African bollworm and its natural enemies in Kenya

Second Edition

Henk van den Berg & Matthew J.W. Cock

CABI Africa Regional Centre

With support from
Crop Protection Programme, DFID
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Preface to the new edition

The first edition of this booklet was produced in 1993 as part of a research project entailing detailed studies of the population ecology and natural enemies of the African Bollworm *Helicoverpa armigera* in smallholder mixed cropping systems, including maize, cotton, sorghum and sunflower. The research was carried out in Kenya from 1988 to 1991 by the former International Institute of Biological Control's Kenya Station (now integrated within CABI Bioscience at CABI Africa Regional Centre), in collaboration with the Kenya Agricultural Research Institute (KARI). It was funded by the Overseas Development Administration (now Department for International Development, DFID) of the British Government, through their Natural Resources Institute (NRI).

One thousand copies of the booklet were produced and distributed between 1993 and 1997 to researchers, extension and NGO staff and educators in Africa and elsewhere. The booklet has proved so popular that copies have been requested by organizations from as far afield as Asia and Latin America for their field staff or for training purposes, reflecting the lack of freely available, user-friendly information on natural enemies in many developing countries. It is hoped that the reprint of this booklet will enable practical information on the incidence and conservation of bollworm natural enemies to become more widely available within Africa and to encourage further studies and awareness-raising of the role of biological control as the cornerstone of Integrated Pest Management.

Preparation and publication of this second edition was supported both by the Crop Protection Programme of the UK Department for International Development, through the agency of Natural Resources International, and by the Swiss Agency for Development & Cooperation (SDC), through their funding of CABI Bioscience's Technical Support Group to the Global IPM Facility.

Contributions to and comments on the updated sections of this new edition from the following colleagues are gratefully acknowledged: Dr Kevin

Gallagher (Global IPM Facility); Dr Rami Kfir (Plant Protection Research Institute, South Africa); Dr Graham Matthews (Imperial Collage, University of London); Dr Robert Kofi Mensah (Australian Cotton Research Institute); and Dr Sam Page (African Farmers' Organic Research & Training, Zimbabwe).

Figures

Beside each photograph a silhouette is provided to show the approximate size of the insect. All photographs were taken in Kenya by H. van den Berg.

Introduction

Biological control is the use of beneficial organisms, or natural enemies, for the control of pests. Natural enemies reduce pest numbers and may thus prevent outbreaks. There are three types of natural enemies: predators, parasitoids and diseases. In East Africa, natural enemies are common in agricultural fields. Often more than we realise, natural enemies keep insect pests below damaging levels, while without the pressure of those beneficial organisms, the pest would become a problem.

Interest in biological control of pests in agricultural crops is increasing. Disadvantages of spraying insecticides to control insect pests have become evident. Apart from the harm they do to human health and the environmemt, insecticides can ealisy disrupt the natural control of pests by killing their natural enemies. Without these beneficial organisms, farmers would become more dependent on the use of insecticides.

In this guide we focus on the African bollworm, *Helicoverpa armigera*, which is one of the most important pests of agriculture in Africa. Its caterpillars (or larvae) feeds on many different crops. It is one of the most important pests on cotton, sunflower and tomato, and also damages sorghum, maize, tobacco, and diffrent kinds of peas and beans, as well as export flower crops such as carnations. There are examples from several areas in Africa, Asia and Australia where the bollworn has developed from a manageable agricultural pest into a major threat to agriculture, mainly in cotton, following the heavy use of insecticides. This has caused farmers to changge to other crops, or abandon some areas.

In East Africa, crops are mostly grown in small farm-holdings, rather than in large schemes. Crops in these small farms are usually grown in a mosaic pattern of small plosts of various crops, or intercrops. Farmers generally apply limited amounts of insecticide. In such a varied and relatively undisturbed farming system, natural enemies are likely to have an important effect on pests such as the bollworm, and in certain situations they can suppress the pest below damaging levels. On the other hand, some high-value crops, such as cotton, still suffer bollworm damage in spite of the action of natural enemies; consequently these crops are often intensively sprayed. For a stable and sustainable system of agriculture, pest control should not rely on chemical insecticides, but should be

based as much as possible on the utilization and encouragement of the natural enemies, allowing for a limited and sensible use of insecticides when necessary.

To do this, farmers need to recognize the natural enemies as well as the pest insects. Many farmers are aware of the insects in their crops, but may not distinguish between pests and beneficial insects which can kill pests. The African bollworm is attacked by many predators, parasitoids and pathogens. In some crops, there are other pests that look similar to the bollworm, and this may complicate monitoring or sampling. This guide presents developmental stages of the bollworm and related pests, and important natural enemies, found in smallholder crops in Kenya.

Smallholder farms in Western Province, Kenya

Understanding natural enemies: farmer-driven training and research

The most successful farmer training initiatives on natural enemies have not been via traditional extension methods such as guidebooks, posters or illustrated talks but have focussed on field observations and discovery-learning by farmers themselves.

Through Farmer Field Schools (FFS) and similar approaches to farmer participatory IPM training, many thousands of farmers in Asia, Latin America and Africa have stepped off the pesticide treadmill and significantly improved their livelihoods. The success of these approaches lies in their focus on the farmer as the key decision-maker in pest management and on the facilitation of a discovery-learning process using non-formal education methods. The field is the primary classroom and the four major principles are:

- Grow a healthy crop
- Observe fields weekly
- Conserve natural enemies
- Farmers understand ecology and become experts in their own fields

By comparing plots under conventional chemical control, as practised by local farmers, with plots where pesticide application and other management practices are under IPM decision-making by the group, participants see the consequences and costs of calendar spraying for themselves over the course of an entire crop season.

Discovery-learning exercises and other experiments are also used to help farmers learn about ecological processes. These include studying pest and natural enemy behaviour and lifecycles by keeping specimens in jars or cages known as 'insect zoos'; assessment of fruiting parts to explore plant compensation for pest damage; and simple parasitism and predation studies. Natural enemy guides such as this one should be used to support field-based training via observation and group discussion, never as a substitute for it. This is equally valid for training with farmers, extension staff or college students. To be effective, training must also be relevant to farmers' needs and local situations. The use of local languages for biocontrol awareness training is extremely important. Often there will be no local name for a particular natural enemy and farmers may be encouraged to invent their own names, based on what they have observed of the insect and what they have come to learn about its lifestyle. For example, Kenyan farmers named green lacewing

larvae species which use prey debris as camouflage "that which carries a heavy load" and parasitized bug eggs "injected eggs" after they became familiar with the egglaying behaviour of parasitic wasps. Not only does this naming process help farmers to become familiar with the insects, but it can also give a real sense of ownership of the learning process.

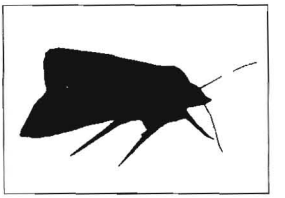
This guide is also intended to support and stimulate on-farm research into pest management which is relevant to the mixed cropping systems of most African smallholders. The information in this guide should not be treated as applicable to all regions. Users need to investigate the natural enemy fauna in their local cropping systems at different sites and seasons. Farmers and field staff can provide valuable new information on their native natural enemies through regular observation. For example, cotton Farmer Field School groups in Zimbabwe recently discovered an effective thrips predator of spider mites, and possibly of bollworn eggs, and a previously unrecorded ladybird beetle.

In South Africa, recent on-farm studies showed that in the absence of insecticides, daily predation rates of bollworm eggs and larvae may be as high as 37% and 30% respectively in cotton. Insecticide applications in cotton and other crops may often reduce the ability of natural enemies to keep bollworms and other pests under control. Training-oriented research needs to look at the impact of local commonly-used pesticides on natural enemies and of cultural control methods which may encourage or hinder important natural enemies. For instance, organic cotton farmers in Zimbabwe observed that an effective black ant predator can be encouraged into cotton by intercropping with cowpea. Kenyan studies showed that natural enemies cause higher mortality of young bollworm in maize compared to other crops and maize can therefore be useful as a border or intercrop with cotton. By studying local agroecology with farmers, researchers and extensionists can help to develop safer, cost-effective and more sustainable pest management options which take full advantage of native natural enemies.

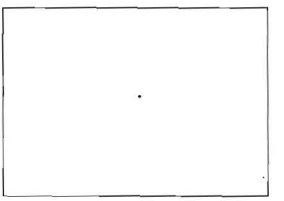
Recognizing the pest

The African bollworm attacks many crops, including cotton, sunflower, tobacco, tomato, maize, sorghum and legumes, but also feeds on many different weeds. It is found throughout sub-saharan Africa, southern Europe, the Middle East, South and South-east Asia and Australia. Adult moths are about 2 cm long in the resting position shown, and are dull-brown to buf fin colour, with a characteristic dot-pattern on their wings.

Moths become active at dusk, and females lay eggs (oviposit) on suitable plants, mostly during the evening hours.



Helicoverpa armigera moth



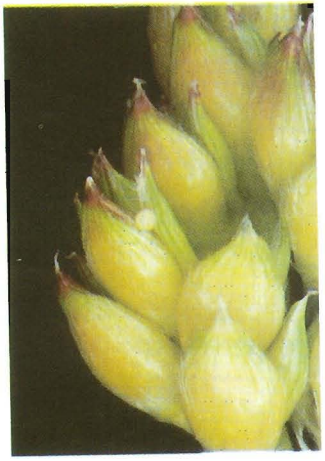
Helicoverpa armigera egg

Eggs are laid singly on fruiting and flowering parts of the plants, or on the leaves. The eggs are white-yellow in colour when they are freshly laid, and turn yellow-brown as they develop. Because of this, older eggs are more difficult to

find against the generally dark plant surface. The egg is round, with a diameter of 0.45-0.5 mm. The distinct ridge structure and the raised micropyle on top can be seen in the field with a hand lens. A single female moth can lay a thousand or more eggs during its lifespan of approximately two weeks. In East Africa, the egg takes 4-6 days to hatch, depending on the temperature.

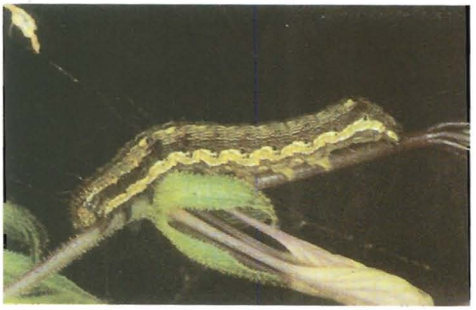
When it hatches, the caterpillar (or larva) first consumes part of the egg shell, and then looks for suitable food. The young caterpillar prefers to feed on the soft plant parts, which are rich in protein, particularly buds and flowers. Older caterpillars are especially damaging, because they consume only a small part

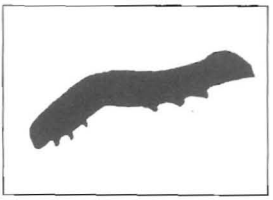
Helicoverpa armigera egg on sunflower



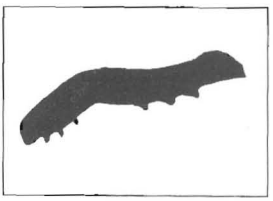
Helicoverpa armigera egg on sorghum

of a flower or fruit, and then move to the next, leaving a trail of damaged flowers or fruits which will produce no harvest.





Helicoverpa armigera caterpillar on a wild host plant



Helicoverpa armigera caterpillar feeding inside a cotton boll

Caterpillars often feed with their front portion hidden inside the hole they have eaten, so that only the hind part of the body shows. Caterpillars have characteristic markings and short hairs. Their general colour and colour pattern is extremely variable, ranging from green to white-yellow to entirely dark brown, often with longitudinal bands of a different colour. The fully fed caterpillar is about 4 cm long. At this stage it moves to the soil, and burrows in to form a resting stage or pupa. Inside the pupa, the moth develops. In due course, the moth emerges from the pupa and burrows out of the soil, ready to mate and repeat the cycle. In areas with a long dry season, some pupae remain without developing (diapause) for several months, until the rains start, and the adult finally emerges.

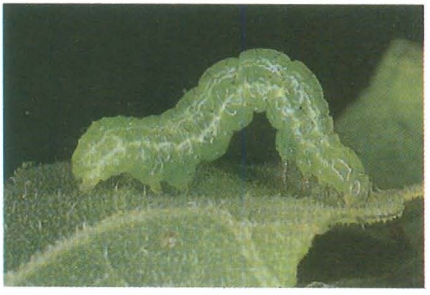
Helicoverpa armigera damage to young flower and to mature seeds of sunflower

Similar pests

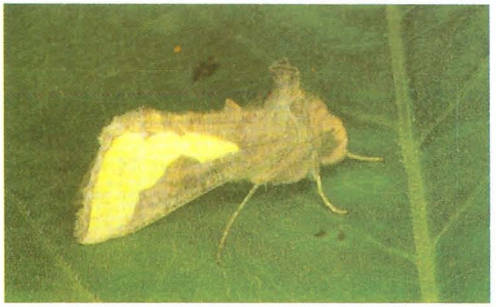
Apart from the African bollworm, other plant feeders can be found on agricultural crops in East Africa, and some of these seem similar to the bollworm. In monitoring or studying the African bollworm, it is important to be able to distinguish it from these other pests. There are no common pests in East Africa which are closely related to the African bollworm. However, common pests easily confused with the bollworm include *Spodoptera littoralis*, *Plusia* and *Ctenoplusia* spp. Eggs and larvae of these pests can be separated when examined closely and carefully.

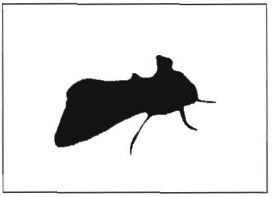
The developmental stages, of *Plusia orichalcea* resemble those of the African bollworm. The moths lay their eggs singly on several different crops. The eggs are round (0.5-0.55 mm) and lighter in colour then those of the African bollworm. With a 10x hand lens, the ridges and micropyle of the egg can easily be seen, but are not as clear as in the African bollworm. The egg is slightly flattened from the top. Larvae grow to about the same size as those of *H. armigera*, but have different markings and hairs, and are always green in colour. Moths of *P. orichalcea* are easily separated by their shiny golden wing markings.

Egg of *Plusia orichalcea*



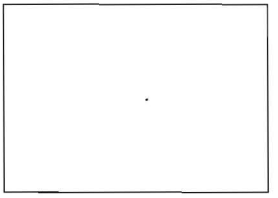
Larva of *Plusia orichalcea*



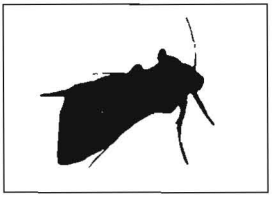


Plusia orichalcea moth

Ctenopulsia limbirena is also a pest of several crops, but rarely causes much damage. Eggs are laid singly on leaves. The egg (0.4-0.5 mm) is rounder than that of *P. orichalcea*, ridges can be seen, but less clearly as those of the African bollworm or *Pulsia orichalcea*. The micropyle is flat and undefined.

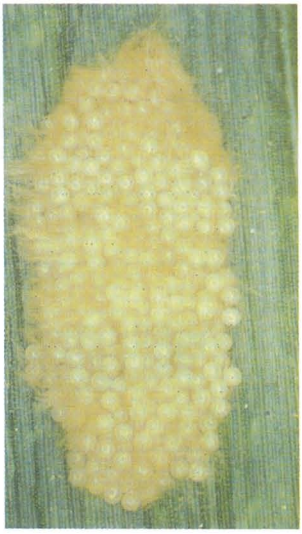


Egg of *Ctenoplusia limbirena*



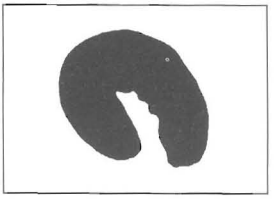
Ctenoplusia limbirena moth

Spodoptera littoralis is a common pest of maize, tomato, cotton etc. and is found in many parts of Africa. Eggs are laid on the underside of leaves in batches of some hundreds, and are covered with hair scales from the body of the female moth. The newly hatched caterpillars at first stay in groups, but later they disperse. Mature larvae are large (5 cm long), dark brown and have pairs of black markings on the front and hind part of the body. Moths have brown wings with white markings.

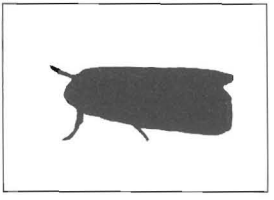


Egg mass of *Spodoptera littoralis*

Detail of eggs

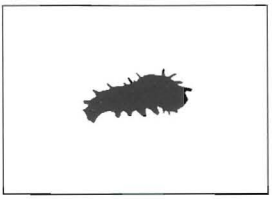


Spodoptera littoralis caterpillar

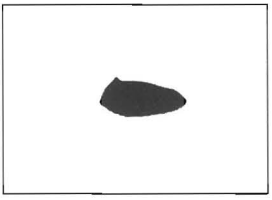


Spodoptera littoralis moth

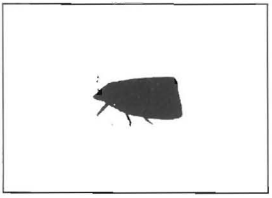
Spiny bollworms, *Earias biplaga* and *E. insulana*, are important pests on cotton. The round blue tinted eggs are laid singly near growing tips, buds and flowers. Caterpillars, which grow up to 2 cm long, can be recognized by the spines on their bodies. They feed mostly inside buds or flowers of cotton and related weeds. The fully fed caterpillar spins a silk cocoon on the plant, or on the soil surface. Inside the cocoon it turns into a pupa, and in turn into an adult. Adults are small moths of distinctive yellow/green colour.



Spiny bollworm caterpillar

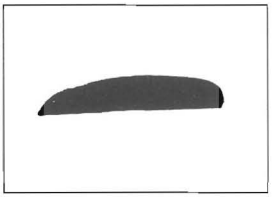


Spiny bollworm cocoon

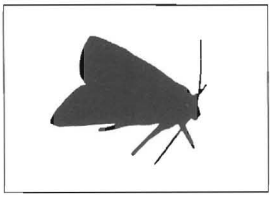


Spiny bollworm moth *(Earias biplaga)*

Caterpillars of the rice armyworm, *Mythimna loreyi*, attack rice, maize and other cereals, where it feeds mostly on the leaves. Eggs are laid in batches of up to 100 in the leaf axil. Caterpillars grow to about the same size as the African bollworm caterpillar. They are variable in colour, and have characteristic stripes along their body. Adult moths are pale brown.



Caterpillar of *Mythimna loreyi*



Mythimna loreyi moth

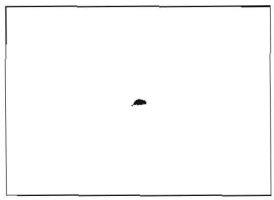
Predators

Predatory insects are often abundant in agricultural crops. They consume an important portion of bollworm eggs and larvae, but also feed on other pest organisms.

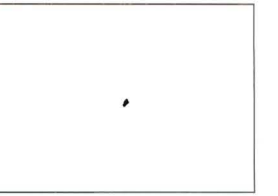
Anthocorid bugs (Anthocoridae)

Anthocorid bugs belong to the insect group Heteroptera, or «true bugs». All true bugs have sucking mouth parts called a rostrum which can be seen in the illustrations. Many feed on plants, but the families Anthocoridae, Lygaeidae, Nabidae and Reduviidae contain mostly predators that feed on other insects.

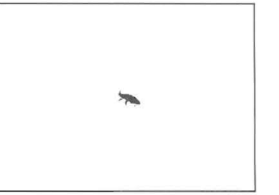
Anthocorids are small (1-3 mm long). They usually inhabit the buds, flowers, fruits and leaf axils of crops, and are therefore difficult to find. They are frequently found in large numbers in agricultural crops throughout the world. Anthocorids pierce and suck the liquid contents of their prey with their sucking mouth parts. They feed on a wide variety of prey, including insect eggs, thrips, mites, aphids, and young caterpillars.



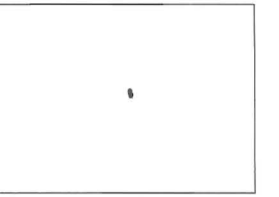
Anthocorid nymph sucking an African bollworm egg



Orius nymphs emerging from eggs embedded in plant tissue



Cardiastethus sp. adult sucking an African bollworm egg



Orius sp. adult

Anthocorids have adaptable feeding habits. As well as their insect food, they can feed on plant pollen and they can suck moisture from the leaves and stems, without causing significant damage to the plants. Some species are even able to develop on a diet of pollen alone.

Adult anthocorids are attracted to the crop when plants start flowering or shedding pollen. They lay eggs inserted into the plant leaf veins. The eggs, which are relatively large considering the size of the adult, are hidden with only the top of the egg visible. The eggs take about 5 days to develop, and then an orange nymph emerges. The nymph is able to immediately attack small prey, such as bollworm eggs. It takes about 15 days to grow up to the adult stage. In Kenya, at least eight species of anthocorids are common on crops. These are *Orius* species, which are usually partially black, and *Cardiastethus* and *Blaptostethus* species, which are usually brown in colour, and slightly larger than *Orius*.

Big-eyed bugs (Lygaeidae)

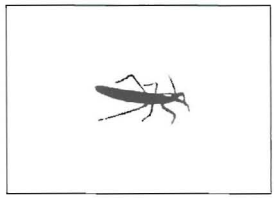
Geocoris amabilis is a compact, brightly coloured bug with large protruding eyes. Although it is not nearly as common as *Orius* or *Cardiastethus* species, this bug is sometimes common on cotton, where it feeds on African bollworm eggs and small caterpillars, and on other pests

Geocoris amabilis adult sucking a young African bollworm caterpillar

such as *Lygus* bugs and mites.

Nabid bugs (Nabidae)

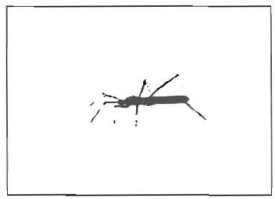
Members of this family are all predators of other arthropods. *Tropiconabis capsiformis* is a slender bug, which lays its eggs into plant stems. Nabidae are usually not very common.



Tropiconabis capsiformis adult sucking an African bollworm caterpillar

Assassin bugs (Reduviidae)

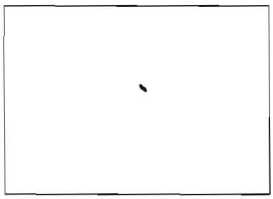
Assassin bugs, such as *Polytoxus flavescens*, are medium to large predatory bugs with well-developed, bent mouthparts. Like Nabids, assassin bugs are not common in East African annual crops.



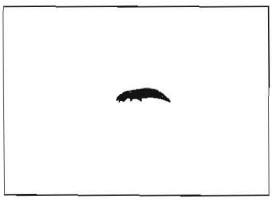
Polytoxus flavescens adult

Green lacewings (Chrysopidae)

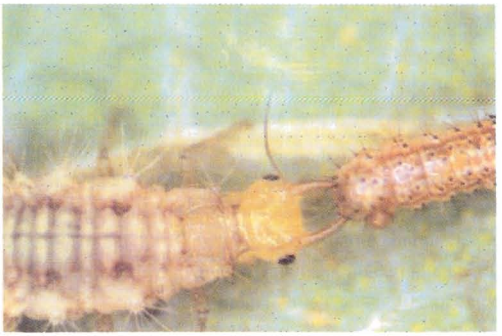
The green lacewing *Chrysoperla* sp. deposits its tiny eggs on plants. The white egg is attached to a plant by a distinctive stalk. Larvae of the green lacewings are predators of a wide variety of insects, including many agricultural pests. The larvae have a pair of curved, sucking mouth parts, which they use to pierce their prey and suck out the body contents. Larvae of some species have a curious camouflage; they carry a load of prey remains and other debris stuck on their back. Mature larvae produce a cocoon and pupate on the plant. Adult lacewings fly by night and feed on plant pollen and nectar.

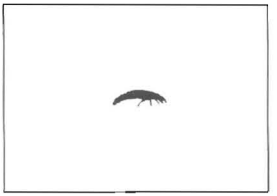


Egg of *Chrysoperla* sp.

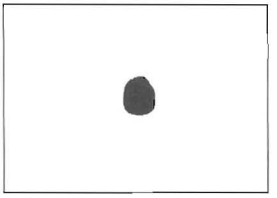


Chrysoperla larva

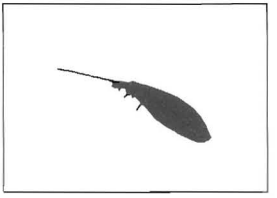




Chrysoperla sp. larva feeding on an African bollworm caterpillar



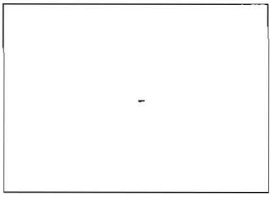
Pupal cocoon of *Chrysoperla* sp.



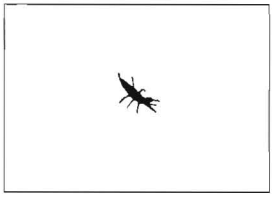
Chrysoperla sp. adult

Brown lacewings (Hemerobiidae)

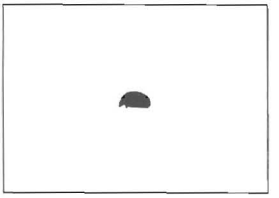
Brown lacewings, such as *Micromus sjostedti*, are slightly smaller than green lacewings. The eggs of *Micromus sjostedti* are laid singly on the plant surface, without a stalk. Their larvae feed mainly on aphids and mites, but may sometimes feed on the eggs and very small larvae of African bollworm. The adults are about 9 mm long. Like the green lacewings, they are only active at night, and feed on plant pollen and nectar.



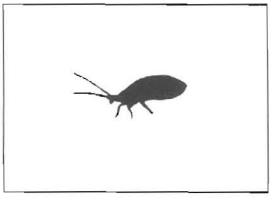
Egg of *Micromus sjostedti*



Micromus sjostedti larva attacking aphids



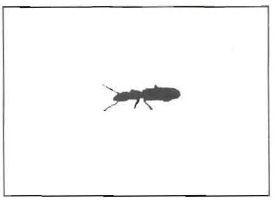
Micromus sjostedti pupa



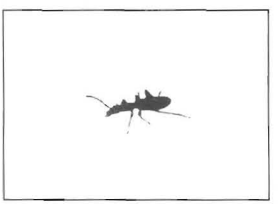
Micromus sjostedti adult

Beetles

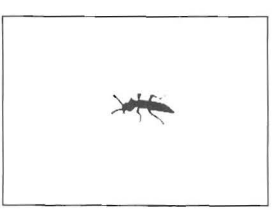
Carabid beetles are one of the most important predatory families among the beetles (Coleoptera). A large number of carabid species are found in East African agricultural systems. The majority are ground-dwelling species, feeding on other soil insects that live or pupate in or on the soil. Only a limited number of carabids visit the vegetation and feed on the pest insects there. Another common family of predators and scavengers are the Staphilinidae; of these *Paederus* species are most commonly encountered on various crops.



Hexagonia sp. nr. *punctatostriata*

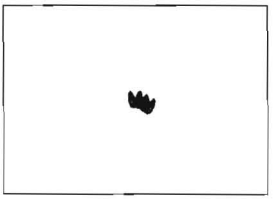


Stenidia sp.

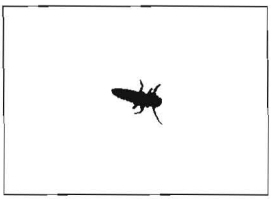


Paederus riftensis

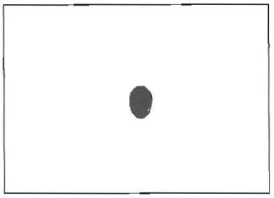
The Coccinellidae, or ladybird beetles, are a large family nearly all of which are predators. Their main prey are aphids, mealybugs and scale insects, but they also feed on other slow moving pests such as eggs and caterpillars of the bollworm. Both larvae and adults are predators. Adult can fly and move into the crop during the course of the season. Adult females deposit their yellow, cigar-shaped eggs in groups of 5-30 on the plant, mostly near colonies or groups of prey. Larvae forage on the plants, and, when fully grown, they pupate on the plant, before emerging as adults.



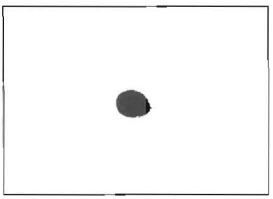
Hatching eggs of *Cheilomenes* sp.



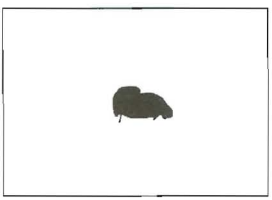
Cheilomenes sp. larva



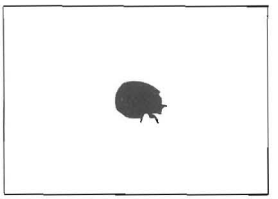
Cheilomenes pupae



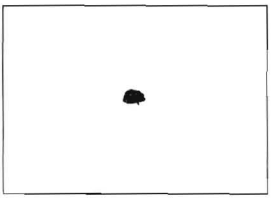
Cheilomenes propinqua adult



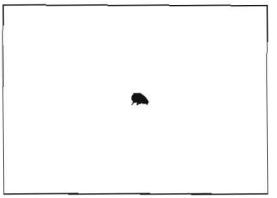
Mating adults of *Cheilomenes lunata*



Adult of *Declivitata* sp. *?olivieri*



Larva of *Platynaspis capicola*



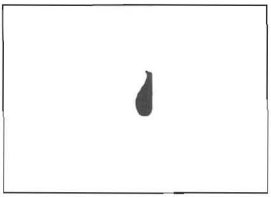
Adult of *Platynaspis capicola*

Hover flies (Syrphidae)

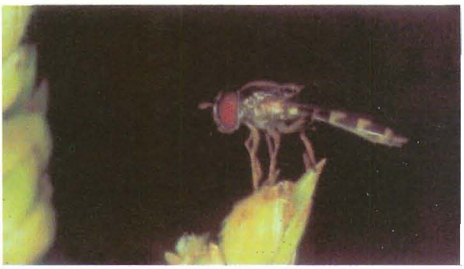
Hover flies are small, brightly-coloured flies that frequently visit flowers where they feed on pollen and nectar. The adult flies lay their white eggs singly on the plant, mostly near aphid colonies, which serve as prey for their offspring. The soft-bodied maggot-like larvae are active mostly at night and feed mainly on aphids. They are not known to feed on African bollworm.

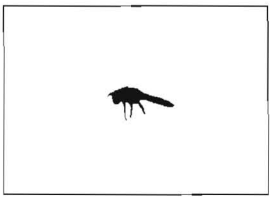
Egg of *Melanostoma annulipes*

Melanostoma annulipes larva



Melanostoma annulipes pupa

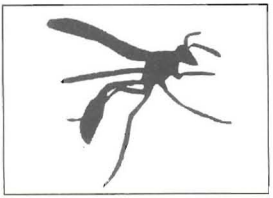




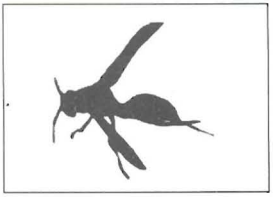
Melanostoma annulipes adult fly

Wasps

Solitary wasps (e.g. Sphecidae) and social wasps (e.g. Vespidae) build nests and provide their offspring with prey, such as caterpillars, returning repeatedly to a crop to collect them.



Belonogaster sp. attacking African bollworm



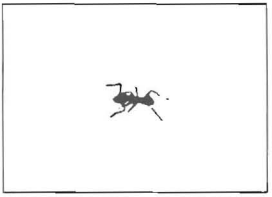
Polistes sp.

Ants (Formicidae)

Most agricultural fields have a rich community of ants. Some ant species are seed-eaters, others feed occasionally or exclusively on other insects. Several studies have shown their importance in tree crops, but also in annual crops they often play an important role in reducing insect pest populations. Ants are usually already found in farmers' fields before planting, and their populations develop further during the growing season. When ants are common they eat many African bollworm eggs and caterpillars. On sunflower, ants were observed to reduce bollworms by as much as 85%.

Some species of ants can be indirectly harmful to a crop because they 'tend'

(i.e. protect and collect honeydew from) scale insects and aphids, and will drive off or kill natural enemies of these pests. Ants are social insects. Most species have nests in the soil or in trees.

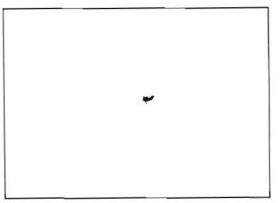


Myrmicaria sp. ants attacking African bollworm

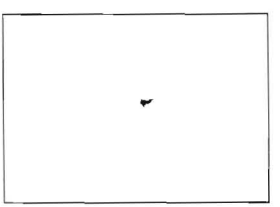
Myrmicaria is a medium-sized ant, which walks rather slowly. In Kenya, this ant is common west of the Rift Valley. *Myrmicaria* ants are sometimes found attacking caterpillars and dragging them to their nest.

Myrmicaria sp. drop from the plant with prey and carry it to the nest

Ants of the genus *Pheidole* are much smaller, and can be very common in the field. They attack small prey stages such as eggs and small caterpillars.

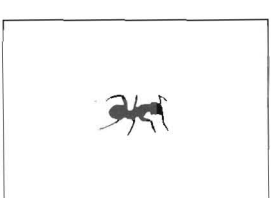


Pheidole sp. feeding on plant exudates on maize



Pheidole sp. carrying an egg of the African bollworm

Other common ants are *Camponotus* spp., which are large and fast-moving.

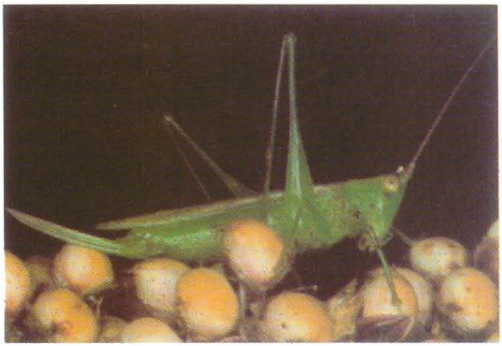


Camponotus sp.

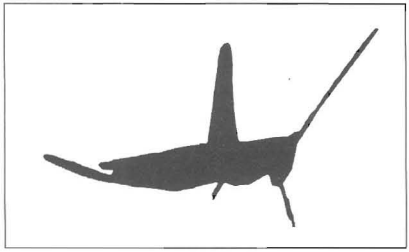
Several crops, such as cotton, maize and sunflower, have glands that produce a nectar secretion. Ants such as *Pheidole* sp. are often found feeding on these nectar sources, but cause no plant damage.

Orthoptera

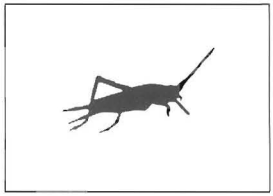
Orthoptera is the insect group including grasshoppers and crickets. Several members are commonly found in the vegetation, and these contain predatory species, and omnivorous species (i.e. feeding on prey as well as on plants). Orthoptera are not very common or important in farmers' fields. Sample photos are shown to aid recognition.



Tettigoniid grasshopper

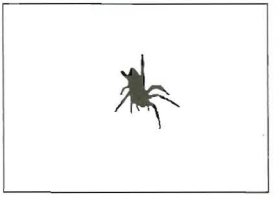


Cricket of the family Gryllidae



Spiders

In several parts of the world, spiders are extremely common, and are among the most important predators of insect pests. However, in East Africa they are not usually common in agricultural crops, Spiders are generalist predators, and feed on most kinds of insect prey of suitable size. Some types will make webs to trap flying prey, others hunt visually for their prey.



Spider

Parasitoids

Unlike predators, that kill more than one prey during their life cycle, parasitoids kill only one prey during their development and the adult is free living. Here, only parasitic flies (Diptera) and wasps (Hymenoptera) are considered.

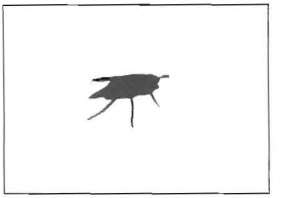
Insect parasitoids are an extremely diverse group, as far as their biology is concerned. In general, adult female parasitoids lay their eggs in or on the host stage (egg, larva or pupa). The larvae that feed within or on the host, kill it during their development. When fully grown, parasitoid larvae pupate, and eventually new adults emerge. Some parasitoids are specialists, and attack only one particular host species; others have a wide host range. Some parasitoids only attack the egg stage of the host, others attack larvae of a certain age, or pupae. Adult parasitoids generally feed on plant pollen or nectar.

The African bollworm is attacked by a large variety of parasitoids, which parasitize its eggs, larvae and pupae. Over the last hundred years, at least 87 different species of parasitoids have been recorded from the bollworm in Africa alone. Usually, however, a field population is attacked by only a few parasitoid species at any one place or time.

The majority of the bollworm's parasitoid species belong to the families Braconidae, Ichneumonidae, Trichogrammatidae and Tachinidae. The first two families are medium-sized wasps that parasitize larvae of the bollworm. Trichogrammatidae are minute wasps parasitic on insect eggs. Tachinidae are parasitic flies that resemble house flies or blow flies.

Tachinid flies (Tachinidae)

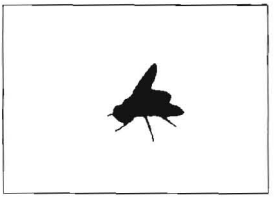
Tachinid flies mostly attack older caterpillars. They feed on their host until the host has reached its last larval, or pupal stage. Some species deposit their eggs on the host. Others lay eggs on the plant close to where the host is feeding; the eggs are then consumed by the host but remain intact and thus enter the host body. Again, other species lay incubated, fully developed, eggs on the leaves, the newly hatched larvae search actively for their host and penetrate the host skin.



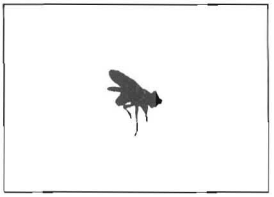
Linnaemya longirostris adult fly

The tachinid *Linnaemya longirostris* is a medium-sized fly, which occurs in much of eastern and southern Africa, and is common in Kenya. *L. longirostris* attack their hosts (mostly bollworm larvae, but also some related species) as they approach full size. The parasitoid larva develops inside the host. After 10-12 days it emerges from the host larval or pupal remains. The parasitoid larva forms a glossy red-brown puparium.

Palexorista laxa is a specialist parasitoid of the bollworm, occuring in parts of Africa and Asia. It is a common species in western Tanzania. Females attach their relatively large eggs to the large host larvae while standing beside the host. The eggs hatch immediately after they are laid, and the hatchlings enter the host. The parasitoid larvae feed inside the host during their development, and after 5-7 days the larvae emerge from the fully matured larva to pupate outside. One or more parasitoids can develop from a single host. *Palexorista quadrizonula* is a similar, but less common species.



Palexorista laxa

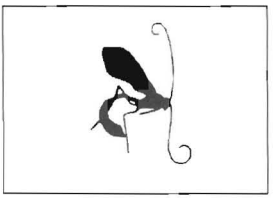


Palexorista quadrizonula with remains of two puparia

Ichneumonid wasps (Ichneumonidae)

Members of this large family are relatively large, slender wasps, and females usually have long ovipositors. They usually parasitize only young caterpillars.

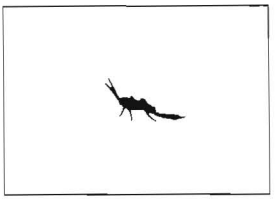
The large orange wasps of *Netelia* sp. lay single eggs in young bollworm larvae. Only one parasitoid larva develops inside the host; it emerges from



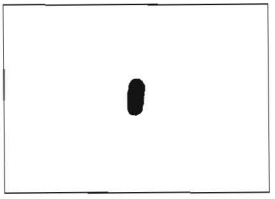
Netelia sp. adult wasp with host remains and empty cocoon

the host when it is ready to pupate, and spins a large cocoon.

Adults of *Charops ater* attack very young larvae of the bollworm and of some other pest species. This slender wasp lays one egg in its host, which develops into a larva, and leaves the host after 14 days as a full-grown larva. Then, it suspends itself from the plant on a short silk thread, where it spins a cocoon with a characteristic pattern.



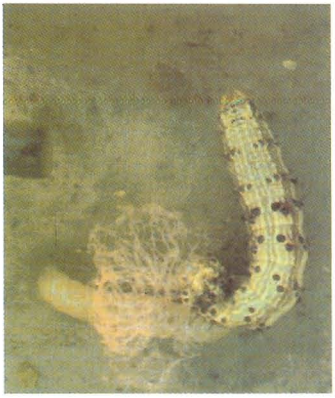
Charops ater

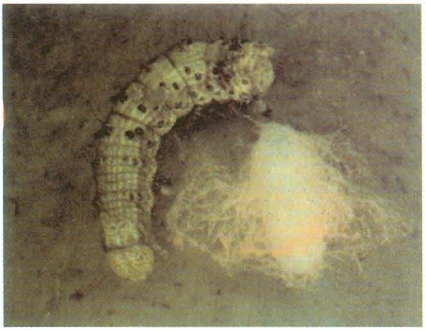


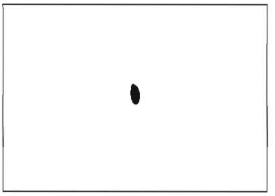
Cocoon of *Charops ater*

Braconid wasps (Braconidae)

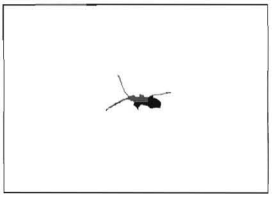
Braconid wasps are another large family of medium sized parasitic wasps. *Dolichogenidea (Apanteles)* sp. is a common parasitoid of the bollworm in East Africa. A single egg is laid inside the young caterpillar, the parasitoid larva develops inside the host and the full-grown parasitoid larva emerges from the host and spins a white cocoon alongside the dead host remains. In other species of *Apanteles*, a large number of parasitoids can emerge from one host. These so-called gregarious species are common parasitoids of stemborers in maize and sorghum.





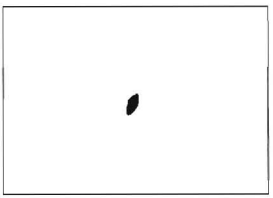


Larva of *Dolichogenidea* sp. spinning a cocoon beside the remains of its host, an African bollworm larva

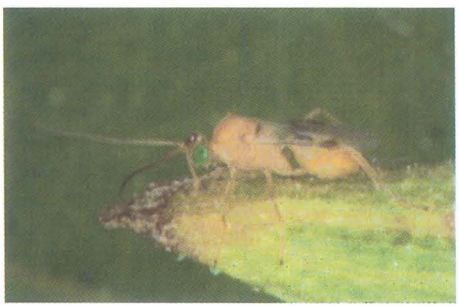


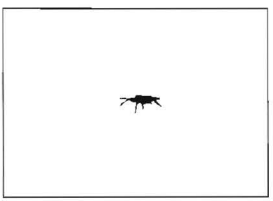
Adult of *Dolichogenidea* sp.

Slightly smaller than *Dolichogenidae* is the light-brown wasp of *Meteorus laphygmarum*, which is wide-spread throughout Africa. The adult female attacks young bollworm larvae, and a single larva develops inside the host. The full-grown larva emerges from the host, and spins a cocoon, which is brown in colour, and can so be distinguished from *Dolichogenidea* spp.



Cocoon of *Meteorus laphygmarum* with remains of African bollworm host





Meteorus laphygmarum adult

Scelionid wasps (Scelionidae)

Scelionid wasps are extremely small and mostly parasitize the eggs of moths, butterflies and bugs. In Africa, *Telenomus ullyetti* is the only member of this family that attacks the bollworm. This specialist parasitoid, which has been recorded in western, eastern and southern Africa, attacks exclusively the young eggs of the African bollworm. Only one egg is deposited per host egg, which develops through its larval and pupal stages inside the host egg and emerges

from the host egg as an adult wasp. The parasitized host egg changes its colour during the development of *T. ullyetti*, from yellow-white to grey. The development period from egg to adult is 14-20 days. Females lay 30-90 eggs during their lifespan of about 18 days.

Telenomus ullyetti adult

Emerged *Telenomus ullyetti* with remains of African bollworm egg

Eulophid wasps (Eulophidae)

Euplectrus laphygmae is a widespread species found throughout tropical Africa. It parasitizes the larvae of several moth species, including the African bollworm. Female wasps paralyze the host larva and then attach their eggs to the outside of its body. The number of eggs laid depends on the size of the host. The hatchlings start feeding on their host by liquifying the body contents and sucking them through the host skin. The paralysed host body gradually collapses as the contents are consumed. This type of attack is called ectoparasitic, and the wasps can be called ectoparasitoids. Mature parasitoid larvae spin their cocoons underneath the host remains. Total development from egg to adult takes 7-11 days.Three to six adults develop per host.

Newly emerged *Euplectrus laphygmae* adult on top of host remains

Trichogrammatid wasps (Trichogrammatidae)

Trichogrammatid wasps are stout-bodied, minute wasps, that can hardly be seen without hand lens or microscope. They parasitize the eggs of moths and butterflies. In Kenya, several different species attack the African bollworm. The most common of these are *Trichogrammatoidea lutea, T. armigera, T. eldana* and *T. simmondsi* (these can only be separated by specialized taxonomists). Trichogrammatids are less specific thn *Telenomus ullyetti*: in addition to the African bollworm, they attack several other host species. One to three parasitoids can develop within a single bollworm egg. The host egg turns black as the parasitoids develop. Hence, old eggs which were parasitized by *Trichogrammatoidea* spp. can be found and recognized in the field. As they emerge, the young adult parasitoids chew a circular opening in the egg shell. Parasitized bollworm eggs take about 12 days to emerge, compared to 4 days for unparasitized eggs. Trichogrammatids can cause considerable mortality of African bollworm eggs in the field.

Trichogrammatoidea sp. parasitizing an African bollworm egg

African bollworm egg parasitized by *Trichogrammatoidea* sp.

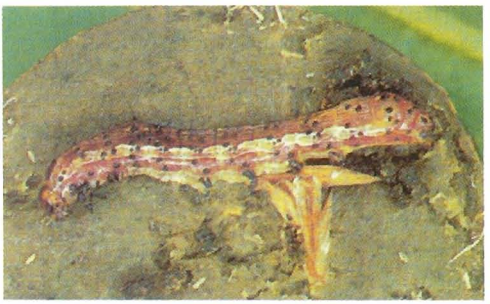
Trichogrammatoidea sp. adult emerging from host egg

Pathogens

Besides predators and parasitoids, bollworms are also attacked by another group of natural enemies, collectively called pathogens. These include parasitic fungi, viruses, bacteria and nematodes.

Nuclear Polyhedrosis Virus (NPV)

Nuclear Polyhedrosis Virus is the only virus which commonly infects African bollworm larvae in the field. Young larvae are most susceptible to NPV infection, and become infected by consuming plant material contaminated with the virus. Diseased larvae change their colour and eventually turn brown-black. The black remains of bollworms killed by NPV can sometimes be seen hanging from the leaves of plants.



African bollworm infected by Nuclear Polyhedrosis Virus

Nematodes

Nematodes of the order Mermithida can sometimes be found in African bollworm caterpillars. Soon after infection, the caterpillar stops feeding and dies after 4-5 days. After developing in the host body, the nematodes emerge

from the host remains and go through an additional development phase in the soil.

Mermithid nematodes with host remains of the African bollworm

Relevance beyond Kenya

The areas in tropical Africa where most studies on natural enemies of African bollworm have been carried out are in East Africa (Kenya, Tanzania, Uganda) and Southern Africa (Botswana, Zimbabwe and Swaziland). The majority of field and laboratory studies have looked at natural enemies, mainly parasitoids, of bollworm in cotton cropping systems. Most studies concentrate on parasitoids, which attack bollworm larvae. Egg parasites and predators of all stages have been poorly studied, as have naturally occurring pathogens.

In total, 83 identified species of parasitoids have been recorded from African bollworm in the continent, the majority from the tachinid fly, and ichneumonid and braconid wasp families. Most attack a range of host species including other larvae of the noctuid family and other moth larvae, although the five species of *Cardiochiles* braconid wasp have only been recorded from African bollworm. Among egg parasitoids, the scelionid wasp *Telenomus ullyetti* is specific to African bollworm whereas trichogrammatid wasp species will parasitize a wide range of moth eggs. There are noticeable differences in the natural enemy fauna between East and Southern Africa, for example, in E. Africa the commmonest recorded parasitoids are wasps while in southern Africa parasitic flies are more frequently recorded.

Geographical distribution of parasitoids and importance within the local natural enemy complex varies considerably between regions, for instance, the braconid wasp *Apanteles diparopsidis* is an important natural enemy of African bollworm in Tanzania where parasitism levels of up to 26% have been recorded. In southern Africa the same parasitoid is only found on red bollworm *Diparopsis castanea* and spiny bollworm *Earias* species. Parasitoid species which are important in both eastern and southern Africa include the following:

Family	Species	Crop/Region	Parasitism rate/occurrence
Tachinid flies	*Palexorista laxa*	sorghum (eastern)	up to 42%
	Palexorista laxa	cotton (southern)	20-30%
	Paradrino halli	various (eastern)	common
	Paradrino halli	citrus (southern)	up to 25%

Family	Species	Crop/Region	Parasitism rate / occurrence
Braconid wasps	*Chelonus curvimaculatus*	various (eastern)	up to 12%
	Chelonus curvimaculatus	maize, citrus (southern)	common

Records show high levels of African bollworm egg parasitism in southern Africa with figures of up to 60-70% in maize, cotton and other crops. In eastern Africa, egg parasitoid records are non-existent or show only very low parasitism. However, lack of records for particular natural enemies does not necessarily mean that they do not occur, but simply that people may not have looked for them! In general, many parasitoid studies on African bollworm larvae observed high parasitism levels only towards the end of the crop season, after the economic damage has been caused for that particular season. However, these parasitoids may play a useful role in reducing pest numbers in the next generation of bollworms.

One of the most interesting findings in African studies on bollworm natural enemies is the huge variation in ocurrence and impact in different host-plant associations. This is especially relevant for African smallholder farmers who typically cultivate a mixture of different crops within a small area. For example, in Tanzania, researchers observed heavy parasitism of African bollworm in sorghum by the tachinid fly *Palexorista laxa* and by the braconid wasps *Chelonus curvimaculatus* and *Apanteles diparopsidis*, compared to other crops. In contrast, bollworm populations on Tanzanian cotton were attacked mainly by *Cardiochiles* braconid wasps, which were rare in maize and sorghum. In the few studies that have compared natural enemy numbers in different crops, sorghum and maize seem to attract more predators and parasitoids as bollworm moths prefer to lay their eggs on these plants.

Bollworm predators tend to be more constant in their range and effectiveness on controlling African bollworm than parasitoids. Green lacewings of *Chrysopa* genus have been recorded as common bollworm predators in cotton in Zimbabwe and Tanzania, while ants have been observed as common or important in Tanzania, Kenya, South Africa and Botswana. In studies on smallholder cotton in Kenya, ants and anthocorid bugs were found to be the commonest predatory species on this pest. Among the pathogens, Nuclear Polyhedrosis Virus (NPV) has been recorded causing high infection rates of African bollworm in Botswana and Tanzania.

The following notes summarize information on key bollworm predator

groups outside Kenya. **Bold** text indicates countries where the natural enemies have been recorded as important or common.

Predatory Bugs

Anthocorid bugs have been recorded preying on African bollworm from Egypt, Senegal, **South Africa,** Uganda and **Zimbabwe** and in South Africa the bugs caused up to 40% mortality of bollworm in cotton and maize. Assassin bugs of the reduviid family have been observed in cotton in Senegal, South Africa, and Uganda. Predatory shield bugs (pentatomid family) attacking eggs and all bollworm larval stages are recorded from South Africa, **Tanzania** and Uganda.

Lacewings

Green lacewings have been recorded in Egypt, South Africa, Sudan, **Tanzania**, Uganda and **Zimbabwe**. In the last country, lacewings are extremely common and important predators of African bollworm eggs and they may eat up to 500 eggs during the larval stage.

Beetles

Rove beetles of the carabid family have been recorded feeding on bollworm larvae in various crops in Senegal. Staphylinid and ladybird beetles are recorded from Egypt. Commonly found ladybird species in Zimbabwean cotton can be important predators of bollworm eggs but do not normally feed on the larvae, except newly hatched ones.

Predatory wasps and ants

Solitary and social wasps have been observed collecting bollworm larvae to take to their nests in Madagascar, Senegal, South Africa, Sudan, **Tanzania** and Zimbabwe, in cotton, citrus, maize and millet. *Myrmicaria* and *Pheidole* ant species are recorded foraging on bollworm larvae in cotton and maize in **South Africa, Tanzania,** Uganda and **Botswana.**

Spiders and mites

There are no official taxonomic records of spiders attacking African bollworm but Zimbabwean researchers have observed one of the commonest spider species in cotton, *Cheiracanthium lawrencei* (clubionid family), regularly feeding on second and third instar African bollworm larvae at night. The importance of spiders in controlling bollworm larvae is reflected in Zimbabwean spray thresholds which include checking the number of spiders in a sample of cotton plants. There are no records for predatory mites preying on African bollworm although they have been observed feeding on red

bollworm eggs in Zimbabwe.

Pathogens and nematodes

NPV is by far the most frequently recorded disease of bollworm larvae, in **Botswana**, Senegal, Sudan, **Tanzania,** Uganda and Zimbabwe, infecting up to 61% of young larvae in sorghum in Botswana and over 50% of larvae in maize in Tanzania. Tanzanian studies have also recorded bacterial diseases as widespread on bollworm larvae collected from the field, for example, infection rates of over 80% were found in larvae from sorghum and cotton in the rainy season. In many samples in this study, bacterial disease was more common than viral disease and mortality due to diseases far higher than that due to parasitism. Fungal diseases of African bollworm appear to be much rarer, recorded only from Tanzania. Mermithid nematodes have been recorded infecting bollworm larvae in Senegal.

Suggested Reading

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Annex

Alphabetical list of species, with order and family manes

Belonogaster sp. (Hymenoptera: Vespidae)
Camponotus sp. (Hymenoptera: Formicidae)
Cardiastethus sp. (Hemiptera (Heteroptera): Anthocoridae)
Charops ater Szepligeti (Hymenoptera: Ichneumonidae)
Cheilomenes sp. (Coleoptera: Coccinellidae)
Cheilomenes lunata (Fabricius) (Coleoptera: Coccinellidae)
Cheilomenes propinqua (Mulsant) (Coleoptera: Coccinellidae)
Chrysoperla sp. (Neuroptera: Chrysopidae)
Ctenoplusia limbirena (Guenée) (Lepidoptera: Noctuidae)
Declivitata sp. ?*olivieri* (Gerstaecker) (Coleoptera: Coccinellidae)
Dolichogenidea (Apanteles) sp. (Hymenoptera: Braconidae)
Earias biplaga (Walker) (Lepidoptera: Noctuidae)
Earias insulana (Boisduval) (Lepidoptera: Noctuidae)
Euplectrus laphygmae Ferrière (Hymenoptera: Eulophidae)
Geocoris amabilis Stål (Hemiptera (Heteroptera): Lygaeidae)
Gryllidae (Orthoptera)
Helicoverpa armigera (Hübner) (Lepidoptera: Noctuidae)
Hexagonia sp. nr. *punctatostriata* (Laferté Sénectère) (Coleoptera: Carabidae)
Linnaemya longirostris (Macquart) (Diptera: Tachinidae)
Melanostoma annulipes (Macquart) (Diptera: Syrphidae)
Meteorus laphygmarum Brues (Hymenoptera: Braconidae)
Micromus sjostedti Weele (Neuroptera: Hemerobiidae)
Myrmicaria sp. (Hymenoptera: Formicidae)
Mythimna loreyi (Duponchel) (Lepidoptera: Noctuidae)
Nematodes
Netelia sp. (Hymenoptera: Ichneumonidae)
Nuclear Polyhedrosis Virus (NPV)
Orius sp. (Hemiptera (Heteroptera): Anthocoridae)
Paederus riftensis Fauvel (Coleoptera: Staphilinidae)
Palexorista laxa (Curran) (Diptera: Tachinidae)
Palexorista quadrizonula (Thomson) (Diptera: Tachinidae)
Pheidole sp. (Hymenoptera: Formicidae)
Platynaspis capicola Crotch (Coleoptera: Coccinellidae)

Polytoxus flavescens Villiers (Hemipera (Heteroptera): Reduviidae)
Polistes sp. (Hymenoptera: Vespidae)
Spodoptera littoralis Boisduval (Lepidoptera: Noctuidae)
Stenidia sp. (Coleoptera: Carabidae)
Telenomus ullyetti Nixon (Hymenoptera: Scelionidae)
Tettigoniidae (Orthoptera)
Trichogrammatoidea armigera Nagaraja (Hymenoptera: Trichogrammatidae)
Trichogrammatoidea eldana Viggiani (Hymenoptera: Trichogrammatidae)
Trichogrammatoidea lutea Girault (Hymenoptera: Trichogrammatidae)
Trichogrammatoidea simmondsi Nagaraja (Hymenoptera: Trichogrammatidae)
Tropiconabis capsiformis (Germar) (Hemiptera (Heteroptera): Nabidae)

Identifications of material used to compile this guide were conducted by the CABI Bioscience Identification Services (integrating the former CAB Scientific Institutes of Biological Control; Entomology; Parasitology; and the International Mycological Institute). For general information about CABI Bioscience Identification Services contact Dr Gerry Saddler (g.saddler@cabi.org); for more detailed enquiries on arthropod pests and natural enemies, Mr John Maxen (j.maxen@cabi.org); plant diseases, Dr John David (j.david@cabi.org) and nematodes, Dr David Hunt (d.hunt@cabi.org).

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