

Southwood, T.R.E. (1978) *Ecological methods with particular reference to the study of insect populations. Second Edition.* London; Chapman & Hall, 524 pp.

Southwood T.R.E.; Jepson, W.F. (1963) Studies on the populations of *Oscinella frit* L. (Dipt: Chloropidae) in the oat crop. *Journal of Animal Ecology* **31**, 481-495.

Taylor, L.R. (1961) Aggregation, variance and the mean. *Nature* **189**, 732-735.

Teakle, R.E.; Jensen, J.M.; Mulder, J.C. (1985) Susceptibility of *Heliothis armigera* (Lepidoptera: Noctuidae) on sorghum to nuclear polyhedrosis virus. *Journal of Economic Entomology* **78**, 1373-1378.

Titmarsh, I. (1985) Population dynamics of *Heliothis* spp. on tobacco in far North Queensland. M.SC. thesis, James Cook University, Townsville, Australia.

Twine, P.H. (1971) Cannibalistic behaviour of *Heliothis armigera* (Hubn). *Queensland Journal of Agricultural and Animal Science* **28**, 153-157.

Twine, P.H. (1978) Effect of temperature on the development of larvae and pupae of the corn earworm, *Heliothis armigera* (Hübner) (Lepidoptera: Noctuidae). *Queensland Journal of Agricultural and Animal Sciences* **35**, 23-28.

van den Berg, H.; Nyambo, B.T.; Waage, J.K. (1990) Parasitism of *Helicoverpa armigera* (Lepidoptera: Noctuidae) in Tanzania: analysis of parasitoid-crop associations. *Environmental Entomology* **19**, 1141-1145.

van den Berg, H.; Waage, J.K.; Cock, M.J.W. (1988) *Natural enemies of* Helicoverpa armigera *in Africa: - a review*. Ascot, U.K.; C.A.B International, 81pp.

van den Berg, H.; Cock, M.J.W. (1991) Beneficial organisms in insect pest control: A field guide to the African Bollworm and its natural enemies. Wallingford, U.K.; CAB International,

van Driesche, R.G.; Bellows, T.S. Jr.; Ferro, D.N.; Hazzard, R.; Maher, A. (1989) Estimating stage survival from recruitment and density data, with reference to egg mortality in the Colorado potato beetle, *Leptinotarsa decemlineata* (Say) (Coleoptera: Chrysomelidae). *Canadian Entomologist* **121**, 291-300.

Vargas, R.; Nishida, T. (1980) Life table of the corn earworm, *Heliothis zea* (Boddie), in sweet corn in Hawaii. *Proceedings, Hawaiian Entomological Society* **23**, 301-307.

Wardhaugh, K.G.; Room, P.M.; Greenup, L.R. (1980) The incidence of *Heliothis armigera* (Hübner) and *Heliothis punctigera* Wallengren (Lepidoptera: Noctuidae) on cotton and other host plants in the Namoi Valley of New South Wales. *Bulletin of Entomological Research* **70**, 113-131.

Weseloh, R.M. (1982) Implications of tree microhabitat preferences of *Compsilura concinnata* (Diptera: Tachinidae) for its effectiveness as a gypsy moth parasitoid. *Canadian Entomologist* **114**, 617-622.

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