icipe

African Insect Science for Food and Health

biennial scientific report
2004–2005

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P. O. Box 30772-00100 Nairobi, Kenya; Tel: +254 (20) 8632000, Fax: +254 (20) 8632001/2; *icipe*@*icipe*.org, www.*icipe*.org

Cover photo of children playing on canal bank in Mwea Division, Central Kenya, courtesy of Santiago Escobar

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Edited by: Ahmed Hassanali, Fritz Schulthess, John Githure and Ian Gordon
Editorial assistance: Dolorosa Osogo
DTP, graphics and cover design: Irene Ogendo
Administrative support: AnnClaire Ndung'u
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The following *icipe* staff provided additional input:
M. Knapp, P. Kaweru, J. Lago, P. Ndiangui, S. Kariuki

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MESSAGE FROM THE DIRECTOR GENERAL

This biennial scientific report for the period 2004–2005 summarises *icipe*'s research and development (R&D) activities carried out at the Nairobi-based headquarters as well as at the various field stations and research sites comprising of over 500 hectares covering most of the ecozones of Africa. Building on a rich research legacy spanning three-and-a half decades, *icipe* has evolved into a major international organisation in Africa, focusing on research to provide, on one hand the much needed solutions to arthropod pest and vector problems that limit the continent's development potential, and on the other, the promise of poverty alleviation through judicious harnessing of useful arthropod biodiversity.

Prof. Christian Borgemeister, Director General, *icipe*

In the first two-and-a-half decades, the late Thomas R. Odhiambo laid the strategic research groundwork crucial to unlocking Africa's development—unravelling little-known basics of the biology, physiology and ecology of mosquitoes, tsetse, ticks, locusts, stemborers just to name a few of Africa's important arthropods. His successor Hans R. Herren sustained this approach, but introduced a new paradigm named the '4Hs' that focused *icipe*'s R&D activities on plant health, animal health, human health and environmental health as the major programme areas. Consequently, the Centre ventured into more applied aspects of insect science.

Unfortunately todate many of these same pests still plague Africa and other parts of the tropical developing world. Increased trade through globalisation has resulted in the continuous spread of invasive species, often with catastrophic consequences for African agri- and horticulture as illustrated by the recent havoc caused by the red spider mite, the diamondback moth and the fruit fly *Bactocera invadens* just to name three. At the same time, however, society has benefitted considerably from insects through silk and honey production, pollination and other ecosystem 'services'. As the third Director General of *icipe*, I am committed to the vision of my two predecessors to find solutions to problems posed by harmful insects, and also to reap the benefits derived from those that provide services and products. This is of course only possible because of the full commitment and cooperation of the dedicated and enthusiastic staff at *icipe* in partnership with visiting scientists and national and international collaborators.

In this comprehensive report you will find that we have continued to build the bridges between research and real products. Some of these products are now ready for commercialisation by the private sector and community-based enterprises for wider distribution and use. Reflected in the biological control programmes at *icipe* is a propensity to target the pests that deprive resource-poor families of their livelihood such as intractable cereal and horticultural pest species, all at virtually no cost to the farmer. After the recent locust infestations, we have now been able to validate, through large-scale field trials at our field station in Port Sudan, the impact of semiochemicals discovered at *icipe* on gregarising desert locusts. Strategies for the control of vectors of debilitating bovine and human diseases such as tsetse, ticks and malaria mosquitoes continue to be developed. Our biodiversity conservation programmes are safeguarding the insect diversity that can be found in tropical forest habitats and exploring the potential of carbon trading. Investigating the economic importance of African noctuid stemborers and associated natural enemies in wild habitats is also being done with active participation of our research partners. The programmes are also providing economic incentives for conservation to forest-adjacent communities that have traditionally derived their existence from the forests. Efforts to improve yields of cultivated cereal grasses in a new technology incorporating the conservation of native grasses (for use as border rows and for crop improvement) in various agroecosystems are improving the livelihoods of African farmers in numerous ways.

icipe continues to provide training opportunities at the postgraduate level (PhD and MSc), the practitioner level (demonstration and extension workers) as well as offering training that targets farmers at the community level, so as to strengthen capacity for participating countries to better handle the developmental complexities.

During the period covered by the report, *icipe* scientists and technicians, in collaboration with our various partners, produced more than 90 publications in international peer-reviewed journals and made over 60 presentations at conferences and meetings.

What does this all add up to?

It indicates that the practice of African insect science at *icipe* has provided food and better health for the peoples of Africa in a number of ways.


PHOTO: Santiago Escobar

BETTER HEALTH: Methods being developed for reducing human–vector contact are helping to lessen the malaria burden for this mother and child as well as for many other families

For example

Increased food as a result of:

- Reduced maize yield losses for farmers (and ensuing purchasing power)
- Improved soil fertility on farms (and ensuing increased agricultural production)
- Extra livestock fodder crops (and ensuing increased milk yields)

Better health as a result of:

- Pesticide-free vegetables in compliance to international food production standards (and ensuing acceptance by clientele, and the safety and health of farm labourers as well as consumers)
- Protection and conservation of forests and other wild habitats (ensuing in healthier environments, protection of beneficial insects for more crops and gainful employment for communities)
- Quality nutrient-rich fruit (and ensuing healthy lifestyles)
- Protection of cattle from tsetse and ticks populations (and ensuing reduction in disease incidence and provision of more meat products)
- Reduced malaria incidence for those at risk (ensuing in reduced child and maternal mortality, and that of the general population).

We therefore wish to affirm to all our donors who have invested in our work; to the various research partners who continue to work with us; and to the beneficiary communities who have invested their trust in our environmentally friendly, knowledge-based development options, that yes, *icipe*'s cutting-edge research strategies and capacity building efforts are helping to meet the needs of our constituency and contributing towards meeting the millennium development goals of many of the developing countries in Africa.

Christian Borgemeister

Christian Borgemeister
Director General

PHOTO: Santiago Escobar

Plant Health

A. Staple food crops pests

Biological Control of Cereal Pests in Africa

Background, approach and objectives

The programme consists of three major projects: (1) Biological Control of Cereal Stemborers in East and Southern Africa (SBCNET) funded by the Government of The Netherlands, (2) IPM of Maize Stemborers in Western Africa funded by BMZ, Germany and (3) Biological Control of the Larger Grain Borer *Prostephanus truncatus* in Kenya funded by the Kirkhouse Trust, UK. A collaborating unit, the Arthropod Pathology Unit is also engaged in research on the biological control of the larger grain borer in Kenya that is funded by the USAID and *icipe* core fund donors.

The SBCNET encompasses 11 countries—Eritrea, Ethiopia, Kenya, Madagascar, Malawi, Mozambique, Uganda, Tanzania (Mainland and Zanzibar), Zambia and Zimbabwe. Each country has its own project, which they manage. These projects are linked in a network coordinated by *icipe*. *icipe* provides training for partner countries and conducts scientific research to support implementation of biological control and habitat management in the 12 countries.

In general, the activities and responsibilities in the project are split as follows among *icipe* and the NARES:

icipe's role is to identify new natural enemies; conduct basic research which will help to predict the efficiency of a natural enemy and effects on non-target species; mass-rear natural enemies for collaborating countries; examine macro-economic impact of BC of stemborers on cereal production in ESA using field data, modelling and GIS; R&D of other IPM techniques (habitat management); gather information on new exotic pests amenable to biological control; organise short-term training courses for NARES scientists; supervise graduate students; assist countries with extensionist and farmers' training.

The NARES conduct country-wide surveys on pest distribution; conduct biological studies in the laboratory and field; mass-rear natural enemies; conduct post-release surveys to determine establishment; study the impact of BC on pest composition and on crop yield; gather information on exotic pests amenable to BC; study the integration of BC with other IPM tactics, such as habitat management techniques; organise training of extensionsists and farmers.

The specific activities vary from country to country depending on the different levels of expertise reached in each country in biological control of stemborers, through earlier collaboration with *icipe*. The basic steps in the approach, however, are similar. Baseline ecological information on distribution of stemborers and associated natural enemies is being collected in cultivated and wild habitats, natural enemies are being released at targeted locations, and economic and biological impact assessments are being made. Moreover, biological control and habitat management techniques are being integrated into small farmer maize systems in a participatory manner. Training at all levels, from farmers to graduate students, is a primary feature of the project.

The project on IPM of Maize Stemborers in Western Africa was initiated in May 2004. The target countries are Cameroon and Benin. The project will greatly profit from the expertise gathered in the SBCNET. It will test *Cotesia sesamiae* strains from Kenya, *Xanthopimpla stemmator* from Asia and a West African strain of *Sturmiopsis parasitica* on *Busseola fusca* in Cameroon and search for parasitoid species to exchange with eastern Africa. In addition, habitat management techniques with emphasis on mixed cropping will be tested.

The SBCNET also started monitoring of the larger grain borer (LGB), *Prostephanus truncatus*, a devastating storage pest amenable to classical BC in several countries. It was accidentally introduced from Central America in the early 1980s. In Kenya, the pest spread to the highland zones and the Lake Victoria region, where it is the major constraint to stored maize. A new project on Biological Control of LGB in Kenya plans to introduce two strains of the predator *Teretrius nigrescens* (Tn) adapted to different climate conditions into the *icipe* containment facilities from the laboratories of the Centro Internacional de Maiz y Trigo (CIMMYT) in Mexico. Presently, molecular tools are being developed that will allow differentiation of the different races in the field.

Work in progress

IPM OF MAIZE STEMBORERS IN WESTERN AFRICA

Benin

Participating scientist: *M. Tamo*

Assisted by: *S. Gounou*

Donor: *BMZ*

Collaborator: *International Institute of Tropical Agriculture*

1. Suitability and interspecific competition

Laboratory colonies of *Sesamia calamistis*, *S. poephaga*, *Eldana saccharina*, *Coniesta ignefusalis*, *Busseola fusca* and *Mussidia nigrivenella* have been established from field-collected borer larvae. They will be tested for their suitability to virulent and avirulent Kenyan races of *Cotesia sesamiae* *(See outputs 37 and 38 under Activities at icipe)* to be introduced in mid-2006. A virulent coastal strain of *C. sesamiae*, introduced and released in 1994, got permanently established on *S. calamistis* in the country. However, for releases in Cameroon, where *B. fusca* is the major pest species, avirulent strains are required.

The different *C. sesamiae* races will also be tested for their effect on the performance on locally occurring parasitoid species.

Cameroon

Participating scientists: R. Ndemah (based at IITA), F. Schulthess

Assisted by: N.-N. Akongnwi, A. Abang

Donor: BMZ, Germany

Collaborators: Institut de Recherche Agronomique pour le Développment, University of Buea

2. Habitat management and biological control

In the mid altitude of Cameroon crop rotation trials with phaseolus beans, soy beans, tephrosia and maize with or without fertiliser were planted at the Njinikom benchmark. Maize with fertiliser had twice the noctuid borer densities (*Busseola fusca* and *Sesamia calamistis*) compared to maize without fertiliser. There were no significant treatment differences for *Chilo* sp. In the high altitude, the trials were destroyed by cattle and have to be replanted in 2006.

Pre-release surveys of borers on maize and four grass species (*Pennisetum purpureum*, *Panicum maximum*, *Sorghum arundinaceum* and *Setaria* sp.) in the high and mid altitude, forest zone and western lowlands were undertaken during the first (June/July) and second (October, November and December) maize cropping seasons to determine the borer species composition, and larval and pupal parasitism. In the first season on maize, *B. fusca* was the predominant borer in the high (99.1%) and mid (60%) altitude and forest zone (75.4%). The second most important borer in the forest zone was *Eldana saccharina* (12%) and in the mid altitude *Chilo* sp. (29%). Other borer species encountered were *S. calamistis*, *Mussidia nigrivenella* and *Cryptophlebia leucotreta*. In the second season in the forest zone and mid altitude, *B. fusca* on maize accounted for, respectively, 59.52 and 27.63%. *Eldana saccharina* increased in importance in the forest zone, *M. nigrivenella* and *Chilo* sp. in the mid-altitudes. On *P. purpureum*, only noctuid borers were encountered with *Poeonoma serrata* being the predominant species in all ecozones. Other borers included *Busseola phaia* and *Sesamia penniseti* and, very rarely, *B. fusca*. On *S. arundinaceum*, the borer species encountered were *Sesamia poephaga* and *B. fusca* while on *P. maximum*, *Chilo* sp. was found. It is concluded that the common occurrence of *B. fusca* on *P. purpureum* reported in the past was due to misidentification of the species.

The braconid larval parasitoid *Cotesia sesamiae*, the most common larval parasitoid of *B. fusca* on maize in eastern Africa was very scarce and only obtained from 9 larvae of 'wild' borer species from *P. purpureum* and *Setaria* sp. The scarcity of *C. sesamiae* opens avenues for the *redistribution* BC approach. For 2006, it is planned to introduce several races of *C. sesamiae* from Kenya, and the tachinid larval parasitoid *Sturmiopsis parasitica* from Benin via the *icipe* containment facilities.

BIOLOGICAL CONTROL OF CEREAL STEMBORERS IN EAST AND SOUTHERN AFRICA

Regional Activities

Ethiopia

Participating scientist: Difabachew Belay

Assisted by: Melaku Wale

Donor: DGIS, The Netherlands

Collaborator: Ethiopian Institute of Agricultural Research

3. Effect of soil fertility on infestation by stemborers and yield of maize

An experiment was conducted to determine effect of level of soil nitrogen in the form of urea and P in the form of tri-super phosphate (TSP) on damage caused by stemborers and yield of maize. During pre-harvest, significant differences were observed only in percent infestation and borers per plant (Table 1). At harvest significant differences were observed in percent infestation, number of exit holes per plant, percent cob damage and yield per plant and per plot. Stemborer incidence and numbers per plant tended to be lower with high dosages of P.

Table 1. Means (± SE) of pre-harvest stemborer damage parameters and yields of maize plots fertilised with different combinations of urea (N) and TSP (P)

Treatment (kg/ha) N	P	% Infestation at vegetative stage	Leaf feeding score[ns]	Borer/plant	Yield/Plot (g)
0	0	7.5 ± 1.2 ab	2.7 ± 0.2	0.5 ± 0.2 bc	7390.7 ± 203 ab
60	0	10.4 ± 2.3 a	2.9 ± 0.3	0.7 ± 0.4 bc	7200.5 ± 251 abc
90	0	6.1 ± 0.7 ab	2.4 ± 0.1	1.5 ± 1.1 b	7945.4 ± 259 a
120	0	8.5 ± 1.6 ab	2.8 ± 0.2	0.2 ± 0.2 bc	6830.6 ± 430 abc
0	60	7.6 ± 1.2 ab	2.5 ± 0.1	0.5 ± 0.2 ab	6633.6 ± 925 bc
60	60	6.0 ± 0.7 ab	2.6 ± 0.2	0.7 ± 0.4 ab	7092.4 ± 329 abc
90	60	6.7 ± 0.9 ab	2.6 ± 0.2	2.2 ± 1.1 a	6668.8 ± 264 abc
120	60	4.5 ± 0.4 b	2.1 ± 0.1	1.5 ± 0.9 b	6896.5 ± 405 abc
0	100	5.4 ± 0.9 ab	2.3 ± 0.1	0.5 ± 0.2 bc	6813.4 ± 228 abc
60	100	7.6 ± 1.4 ab	2.5 ± 0.2	0.2 ± 0.2 bc	7720.2 ± 373 ab
90	100	6.4 ± 0.9 ab	2.4 ± 0.1	1.5 ± 0.6 ab	7137.6 ± 203 abc
120	100	4.9 ± 0.5 b	2.4 ± 0.1	0.01 ± 0.0 c	7139.1 ± 527 abc
0	140	8.3 ± 1.8 ab	2.5 ± 0.1	0.01 ± 0.0 c	6172.5 ± 740 c
60	140	7.1 ± 0.9 ab	2.5 ± 0.2	0.2 ± 0.2 bc	7817.6 ± 402 ab
90	140	4.3 ± 0.5 b	2.3 ± 0.1	0.2 ± 0.2 bc	6991.1 ± 327 abc
120	140	4.6 ± 0.4 b	2.3 ± 0.1	0.2 ± 0.2 bc	7687.6 ± 544 b

*ns = non-significant; means within a column followed by the same letter are not significantly different at P = 0.05 (SNK).

4. *Mixed cropping experiments*

Lepidopteran stemborers are the main pests of cereals in Ethiopia. In recent years, habitat management (HM) techniques, which aim at increasing plant biodiversity, have gained increased attention in stemborer control. Severity of pest infestations may vary with season and year and the question arises if HM techniques are still profitable under low pest infestations. In the present study, the profitability of mixed cropping of maize with haricot beans at different ratios and PP was studied in areas where pest infestations are known to vary considerably.

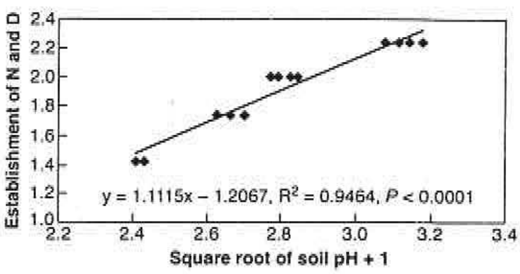


Figure 1. Effect of soil pH on establishment of Napier grass (N) and greenleaf desmodium (D) during 2004 in western Ethiopia (Sibu-Sire Woreda)

In Melkassa, pest infestations were too low for the cropping system to significantly affect pests, plant damage and yields while in Mieso, where the pest densities were high, intercropping of maize with beans at ratios of 1:4 to 1:3 significantly decreased borer densities compared to pure maize stands. Land equivalent ratios of > 1 indicated higher land use efficiency in mixed compared to sole cropping, even if pest densities were low.

Establishment of desmodium and Napier grass in push-pull trials varied from site to site, and poor establishment was observed in plots with low pH (Figure 1) and P. Where per area yields varied significantly, they were lower in the push-pull than sole maize, due to the smaller area planted to maize. Thus, in the absence of striga and at lower borer densities the PP system had no yield advantage over the sole maize crops.

5. *Release of new natural enemies*

Xanthopimpla stemmator was imported from *icipe* and released in Ethiopia at three sites (Bofa, Wulnchiti and Mieso areas) in August 2005 where *Chilo partellus* was the dominant stemborer species. This is the first time the Ethiopian quarantine authorities have granted an import permit for a natural enemy. To date, no recovery of the parasitoid has been made. Attempts to initiate a colony of the parasitoid at Melkassa have began.

6. *Larger grain borer (LGB) monitoring*

Larger grain borer traps were set at Ethio-Kenya border (at Moyale) in collaboration with Ministry of Agriculture and Rural Development, quarantine division of the crop protection department. Samples were collected from the traps and kept at Moyale. The trap catches have not yet been identified.

Eritrea

Participating scientists: *Adugna Haile, Kidane Negassi*

Donor: *DGIS, The Netherlands*

Collaborators: *Ministry of Agriculture*

7. Intercropping

An intercropping trial was conducted at Halhal Begos using haricot beans, cowpea, desmodium and *Dolichos lablab* as companion crops with sorghum. The treatments were replicated three times. Egg counts varied from 12.7 to 65. The highest egg, larvae, pupae and deadheart counts were recorded on pure sorghum stand followed by sorghum with cowpea and *Dolichos lablab*. Deadheart damage due to stemborers was very low in the intercropping plots. Lowest pest numbers and damage was recorded on Furadan-treated sorghum (Table 2).

Table 2. Effect of intercropping on stemborer population

Treatment	No. of eggs	No. of larvae	% dead-hearts	No. of pupae	Plant height
Sorghum pure stand	65.0	24.7	27.3	8.3	123.7
Sorghum-cowpea	27.7	12.3	11.0	6.0	151.3
Sorghum-haricot bean	19.7	16.3	10.6	11.3	139.3
Sorghum-desmodium	17.2	7.5	8.5	5.6	158.3
Sorghum-*Dolichos lablab*	27.3	12.5	12.5	11.2	145.7
Furadan	12.7	4.0	2.6	1.7	166.3
Mean	31.3	14.3	12.9	6.8	145.2
SE	4.1	3.1	2.5	3.4	5.0
LSD	10.2	7.6	6.1	8.3	12.3

8. Release of parasitoids

Import permit for the parasitoid *Xanthopimpla stemmator* was obtained in August 2004. Out of 300,000 *Cotesia flavipes* imported 200,000 were released in Hamelmalo and 100,000 in Sheeb. 1000 *X. stemmator* were released in Sheeb and 2000 in Halhal and Hamelmalo.

Kenya

Participating scientist: *J. Songa*

Donor: *DGIS, The Netherlands*

Collaborators: *Kenya Agricultural Research Institute, Moi University*

9. *The bionomics of the egg parasitoid* Telenomus busseolae *(Gahan) (Hymenoptera: Scelionidae) on* Busseola fusca *Fuller and* Sesamia calamistis *Hampson (Lepidoptera: Noctuidae)*

The suitability of 1–3-day-old eggs of *Busseola fusca* Fuller and *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) to a strain of *Telenomus busseolae* (Gahan) (Hymenoptera: Scelionidae) collected in mid-altitudes of Kenya was assessed in the laboratory. For both species, age of egg did not affect progeny production but 2-day-old *B. fusca* eggs yielded more progeny than *S. calamistis* eggs of the same age. With *S. calamistis*, development time of *T. busseolae* increased with age of eggs, while host species had no effect. Neither borer species nor age of eggs significantly affected the sex ratio. Longevity of *T. busseolae* was greater and total fecundity higher on *B. fusca* than *S. calamistis*. The intrinsic rate of increase and the net reproductive rate were greater with *B. fusca* than *S. calamistis* eggs as host. The values were considerably lower than those reported from the same species in West Africa, indicating that there are differences in strains between regions. Females begun ovipositing on the first day of emergence and the average daily number of eggs laid and the proportion of females decreased with age of the female, on both hosts. The ability of *T. busseolae* females to accept and develop in *B. fusca* and *S. calamistis* of different ages is an advantage, especially during times of host scarcity, which is common during the dry season. In a Y-tube experiment no preference for either stemborer species was observed. Similarly, in the field, there was no significant variation in parasitism between *B. fusca* and *S. calamistis* eggs.

10. *Monitoring and status of the spread and abundance of the larger grain borer* Prostephanus truncatus *Horn*

Since its accidental introduction into Kenya in the early 1980s, through the Kenya–Tanzania border town of Taveta, the larger grain borer *Prostephanus truncatus* has continued to be the most devastating storage pest of maize and cassava in Kenya. Losses in maize are estimated at 30–90%, and which according to the Ministry of Agriculture records, lead to grain loss of 1.8 million 90-kg bags a year, valued at KShs 8.1 billion annually.

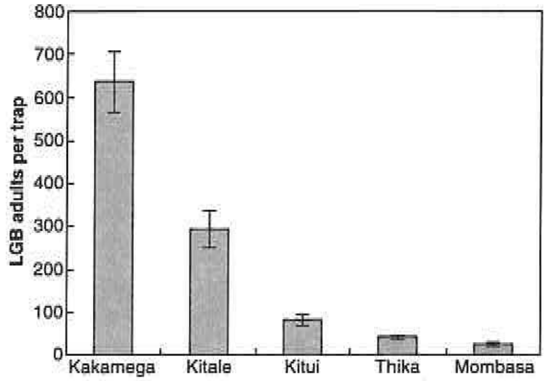


Figure 2. Mean ± number of larger grain borer adults per trap in each of 5 maize growing areas in Kenya during the period January–December 2005

The spread of this pest in Kenya was initially monitored through a collaborative effort between KARI and DFID, between 1991–1999. However, after this period, further spread of this pest could not be reliably tracked, due to lack of a monitoring system. There were increasing reports from farmers of this pest in new areas, such as Nyanza province in the late 1990s. Due to the seriousness of this pest, and fears about its potential spread to western Kenya, which is the main maize growing region in Kenya, there was an increasing need of a monitoring system for the LGB. A reliable monitoring

Table 3. Mean (± SEM) number of stemborers per maize plant in various cropping systems and in maize, sorghum and millet pure stands at Katumani and Kiboko during the short rains (SR) 2004, and long rains (LR) of 2004 and 2005

Cropping system	SR 2004	LR 2004	LR 2005
Katumani			
Maize			
Maize mono	0.02 ± 0.01	0.23 ± 0.06 a	0.29 ± 0.06
Maize-Sorghum	0.02 ± 0.01	0.11 ± 0.03 ab	0.14 ± 0.03
Maize-Bean	0.01 ± 0.01	0.13 ± 0.02 ab	0.13 ± 0.04
Maize-Millet	0.07 ± 0.05	0.15 ± 0.04 ab	0.20 ± 0.06
Maize-Millet-Bean	0.00 ± 0.00	0.07 ± 0.03 b	0.29 ± 0.09
Maize-Millet-Bean-Sorghum	0.06 ± 0.04	0.13 ± 0.04 ab	0.09 ± 0.03
F	1.27	2.66	2.52
P	0.277	0.022	0.028
Millet			
Millet mono	0.00 ± 0.00 b	0.03 ± 0.01	0.12 ± 0.03
Maize-Millet	0.00 ± 0.00 b	0.04 ± 0.02	0.04 ± 0.02
Maize-Millet-Bean	0.00 ± 0.00 b	0.08 ± 0.03	0.07 ± 0.03
Maize-Millet-Bean-Sorghum	0.08 ± 0.04 a	0.11 ± 0.03	0.12 ± 0.07
F	5.05	2.74	1.19
P	0.002	0.043	0.314
Sorghum	1.39 ± 0.17	0.33 ± 0.03	0.72 ± 0.10
Kiboko			
Maize			
Maize mono	0.15 ± 0.04	0.50 ± 0.03 a	0.26 ± 0.06 ab
Maize-Sorghum	0.16 ± 0.04	0.36 ± 0.03 b	0.21 ± 0.04 ab
Maize-Bean	0.08 ± 0.02	0.30 ± 0.03 b	0.25 ± 0.04 ab
Maize-Millet	0.14 ± 0.04	0.31 ± 0.05 b	0.39 ± 0.09 a
Maize-Millet-Bean	0.19 ± 0.06	0.29 ± 0.04 b	0.17 ± 0.05 b
Maize-Millet-Bean-Sorghum	0.19 ± 0.14	0.38 ± 0.05 b	0.12 ± 0.04 b
F	0.84	5.41	2.12
P	0.525	0.0001	0.061
Millet			
Millet mono	0.12 ± 0.03	0.19 ± 0.03	0.23 ± 0.06
Maize-Millet	0.10 ± 0.04	0.15 ± 0.04	0.18 ± 0.05
Maize-Millet-Bean	0.08 ± 0.03	0.17 ± 0.04	0.09 ± 0.04
Maize-Millet-Bean-Sorghum	0.07 ± 0.03	0.20 ± 0.04	0.17 ± 0.06
F	0.54	0.37	1.14
P	0.656	0.777	0.234
Sorghum			
Sorghum mono	1.43 ± 0.10	0.50 ± 0.03	1.96 ± 0.17

system for this exotic pest is essential for development of an effective classical biological control programme. This information is also essential for better targeting of other pest management strategies against this pest.

Monitoring of the larger grain borer *P. truncatus* (an exotic), was conducted in the period January to June 2005, in each of five major maize growing regions in Kenya, using pheromone traps. Trap catches were highest at Kakamega followed by Kitale, while the Kenyan coast had the lowest (Figure 2).

11. Integration of cropping systems and biological control for stemborer management in maize in eastern Kenya

The effects of maize–millet–sorghum–bean mixed cropping systems in eight different arrangements on infestations of cereals by lepidopteran stemborers and on associated parasitoids were assessed during three consecutive rainy seasons at two sites in the semi-arid Eastern Region of Kenya (Table 3). Yields of all crops and their land equivalent ratios (LER) were evaluated. If infestations were high, maize intercropped with bean grown in alternative rows reduced stemborer densities and plant damage. Intercropping with millet had an effect on stemborer species composition but not overall borer density. Across seasons and sites, maize intercropped with beans had the highest LER. In general, intercropping maize with other cereals was not as beneficial in terms of land use efficiency and pest reductions as were mixtures with cassava or leguminous crops reported in the literature.

12. Training of farmers and extensionists

Farmers and extension personnel in Kakamega and Thika were trained on the stemborers of maize and their management, with emphasis on biological control. In Kakamega, a total of 50 farmers (27 men and 23 women) and 8 extension personnel (3 men and 5 women) from Kabras, Lubao, Khayega, Ilesi, Bukura, Kwishero and Municipality locations attended the training. In Thika, a total of 31 farmers (18 men and 13 women) and 7 extension personnel (2 men and 5 women) from Munyu and Gatuanyaga locations attended the training.

Madagascar

Participating scientists: *J. Ravololonadrianina, N. Rahalivavololona, L. Ravaomanarivo*

Donor: *DGIS, The Netherlands*

Collaborators: *H. T. Andrianaivo, L. A. Rasmizafy*

13. Surveys for stemborers and associated natural enemies

In the 1960s and the 1970s, several introductions of parasitoids were done in Madagascar by the French. This present work aims at cataloguing the borer complex and associated parasitoids in the Southern Highlands, Mid West, Mid East, South and South West, South East and the North West.

Borer incidence

The percentage number of plants infested varied significantly with zone ($F = 3{,}6271$; $P < 0.004$), though overall infestation levels were low. Borer incidence was higher in the Mid West, the Southern Highlands and the North West than the South and South West, Mid East and South East (Table 4). In the South- and Mid East, rice is crop number one and maize is rare. In the South East and Mid East, rice is crop number one and maize is rare while in the South and South West maize is a very important staple. However, unreliability of rainfall and scarcity of water limit maize production. Nevertheless, high infestations of around 45% were observed in some localities.

Borer species composition

Three borer species were found attacking maize in Madagascar: the noctuids *Sciomesa biluma* and *Sesamia calamistis*, and the crambid *Chilo orichalcociliellus*. *Sciomesa biluma* was only found

Table 4. Relative importance (%) of stemborer species in the different regions of Madagascar

Region	Altitude (m)	*Sesamia calamistis*	*Sciomesa biluma*	*Chilo orichalcociliellus*	% plants infested
Mid West	1000	87.8 ± 16.6	0.0 ± 0.0	12.2 ± 12.2	12.3 ± 3.3 a
Southern Highlands	1067	64.7 ± 10.0	0.0 ± 0.0	35.3 ± 10.2	10.7 ± 1.9 ab
North West	399	44.9 ± 15.5	0.0 ± 0.0	55.1 ± 16.4	8.0 ± 2.3 b
South and South West	667	31.9 ± 9.6	0.0 ± 0.0	68.1 ± 10.1	4.0 ± 1.4 c
Mid East	199	100.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	3.7 ± 4.4 c
South East	1218	73.9 ± 10.6	20.2 ± 9.6	5.9 ± 5.9	1.5 ± 2.1 c

Means (± SE) in the same column followed by the same letter are not significantly different (Student-Newman-Keuls multiple comparison test, $P < 0.05$).

in the high altitudes above 1200 m. *Sesamia calamistis* was the most common borer species in all zones, except for the North West and South and South West, where *C. orichalcociliellus* dominated (Table 4). *Chilo orichalcociliellus* occurred in all zones except in the Mid East.

Parasitism

In general, larval and pupal parasitism was exceedingly low. In the Mid West and the North West, some *C. orichalcociliellus* larvae were found parasitised by the ichneumonid *Syzeuctus gaullei*. The eulophids *Pediobius furvus* and *Tetrastichus howardi* were reared from some *S. calamistis* and *S. biluma* pupae. *Pediobus furvus* was introduced by the French in 1960 for the control of *S. calamistis*. No pupal parasitoids were obtained from *C. orichalcociliellus*. *Cotesia flavipes*, which was introduced by the French in the 1960s against the invasive *C. sacchariphagus* was not recovered during the present surveys.

Pupal parasitoids were observed in three areas, and parasitism levels were low. The highest parasitism was 2.5% observed in the South East. In the highlands, parasitism was only 1% and in the Mid West 0.47%.

14. Training

A total 47 farmers and 3 postgraduate students were trained between 2004 and 2005.

Malawi

Participating scientists: *E. Kapeya, T. Maulana*

Donor: *DGIS, The Netherlands*

Collaborators: *Bvumbwe Agricultural Research Station, Bunda College*

15. Monitoring the larger grain borer

The traps were placed near storage sheds at five locations in each of three districts in the southern region. At each site the traps set were left for a period of 15 days. Trap catches from three districts in two months of 2004 and three months of 2005 are given in Table 5.

Table 5. Larger grain borer catches in some districts of southern Malawi

District	Mean number of larger grain borer (LGB) September	October	February	April	May
Nsanje	75 b	77 c	150 b	120 b	78 b
Chikwawa	264 a	189 b	614 a	403 a	403 a
Mangochi	345 a	863 a	591a	666 a	157 a
Total	3421	5645	6775	5941	2168
Mean	228	376	452	396	145
CV%	151	206	108	109	99

Means in a column followed by the same lower case letters are not statistically significant ($P < 0.005$).

16. Release, establishment and spread of exotic parasitoids

Malawi continued to release *Cotesia flavipes* in selected areas, especially in the southern region, where *Chilo* is a major pest. Additional release sites were identified in Thuchila (Mulanje), Njuli (Chiradzulu) and Nsipe (Ntcheu).

Mozambique

Participating scientists: *D. Cugala, E. Mambo*

Donor: *DGIS, The Netherlands*

Collaborators: *Eduardo Mondlane University, Department of Plant Protection*

17. Release and establishment of the exotic pupal parasitoid Xanthopimpla stemmator *Thunberg (Hymenoptera: Ichneumonidae) at different agroecological zones*

First releases of *Xanthopimpla stemmator* were made in July 2001 in five sugar cane fields in a lowland area at Açucareira de Mafambisse. Additional releases were conducted during the 2002/03 growing season in maize farmers' fields at three agroecologically different zones in Mozambique which have distinctly different stemborer complexes: (1) lowland area at less than 200 masl where *Chilo partellus* constitute for more than 95% of the total stemborer population, (2) mid to high elevation areas at 800 masl, where both *C. partellus* and *Busseola fusca* occur with nearly equal frequency and (3) at high elevation area at about 1400 masl in northern province of Niassa where *B. fusca* is the dominant species with more than 90% of the total stemborer population followed by *Sesamia calamistis* and *C. partellus*. At each location, *X. stemmator* was released in four selected farmers' fields when the stemborer pupal stage peak was expected. During post-release surveys pupae of three stemborer species were collected at all sampling sites including *C. partellus, B. fusca* and very few of *S. calamistis*. *Chilo partellus* was abundant in lowland and *B. fusca* found in mid to high elevation zones. *Xanthopimpla stemmator* was recovered only from *C. partellus* pupae collected mainly from locations where *C. partellus* was dominant. No *X. stemmator* individuals were reared from either *B. fusca* or *S. calamistis*. The number of *X. stemmator* recovered was significantly highest at Tica-Mafambisse ($F = 4.56$, df = 6, $P = 0.0003$) followed by Magude (12 ± 0.54) and Xai Xai (10 ± 0.49). *Xanthopimpla stemmator* was not recorded at Lichinga. The levels of parasitism due to the exotic *X. stemmator* on *C. partellus* pupae under environmental field conditions was significantly high at Tica-Mafambisse and Magude ($F = 3.04$, df = 6, $P = 0.0082$) followed by Guija (11.0 ± 3.51) and Xai Xai (8.5 ± 2.36).

18. Assessment of the impact of natural enemies on stemborer infestations and yield loss in maize using selected insecticides

The effect of natural enemies on stemborer infestations and maize grain yields was estimated using an insecticide exclusion method. Field experiments were conducted at low, mid and high elevation zones, which vary in the stemborer species composition. Dimethoate was applied to exclude natural enemies and cypermethrin to suppress stemborers, while other plots served as control. At all study sites more stemborer larvae and pupae were collected when natural enemies were excluded. Parasitism as well as maize grain weight in the unprotected plots

Table 6. Effect of treatments on cob and grain weight and yield losses in the presence and absence of natural enemies (±SE)

Location/ treatment	Cob weight	Grain weight kg/plot	Yield losses from: Unprotected plots[1]	Exclusion plots[2]
(a) Chokwe				
Unprotected	18.6 ± 2.8 b	17.1 ± 1.5 b	-	26.1
Exclusion	17.5 ± 3.3 b	12.6 ± 1.48 c	-	-
Fully protected	26.1 ± 3.5 a	22.3 ± 1.0 a	28.9	43.3
df	2, 12	2, 12		
F	8.25	2.9		
P-values	0.0093	<0.0001		
(b) Machipanda				
Unprotected	16.6 ± 2.2 b	14.1 ± 2.6 b	-	11.2
Exclusion	16.2 ± 5.3 b	12.9 ± 5.5 b	-	-
Fully protected	28.1 ± 1.4 a	21.4 ± 3.4 a	34.5	40.8
df	2, 12	2, 12		
F	15.6	5.4		
P-values	0.0012	0.0290		
(c) Lichinga				
Unprotected	18.2 ± 1.70 b	14.5 ± 2.19 b		7.6
Exclusion	17.6 ± 0.91 b	13.4 ± 1.00 b		
Fully protected	25.3 ± 2.32 a	21.1 ± 2.01 a	31.2	36.4
df	2, 12	2, 12		
F	24.1	21.1		
P-values	0.0002	0.0004		

[1]Yield losses in the presence of natural enemies (comparing fully protected and unprotected plots).
[2]Yield losses in the absence of natural enemies (comparing unprotected and exclusion plots and fully protected and exclusion plots for first and second values respectively).

Table 7. Effect of treatment on stemborer density and parasitism at the three study sites (±SE)

Location/ Treatment	% plants infested	No. of stemborers	*Cotesia flavipes*	*C. sesamiae*	*Sturmiopsis parasitica*	*Dentichasmias busseolae*	*Procerochasmias nigromaculatus*
(a) Chokwe							
Unprotected	75 ± 0.1 b	2.9 ± 2.3 b	5.8 ± 2.1 a	13.2 ± 4.2 a	-	36.7 ± 5.2 a	-
Exclusion	90 ± 1.2 a	5.8 ± 3.2 a	0.0 ± 0.0 b	0.9 ± 1.4 b	-	10.3 ± 2.4 b	-
Fully protected	15 ± 0.2 c	0.9 ± 0.8 c	0.0 ± 0.0 b	0.0 ± 0.0 c	-	0.0 ± 0.0	-
df	2,119	2,119	2,119	2,119		2,119	
F	45.5	22.0	3.3	34.6		21.8	
P-values	<0.0001	0.0003	0.0474	<0.0001		<0.0001	
(b) Machipanda							
Unprotected	45 ± 0.4 b	3.4 ± 2.2 b	15.4 ± 3.1 a	20.4 ± 4.4 a	7.2 ± 3.9 a	20.9 ± 2.4 a	0.0 ± 0.0
Exclusion	60 ± 0.8 a	6.8 ± 3.2 a	2.2 ± 1.3 b	5.1 ± 2.1 b	1.5 ± 0.4 b	4.0 ± 3.2 b	0.0 ± 0.0
Fully protected	5 ± 0.0 c	0.5 ± 0.8 c	0.0 ± 0.0 c	0.0 ± 0.0	0.0 ± 0.0 b	0.0 ± 0.0	0.0 ± 0.0
df	2,119	2,119	2,119	2,119	2,119	2,119	
F	47.2	27.9	16.9	30.3	8.7	10.5	
P-values	<0.0001	<0.0001	<0.0001	<0.0001	0.0078	<0.0001	
(c) Lichinga							
Unprotected	80 ± 1.2 a	4.8 ± 2.4 b	0.0 ± 0.0	3.6 ± 1.5 a	4.5 ± 1.3 a	0.0 ± 0.0	48.6 ± 10.4 a
Exclusion	95.5 ± 1.5 a	7.8 ± 3.1 a	0.0 ± 0.0	0.0 ± 0.0 a	1.2 ± 0.9 a	0.0 ± 0.0	2.6 ± 1.2 b
Fully protected	10 ± 0.1 b	1.2 ± 1.6 c	0.0 ± 0.0	0.0 ± 0.0 a	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0 c
df	2,119	2,119		2,119	2,119		2,119
F	56.0	78.8		5.1	8.3		27.0
P-values	< 0.0001	< 0.0001		0.0479	0.0004		0.0002

Means followed by the same lowercase letter within a column are not significantly different at $P < 0.05$ (SNK).

was significantly higher than in the exclusion plots. Yield losses increased in 28.9% in unprotected to 43.3% in exclusion plots (Table 6). The most abundant parasitoids of *Chilo partellus* were *C. sesamiae*, *C. flavipes* and *Dentichasmias busseolae* while for *Busseola fusca* they were *C. sesamiae*, *Sturmiopsis parasitica* and *Procerochasmias nigromaculatus* (Table 7). It was concluded that exclusion of natural enemies caused an increase in stemborer populations; thus, the parasitoids play an important role in suppressing stemborer infestations in maize.

19. Other exotic pests amenable to classical biological control

The larger grain borer

Surveys on the larger grain borer (LGB) were conducted in some areas in the central and southern regions in January and July 2005. *Prostephanus truncatus* was first reported in provinces of Tete, Niassa and Cabo Delgado bordering Tanzania, Malawi and Zambia. However, current results reported the occurrence of this storage pest in the central and southern provinces of Manica, Sofala and Inhambane mainly along the National Road No. 1 through which maize grain is transported from the North and Centre to South where maize is commercially grown.

To evaluate the incidence, distribution and dispersion of *P. truncatus*, pheromone traps were installed at various susceptible locations for *P. truncatus* infestations along the National Road No. 1 and Beira Corridor in January and in selected areas in Manica province in July 2005 (Figure 3). The impact of *P. truncatus* and other storage pests on weight loss in stored maize was evaluated.

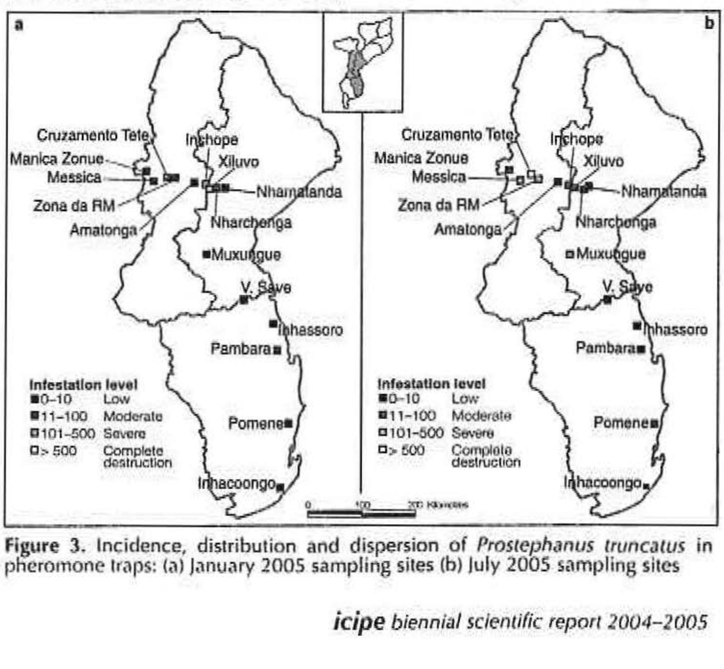


Figure 3. Incidence, distribution and dispersion of *Prostephanus truncatus* in pheromone traps: (a) January 2005 sampling sites (b) July 2005 sampling sites

20. Training

BSc Students who did their degree-related work within the context of the project

Name	Topic
A. Balate	Economic aspects of the use of biological control agents to control stemborers in Chokwe district, Gaza province.
N. Banze	Assessment of establishment and spread of *Xanthopimpla stemmator* in Manhica district, Maputo province.
R. George	Assessment of establishment and spread of *Xanthopimpla stemmator* in Gondola district, Manica province.
R. Niquice	Assessment of establishment and spread of *Xanthopimpla stemmator* in Manica district, Manica province.
V. Gonga	Assessment of establishment and spread of *Xanthopimpla stemmator* in Nhamatanda district, Sofala province.
S. Mussa	Status of groundnut leaf miner, *Aproaerema modicella* and its impact on yield losses in Inhambane province.
F. Graça	Status of groundnut leaf miner, *Aproaerema modicella* and its impact on yield losses in Gaza province.
S. Amaro	Status of groundnut leaf miner, *Aproaerema modicella* and its impact on yield losses in Maputo province.
S. Comé	Incidence and distribution of groundnut leaf miner, *Aproaerema modicella* and potential zones on risk of invasion in Sofala province.
E. Condo	Incidence and distribution of groundnut leaf miner, *Aproaerema modicella* and potential zones on risk of invasion in Nampula province.
A. Macaringue	Incidence and distribution of groundnut leaf miner, *Aproaerema modicella* and potential zones on risk of invasion in Inhambane province.
R. Egidio	Incidence and distribution of groundnut leaf miner, *Aproaerema modicella* and potential zones on risk of invasion in Gaza province.
M. Berguete	Incidence and impact of *Prostephanus truncatus* on maize grain weight loss and its associated natural enemies in Manica province.
M. Maposse	Evaluation of resistant varieties against groundnut leaf miner, *Aproaerema modicella*.

Tanzania-Mainland

Participating scientist: *B. Pallangyo*

Donor: *DGIS, The Netherlands*

Collaborator: *V. Mgoo*

21. *Maize yield loss attributed to the stemborer* Chilo partellus *(Swinhoe). (Lepidoptera: Crambidae) at different nitrogen application rates*

Field trials were conducted at Kibaha and Morogoro in Eastern Tanzania during two seasons to evaluate the effect of nitrogen fertilisation (0, 50, 75, 100 kg [N]/ha) on pest abundance, plant damage and yield loss of maize due to stemborers. Stemborer density was higher in Kibaha than in Morogoro, and higher during the short than the long rainy seasons. Nitrogen positively affected stem diameter, plant height and yield of maize though it had no effect on percentage of stem tunnelling and internodes bored. In general, ear and grain weights increased linearly with nitrogen level (Table 8). In the infested plot, grain weight increased 2.5- and 1.8-fold from

Table 8. Maize cob and grain yield (g/plant) at different nitrogen levels of Furadan-treated (T) and untreated (UT) maize at pre-tasselling and at harvest during two cropping seasons and at two locations

	Short rains season		Long rains season	
	Grain yield		Grain yield	
N-levels	T	UT	T	UT
Kibaha				
0	93.2 ± 5.3 b	44.0 ± 6.2 c	93.0 ± 5.9 d	67.8 ± 4.6 d
50	104.3 ± 5.0 b	62.8 ± 6.3 b	108.5 ± 4.3 c	84.8 ± 5.2 c
75	125.1 ± 3.7 a	95.3 ± 6.8 a	130.1 ± 4.0 b	109.0 ± 6.4 b
100	137.9 ± 4.9 a	111.1 ± 5.4 a	146.3 ± 4.3 a	124.6 ± 5.6 a
F	18.0	24.1	24.9	21.3
P	0.0001	0.0001	0.0001	0.0001
Morogoro				
0	110.1 ± 7.4 c	108.2 ± 6.9 c	111.0 ± 4.7 b	96.3 ± 5.7 d
50	123.1 ± 7.2 bc	124.7 ± 6.5 bc	119.9 ± 4.8 b	112.8 ± 5.3 c
75	138.4 ± 5.3 ab	136.4 ± 5.8 ab	138.8 ± 5.7 a	135.0 ± 4.9 b
100	153.0 ± 4.1 a	152.5 ± 5.3 a	151.0 ± 4.6 a	150.4 ± 5.2 a
F	9.2	9.3	13.3	20.3
P	0.0001	0.0001	0.0001	0.0001

Means within columns followed by the same lower case letter do not significantly differ at $P \leq 0.05$ (Student-Newman-Keul's test).

0 to 100 kg [N]/ha in short and long rainy seasons, respectively, at Kibaha, and 1.4 and 1.6 times at Morogoro. Yield loss decreased with an increase in nitrogen application and the effect was stronger under high than low borer infestation levels (Figure 4). The results show again the beneficial effect of nitrogen on the plants' ability to compensate for borer damage.

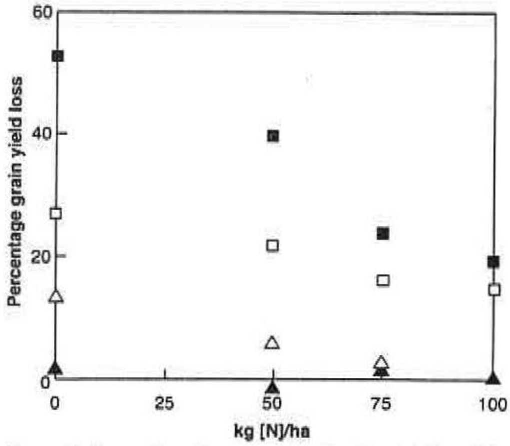


Figure 4. Regression of percentage of grain yield loss (Y) on different nitrogen dose applications (X). SR and LR represent short and long rains season. ■ Kibaha SR: Y = 33.72(± 3.37) (P = 0.004)-0.35(± 0.05)X (P = 0.020) R^2 = 0.961; □ Kibaha LR: Y = 27.28 (± 1.15) (P = 0.002)-0.13 (± 0.02) (P = 0.02), R^2 = 0.966; ▲Morogoro SR: Y = 1.04 (± 1.47) (P = 0.554)-0.01 (± 0.02) (P = 0.730), R^2 = 0.073; △Morogoro LR: Y = 12.91 (± 0.56) (P = 0.002) -0.13 (± 0.01) (P = 0.004), R^2 = 0.992

22. *Field surveys for yield loss assessments*

Surveys were conducted to determine the damage/loss caused by stemborers on maize in five districts. Site selection was based on the maturity of the crop. Sampling was conducted at a minimum of 5 km interval depending on the availability of fields at maturity stage. In each sampled field, 20 plants were selected at random. Information collected included plant height, stem diameter, stemborer densities, tunnel length, number of holes, cob weight and % cob damage. The general linear model procedure (Proc GLM, SAS Institute 1993) was used to analyse differences of these variables between districts. Mean borer incidence was 17.7%. In all districts, *C. partellus* and *S. calamistis* were the most common species accounting for 47.7 and 23.3% respectively. *Busseola fusca* accounted for 29.0% of all stemborers and was found in two districts only (Hai at 70% and Arumeru at 33.3%).

Larval densities of both *B. fusca* and *C. partellus* varied significantly among districts, while those of *S. calamistis* were not significantly different. *Busseola fusca* density was highest in Hai followed by Arumeru district, while no *B. fusca* larvae were recovered in Muheza and Moshi rural districts. *Chilo partellus* larval density was highest in Muheza followed by Moshi rural and lowest in Hai district. Larval density of *S. calamistis* was highest in Moshi rural, followed by Muheza, and lowest in Hai districts (Table 9).

Table 9. Densities of three stemborer species in four districts in Tanzania

Region	District	N	*Busseola fusca*	*Chilo partellus*	*Sesamia calamistis*
Arusha	Arumeru	220	0.08 ± 0.03 b	0.05 ± 0.03 b	0.04 ± 0.03
Kilimanjaro	Hai	131	0.23 ± 0.03 a	0.11 ± 0.03 b	0.01 ± 0.02
	Moshi rural	200	0.00 ± 0.00 b	0.23 ± 0.05 a	0.02 ± 0.04
Tanga	Muheza	140	0.00 ± 0.00 b	0.19 ± 0.03 a	0.07 ± 0.02
		P-value	<0.0001	<0.0001	0.1829

Means within columns followed by the same lowercase letter do not differ significantly at $P \leq 0.05$ (SNK).

In all districts, damage variables followed the same trend as the total numbers of stemborer density. Cob weight varied significantly among districts and ranged between 109.4–144.8 g/plant (P < 0.0001). Average losses were around 12.9%.

23. *Releases of* Cotesia flavipes *and* Xanthopimpla stemmator

Releases

Releases of two exotic parasitoids *Cotesia flavipes* and/or *Xanthopimpla stemmator* were conducted in five regions (Table 10).

Monitoring surveys

In April to June 2005 monitoring surveys were conducted in Tanga and Morogoro, Dodoma and Mara regions to determine the spread of *Cotesia flavipes* and in Arusha region to determine the establishment of *Xanthopimpla stemmator.* Parasitisation rates on *Chilo partellus* by *C. flavipes* of 4.8 and 2.5 were recorded in Tanga and Coast regions, respectively. These results indicate that *C. flavipes* is spreading although the population is low. The highest number of cocoons was collected from Dodoma (65), followed by Mara (31), and Arusha (18) regions. The lowest number of cocoons (1) was collected in Singida region. Parasitisation ranged from 0.6–85% whereby the highest rate was recorded in Mara region (85%) followed by Arusha (41.8%). The lowest parasitisation (0.61%) was recorded in Singida region. Parasitism rate of 30% for Dodoma was remarkable because releases had not been made there until the time of the survey. *Cotesia flavipes* must have spread from Mara region, where establishment was reported in the mid-1990s. The high rates of parasitism in Mara region were expected since parasitoid populations have been building over time. To date no recoveries of *X. stemmator* have been made.

Table 10. Location of release sites and number of *Cotesia flavipes* and *Xanthopimpla stemmator* released in Tanzania, April–June 2004

Region	*Cotesia flavipes*	*Xanthopimpla stemmator*
Morogoro	200,000	-
Dodoma	200,000	1000
Tanga	200,000	1000
Mara	600,000	1000
Arusha	-	1000

Tanzania-Zanzibar

Participating scientists: *Z. Abdalla, V. Lada*

Donor: *DGIS, The Netherlands*

Collaborator: *Department of Plant Protection, Zanzibar*

24. Habitat management/intercropping trial

The trial was planted at Mahonda Agricultural Station plantation area and lasted for three seasons (short–long–short rains). The treatments were maize monocrop, maize intercropped with cassava/ green gram, maize intercropped with cowpea and maize intercropped with groundnuts.

During the short rains of 2004, maize plants in the cropping system with cassava had significantly lower tunnel length, number of exit holes and damaged internodes than cropping systems without cassava (Table 11).

During the long rains of 2004/05 maize with cowpea as companion crop tended to have less damage symptoms than the other treatments while maize in pure stands tended to have the highest (Table 12). However, again, the trends were not always that clear.

During the short rains of 2005, differences between treatments were mostly not significant (Table 13). As shown by other researchers, the effect of mixed cropping systems on pest numbers is variable if the crop to be protected is not planted after the companion crops.

Table 11. Plant growth and damage variables during the short rains of 2004

	Height	Diameter	Cob weight	Damaged internodes	Exit holes	Tunnel	Cob damage
Maize Mono	116.3 ± 3.1ab	2.0 ± 0.06	115.2 ± 6.9	1.29 ± 0.16 ab	1.80 ± 0.2 a	7.9 ± 1.2 ab	7.1 ± 1.60 ab
Maize/cowpea	126.4 ± 3.0 a	2.2 ± 0.06	118.1 ± 6.8	1.70 ± 0.16 a	1.84 ± 0.2 a	11.8 ± 1.2 a	8.4 ± 1.58 a
Maize/cassava/gg	114.1 ± 3.1 b	2.1 ± 0.06	107.5 ± 6.7	0.84 ± 0.15 b	1.03 ± 0.2 b	5.0 ± 1.2 b	8.6 ± 1.58 a
Maize/g. nut	125.6 ± 3.1 a	2.2 ± 0.06	132.2 ± 6.8	1.47 ± 0.15 a	1.93 ± 0.2 a	10.0 ± 1.2 a	6.6 ± 1.57 b

gg, green gram.
Means (± SE) in the same column followed by the same letter are not significantly different (Student-Newman-Keuls multiple comparison test, $P < 0.05$).

Table 12. Plant growth and damage variables during the long rains of 2004/05

	Height	Diameter	Cob weight	Damaged internodes	Exit holes	Tunnel	Cob damage
Maize Mono	168.3 ± 5.8	2.3 ± 0.08 a	133.5 ± 8.8 a	1.90 ± 0.20 a	2.30 ± 0.20 a	13.2 ± 1.77 a	4.35 ± 1.4 ab
Maize/cowpea	157.3 ± 5.6	2.2 ± 0.1 ab	133.0 ± 8.6 a	0.76 ± 0.20 b	0.95 ± 0.27 b	5.3 ± 1.73 b	1.23 ± 1.3 b
Maize/cassava/gg	150.7 ± 5.8	2.0 ± 0.08 b	98.7 ± 8.9 b	1.72 ± 0.02 a	1.70 ± 0.28 ab	12.1 ± 1.77 a	9.02 ± 1.4 a
Maize/g. nut	148.2 ± 5.7	2.0 ± 0.08 ab	110.3 ± 8.8 ab	1.22 ± 0.02 ab	1.40 ± 0.28 ab	9.1 ± 1.80 ab	2.25 ± 1.4 b

gg, green gram.
Means (± SE) in the same column followed by the same letter are not significantly different (Student-Newman-Keuls multiple comparison test, $P < 0.05$).

Table 13. Plant growth and damage variables during the short rains of 2005

	Height	Diameter	Cob weight	Damaged internodes	Exit holes	Tunnel
Maize Mono	135.6 ± 4.8	1.92 ± 0.11 a	130.0 ± 16.2	2.55 ± 0.35 a	4.80 ± 1.0	9.3 ± 2.1
Maize/cowpea	133.9 ± 4.8	1.37 ± 0.11 b	123.0 ± 16.2	2.32 ± 0.21 a	4.60 ± 1.0	9.2 ± 2.1
Maize/cassava/gg	132.2 ± 4.8	1.97 ± 0.11 a	145.0 ± 16.1	3.95 ± 0.35 b	5.80 ± 1.1	13.9 ± 2.1
Maize/g. nut	128.5 ± 4.8	1.64 ± 0.11 ab	136.4 ± 15.0	3.76 ± 0.34 b	6.23 ± 1.0	11.7 ± 2.1

gg, green gram.
Means (± SE) in the same column followed by the same letter are not significantly different (Student-Newman-Keuls multiple comparison test, $P < 0.05$).

25. Surveys for invasive pest species amenable to classical biological control

The spiralling whitefly

The survey was conducted during the dry season in February–March 2005 on both Unguja and Pemba Islands. Four and three farming system zones of Unguja and Pemba, respectively, were surveyed. The main objective was to determine the incidence of spiralling whitefly *Aleurodicus dispersus* Russel (Homoptera: Aleyrodidae) on the islands. Five villages were selected in each zone of Unguja and three villages on Pemba. Four fields were selected from each village.

A scoring system was used to assess the infestation level of spiralling whitefly. Five plants were observed in each field and four leaves on each plant were scored; two leaves from the upper and lower part of the plant were sampled. The score focused on adults, eggs and nymphs of spiralling whitefly. For adults the score was based on number of adults observed on the leaves (0 = none; 1 = 1 to 10; 2 = 11 to 20; 3 = more than 20 and 4 = above 50). For eggs and nymphs the percentage leaf area covered was scored as 0 = none; 1 = less than 25%; 2 = 50%; 3 = between 50–75%; and 4=more than 75% (Table 14).

Table 14. Means (± SE) score of spiralling whitefly by farming system zones in Unguja and Pemba

Zone	No. of plants	Average score for adults	% area covered by eggs	% area covered by nymphs
Unguja				
2	460	0.615 ± 0.03 a	0.981 ± 0.04 a	0.500 ± 0.03 a
3a	601	0.606 ± 0.03 a	0.981 ± 0.03 a	0.483 ± 0.03 ab
1	419	0.591 ± 0.03 a	1.070 ± 0.03 a	0.552 ± 0.02 a
4	520	0.407 ± 0.03 b	0.830 ± 0.04 b	0.394 ± 0.02 bc
3b	380	0.317 ± 0.03 b	0.800 ± 0.03 b	0.313 ± 0.03 c
4b	260	0.857 ± 0.04 a	1.388 ± 0.05 a	0.984 ± 0.06 a
Pemba				
1	220	0.518 ± 0.05 b	0.822 ± 0.05 b	0.405 ± 0.04 bc
5	279	0.394 ± 0.03 bc	0.792 ± 0.04 b	0.539 ± 0.04 b
2	240	0.375 ± 0.04 bc	0.583 ± 0.05 c	0.454 ± 0.04 bc
3	238	0.375 ± 0.05 bc	0.808 ± 0.05 b	0.291 ± 0.03 c
4a	139	0.207 ± 0.06 c	0.735 ± 0.06 bc	0.464 ± 0.05 bc

Means (± SE) in the same column followed by the same letter are not significantly different (Student-Newman-Keuls multiple comparison test, $P < 0.05$).

The crops studied were cassava and some vegetable crops (capsicum, okra, egg plant and bitter egg plant). These were the most commonly found vegetable crops during the period. All the fields visited were infested by spiralling whitefly. Highest densities were observed on capsicum followed by cassava.

A total of 2380 and 1376 plants were observed in Unguja and Pemba islands. Spiralling whitefly was found in all farming system zones in both islands at different population levels.

26. Regional surveys for stemborers and parasitoids

Studies were conducted in the major maize and sorghum growing areas of Zanzibar. Twenty sites were randomly selected from the regions where *Cotesia flavipes* was released from 1999–2003, i.e. Central, South, North and West. Study sites were farmers' fields of approximately 0.5–1.0 ha and at least 5 km apart. Only farms where farmers did not apply pesticides were selected. Surveys were conducted during the long and short rains seasons of 2004. Each field was divided into four quadrants. Fifteen infested plants were removed from each quadrant. Forty plants were selected randomly per field. The sampling was done at the milking and hard dough stages. The number of stemborer larvae or pupae and species were recorded. A third sampling will be carried out during the harvesting period. Percentage of ears damaged, ear weight without husk, shelled grain weight per cob and number of borers per plant was recorded. Densities and relative importance of individual borer species did not vary with region. The predominant species were *Chilo partellus* (Cp) followed by *Sesamia calamistis* (Sc) and *C. orichalcociliellus* (Co) (Table 15).

Table 15. Stemborer density (means ± SE) and species composition (%) in Zanzibar of 2004 short rains season

Region	Borers	Cp	Sc	Co
Central	1.86 ± 0.18	1.11 ± 0.14 (64.04 ± 4.26)	0.59 ± 0.10 (25.78 ± 3.75)	0.16 ± 0.04 (10.18 ± 2.51)
North	2.38 ± 0.24	1.45 ± 0.19 (66.54 ± 4.68)	0.76 ± 0.16 (26.11 ± 4.19)	0.18 ± 0.05 (7.35 ± 2.37)
South	2.27 ± 0.29	1.44 ± 0.25 (65.59 ± 6.05)	0.68 ± 0.17 (24.00 ± 5.21)	0.15 ± 0.06 (10.42 ± 3.93)
West	2.14 ± 0.24	1.26 ± 0.17 (65.83 ± 4.95)	0.61 ± 0.13 (25.67 ± 4.47)	0.18 ± 0.06 (5.96 ± 1.93)
F	2.88	1.78	0.48	0.08
P	0.0353	0.1497	0.6951	0.9683

Cp, Chilo partellus; Sc, Sesamiae calamistis; Co, Chilo orichalcociellus.

Table 16. Parasitism in different regions. Percentage of parasitism (%) is shown in parentheses

	Central	North	South	West
Cf-Cp	31/224 (13.84)	16/174 (9.20)	14/117 (12.00)	18/202 (8.91)
Cs-Sc	7/118 (5.93)	4/91 (4.40)	4/55 (7.3)	2/98 (2.04)

Cf, *Cotesia flavipes*; Cp, *Chilo partellus*; Cs, *Cotesia sesamiae*; Sc, *Sesamia calamistis*.

Parasitism of *C. partellus* by *C. flavipes* ranged between 8.9 and 13.8% while that of *C. sesamiae* on *S. calamistis* was less than 10% (Table 16). The number of parasitised host and total number of stemborers are presented in Table 16.

27. The effect of pesticides and nitrogen fertiliser on pests and Cotesia flavipes

The effect of nitrogen levels of 0, 60, 120 and 266 kg/ha and insecticide treatment (Furadan) on population densities and parasitism of lepidopteran stemborers, and maize yields were studied in Zanzibar during 2004/05 (Tables 17 and 18). *Chilo partellus* dominated by 3-fold over *Sesamia calamistis* and 42-fold over *Chilo orichalcociliellus* (Table 17). Stemborer density per plant and parasitism by *Cotesia flavipes* increased with nitrogen application level (Table 17). Percentage of bored internodes per plant caused by stemborer

Table 17. Borer density (mean ± SE/plant) according to species at different N application rates during the short and long rains in Zanzibar, during the 2004/05 season

Treatment	*Chilo partellus*	*Sesamia calamistis*	*C. orich.*	Total no. borer
Short rains				
N0	1.0 ± 0.2 b	0.37 ± 0.1	0.08 ± 0.04	1.5 ± 0.2 c
N1	1.7 ± 0.2 ab	0.58 ± 0.1	0.13 ± 0.05	2.4 ± 0.3 b
N2	3.0 ± 0.4 a	0.59 ± 0.1	0.11 ± 0.05	3.7 ± 0.4 a
N3	2.1 ± 0.3 ab	0.71 ± 0.2	0.07 ± 0.03	3.0 ± 0.32 b
F-value	5.84	0.88	0.47	16.58
P-value	0.0006	0.452	0.700	< .0001
Long rains				
N0	0.7 ± 0.1 b	0.10 ± 0.03	0.01 ± 0.01	1.0 ± 0.2
N1	1.0 ± 0.1 ab	0.20 ± 0.08	0.01 ± 0.01	1.0 ± 0.1
N2	1.3 ± 0.2 a	0.20 ± 0.05	0.02 ± 0.02	1.4 ± 0.2
N3	1.1 ± 0.1 a	0.10 ± 0.04	0.04 ± 0.04	1.2 ± 0.1
F-value	3.86	1.31	1.22	0.74
P-value	0.009	0.271	0.302	0.527

Means (± SE) in the same column followed by the same letter are not significantly different (Student-Newman-Keuls multiple comparison test, $P < 0.05$).

Table 18. Effect of different nitrogen levels on percentage parasitism of stemborers *Chilo partllus*, *Sesamia calamistis* and *Chilo orichalcociliellus* by *Cotesia flavipes* and *C. sesamiae*

Parasitoid	Host	N0	N1	N2	N3	χ^2	*P*
Short rains							
Co. flavipes	*Ch. partellus*	3.33	9.61	5.38	7.17	3.69	0.30
	S. calamistis	0.00	2.80	2.8	0.00	5.63	0.13
	Ch. orichalcociliellus	0.00	0.00	0.00	37.50	115.57	0.0001
Co. sesamiae	*Ch. partellus*	0.00	1.44	0.83	0.30	2.79	0.43
	S. calamistis	0.00	1.40	2.8	4.7	6.15	0.10
	Ch. orichalcociliellus	0.00	0.00	0.00	0.00	-	-
Co. flavipes	All borer species	2.3	7.5	3.6	6.1	9.29	0.026
Co. sesamiae	All borer species	0.00	1.4	0.9	1.5	4.47	0.215
Long rains							
Co. flavipes	*Ch. partellus*	5.82	6.76	6.60	5.66	0.19	0.98
	S. calamistis	0.00	3.22	4.54	21.42	36.69	0.0001
	Ch. orichalcociliellus	50.0	100.0	63.36	36.36	296.68	0.0001
Co. sesamiae	*Ch. partellus*	0.90	0.00	0.90	1.25	2.78	0.43
	S. calamistis	10.0	0.00	18.18	0.00	43.87	0.0001
	Ch. orichalcociliellus	50.0	100.0	9.00	0.00	416.90	0.0001
Co. flavipes	All borer species	6.0	7.8	10.6	9.5	2.42	0.489
Co. sesamiae	All borer species	2.6	1.2	2.3	1.11	1.55	0.672

decreased with N levels during the short rains season. Pesticide application reduced densities of all stemborer species during the short rains season, when infestations were high. Maize yield increased 2 to 8 times with N level, compared to the zero treatment, but the effect was less pronounced in the protected plots.

Uganda

Participating scientist: *S. Kyamanywa*

Donor: *DGIS, The Netherlands*

Collaborator: *T. Kauma-Matama*

28. Abundance of stemborers and their parasitoids

The objective of this study was to determine the incidence of stemborers and parasitism levels with emphasis on the introduced braconid *Cotesia flavipes* Cameron. The surveys started in 2003 were conducted in farmers' fields in four agroecological zones (AEZs) in 2004. Three surveys were carried out per season in 2004 at different maize growth stages, i.e. at the whorl, tasselling and maturity stages. Forty plants were randomly sampled per field and a total of 15–25 fields per AEZ. *Busseola fusca* Fuller (Noctuidae) and *Chilo partellus* Swinhoe (Crambidae) were the most important stemborers recorded. *Chilo partellus* represented 77% of the stemborers in the Eastern AEZ while *B. fusca* was dominant (60–79%) in the other AEZs. Infestation levels were found at 16–31% plants infested and a borer density of 0.2–0.5 borers per plant (Table 19). *Telenomus busseolae* Gahan (Scelionidae), the only egg parasitoid recovered was found to cause egg parasitism of up to 46% on *B. fusca*. Several larval and pupal parasitoid species were recorded; however, the most common were the larval braconid *Cotesia sesamiae* and the introduced *Cotesia flavipes* Cameron. Mean parasitism by the indigenous *C. sesamiae* ranged between 2.0 and 29.4% on *B. fusca* while that on *C. partellus* was found at 0–13% (Table 20). *Cotesia flavipes* was recovered at most of the locations with a parasitism level of 0–30.5% on *C. partellus*. Results further indicated that the parasitoid has not attained equilibrium 5 years after its introduction but it is important that impact studies be conducted.

Table 19. Mean number of borers per plant (± SE) according to species and infested plants (%) at the reproductive stage of maize in four agroecological zones during the first and second rainy seasons in 2004

AEZ	Total borers	*C. partellus*	*B. fusca*	*S. calamistis*	% infested plants
First rains 2004					
Eastern	0.19 ± 0.01 b	0.12 ± 0.01	0.06± 0.01 b	0.00	29.9 ± 2.7 a
South eastern	0.45 ± 0.01 a	0.14 ± 0.01	0.30± 0.01 a	0.01 ± 0.00	31.2 ± 2.9 a
df	1, 1797	1, 1797	1, 1797	1, 1797	1, 40
F-value	42.33	0	67.77	0.86	0.15
P-value	0.0001	0.9617	0.0001	0.3527	0.6982
Second rains 2004					
Eastern	0.53 ± 0.02 a	0.42± 0.02 a	0.09± 0.01 c	0.00	30.4 ± 5.0 a
L. Albert Crescent	0.26 ± 0.01 b	0.08± 0.01 bc	0.18 ± 0.01 ab	0.00	20.5 ± 4.0 ab
L. Victoria Crescent	0.33 ± 0.01 b	0.05± 0.01 c	0.26± 0.01 a	0.00	17.8 ± 3.7 b
South eastern	0.27 ± 0.01 b	0.10 ± 0.01 b	0.16 ± 0.01 b	0.00	16.4 ± 2.2 b
df	3, 4715	3, 4715	3, 4715	3, 4715	3, 70
F-value	42.11	117.26	10.50	1.21	2.97
P-value	0.0001	0.0001	0.0001	0.3031	0.0377

For each season, means within a column followed by the same letter are not significantly different at $P \leq 0.05$ (Student-Newman-Keul's test).

Table 20. Mean percentage parasitism of *Chilo partellus* and *Busseola fusca* by *Cotesia flavipes* and *C. sesamiae* across agroecological zones (AEZs) during 2004

	Chilo partellus		*Busseola fusca*	
AEZs	*C. flavipes*	*C. sesamiae*	*C. flavipes*	*C. sesamiae*
First rains 2004				
Eastern	5.4 ± 2.9 a	0.0 ± 0.0 a	0.0 ± 0.0 a	16.7 ± 16.7 a
South eastern	8.2 ± 5.4 a	1.7 ± 1.7 a	12.0 ± 5.4 a	5.1 ± 2.2 a
df	1, 30	1, 30	1, 28	1,28
F-value	1.02	0.59	0.28	0.97
P-value	0.8823	0.4366	0.6192	0.3324
Second rains 2004				
Eastern	30.5 ± 4.1 a	4.1 ± 2.7 a	3.3 ± 3.3 a	29.4 ± 13.3 a
South eastern	5.2 ± 3.8 b	1.2 ± 1.2 a	0.0 ± 0.0 a	4.4 ± 3.1 b
L. Albert Crescent	0.0 ± 0.0 b	0.0 ± 0.0 a	5.0 ± 3.3 a	7.5 ± 5.3 b
L. Victoria Crescent	0.9 ± 0.9 b	7.3 ± 5.6 a	1.3 ± 0.9 a	2.2 ± 1.1 b
df	3, 39	3, 39	3, 46	3, 46
F-value	18.26	0.92	1.82	4.84
P-value	0.0001	0.4379	0.1576	0.0052

For each season, means within a column followed by the same letter are not significantly different at $P \leq 0.05$ (Student-Newman-Keul's test).

29. Stemborer abundance and diversity on selected grasses

The objective of this study was to assess the infestation levels and diversity of lepidopteran stemborers and their parasitoids on four selected wild grasses. Surveys were conducted in four agroecological zones during the dry season of 2004 (Jan–Feb) and wet season of 2005 (May–August). The grass species included *Panicum maximum* Jacq., *Pennisetum purpureum* Schumach., *Pennisetum polystachion* (L.) Schult. and *Sorghum arundinaceum* (Desv.) Stapf. The selection of grasses was based on a preliminary survey of wild grasses in 2003 and work by Ingram in 1958 who indicated that these grasses were major refuges for stemborers near cultivation. Stemborer incidence was low ranging between 0.3 and 10.8% with highest infestation levels on *S. arundinaceum*. Larval density was lower (0–0.07 borers/ tiller) compared to the densities in cultivated cereals. Among the 13 species identified, 8 were noctuids, 2 crambids, 1 pyralid, 1 plagitanid and unidentified cossids (Table 21). The noctuids represented 64.3% of the total number of larvae collected followed by crambids with 35.3%. The economically important crambid *Chilo partellus* Swinhoe (Crambidae) and the noctuid *Busseola fusca* Fuller (Noctuidae) were mainly found on *S. arundinaceum* and were rare on the other three grass species. The other grass species were important host plants of stemborers mainly confined to the wild such as *Busseola phaia* Bowden (Noctuidae) and *Manga melanodonta* Fletcher (Noctuidae) on *P. maximum* and *Sesamia penniseti* on *P. purpureum*. *Busseola phaia* was also a species on *P. purpureum*. The braconid larval parasitoids *Cotesia* spp. were common on *C. partellus* from *S. arundinaceum* and *Sesamia* spp. from *P. purpureum*. Several other parasitoids were recovered on the different wild grasses (Table 22). It was concluded that in Uganda, with the exception of *S. arundinaceum*, the other three wild grasses play a minor role in the seasonal carry-over of *C. partellus* and *B. fusca*.

Table 21. Stemborer species diversity on four selected grasses during 2004 and 2005 in Uganda

Stemborer species	P. max	P. poly	P. purp	S. arund	AEZs where found
Noctuidae					
Busseola fusca Fuller	+	-	+	+++	En, LAC, LVC, Sen
Busseola phaia Bowden	+++	+	++	++	En, LAC, LVC, Sen
Manga melanodonta Fletcher	+++	-	+	+	En, LAC, LVC, Sen
Peonoma serrata Hampson	-	-	+	-	En
Sesamia calamistis Hampson	++	-	++	+++	En, LAC, LVC, Sen
Sesamia penniseti Tams & Bowden	-	-	+++	-	En, LAC, LVC
Sesamia poephaga Tams & Bowden	++	-	+	-	En, LVC
Sesamia sp.	-	++	+	+	En, LVC
Crambidae					
Chilo partellus Swinhoe	+	+	+	+++	En, LAC, LVC, Sen
Chilo sp.	++	-	-	-	En, LVC
Pyralidae					
Eldana saccharina Walker	-	-	-	+	LVC
Cossidae	-	-	+	-	LAC
Plegatinae	-	-	+	-	En

P. max, Panicum maximum; P. poly, Pennisetum polystachion; P. purp, Pennisetum purpureum and *S. arund, Sorghum arundinaceum.*
-, stemborer species not recorded from a host plant; +, not common; ++ common; +++ , very common on host plant; En, Eastern; LAC, Lake Albert Crescent; LVC, Lake Victoria Crescent; Sen, South eastern.

Table 22. Parasitoid species of stemborers recovered on four wild grasses during 2004 and 2005 in Uganda

Parasitod species	Order: Family	Host plant	Host	Host stage
Cotesia flavipes Cameron	Hym: Braconidae	*S. aru, P. purp*	*Cp, B, S*	Larvae
Cotesia sesamiae Cameron	Hym: Braconidae	*S. aru, P. purp, P. poly, P. max*	*Cp, Bf, B, S*	Larvae
Bracon sp.	Hym: Braconidae	*P. max*	*Manga* sp.	Larvae
Dolichogenidae sp.	Hym: Braconidae	*P. max*	*B*	Larvae
Sturmiopsis parasitica Curran	Diptera: Tachinidae	*P. max*	*Manga* sp.	Larvae
Brachymeria sp.	Hymn: Chalcididae	*S. aru*	*Cp*	Pupae
Pediobius furvus Gahan	Hym: Eulophidae	*S. aru*	*Cp*	Pupae
Dentichasmias busseolae Heinrich	Hym: Ichneumonidae	*S. aru*	*Cp*	Pupae
Grambroides numbipennis Seyrig	Hym: Ichneumonidae	*S. aru*	?	?Pupae
Unknown species	Hymenoptera	*P. max*	*B*	Larvae
Aphanogmus fijiensis Ferrière	Hym: Ceraphronidae	*S. aru*	*Cotesia* spp.	Hyper

Hym, Hymenoptera; S. aru, Sorghum arundinaceum; P. purp, Pennisetum purpuruem; P. poly, Pennisetum polystachion; P. max, Panicum maximum; Cp, Chilo partellus; Bf, Busseola fusca; B, Busseola sp.; S, Sesamia calamistis; Hyper, Hyperparasitoid.

30. Oviposition preference and larval survival of Chilo partellus

The oviposition preference and larval survival of *Chilo partellus* on selected grasses were assessed with the aim of elucidating their role as trap plants or refugia for stemborers. The grass species tested included *Panicum maximum* Jacq., *Pennisetum purpureum* Schumach., *Pennisetum polystachion* (L.) Schult. and *Sorghum arundinaceum* (Desv.) Stapf. Cultivated sorghum was also included in the study being one of the major cereals attacked by *C. partellus*. Two-choice tests were used and one mated female was paired with one male in each test. Maize was compared with one test plant at a time in cages of 0.5 x 1 x 1 m and one pair of moths (female and male) released per cage. To assess larval survival ten (10) first instar larvae were introduced per tiller or plant of the potted plants in the screen house. The experiment was replicated six times. Plants were dissected at 7, 14, 21, 28, 35, 42 and 49 days after infestation (DAI) to determine the number of larvae surviving and to record their weights. Results showed that the number of eggs laid per *C. partellus* female did not significantly vary between maize and each of the host plants tested in the two-choice tests (Figure 5). However, larval survival varied across host plants. Among the wild grasses tested *S. arundinaceum* had the highest number of larvae surviving and was significantly different from that on maize except at 28 and 49 DAI (Figure 6). *Panicum maximum, P. purpureum* and *P. polystachion* had significantly lower number of larvae surviving compared to the other test plants at all sampling dates after infestation. These results concur with the field observations where few *C. partellus* were recovered on these three wild grasses and *S. arundinaceum* was found to be the major wild host plant of *Chilo partellus*.

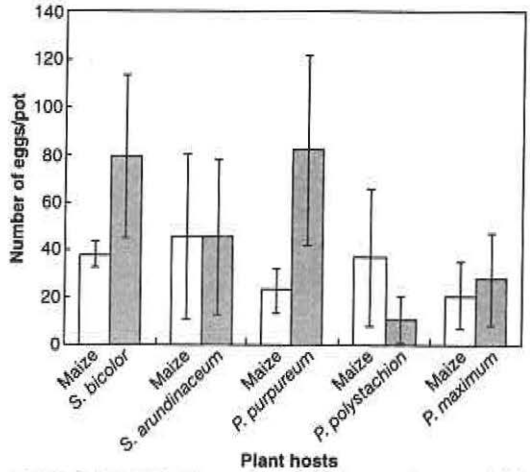


Figure 5. Mean (± SE) number of *Chilo partellus* eggs laid per female on maize, *Sorghum bicolor* and four selected wild grasses (Wilcoxon test)

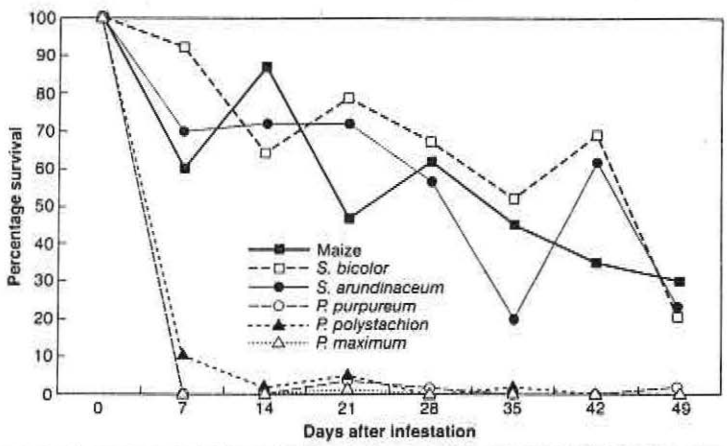


Figure 6. Survival of *Chilo partellus* larvae on maize, *Sorghum bicolor* and four selected wild grasses

Zambia

Participating scientists: *A. Sumani, P. Nkunika*

Donor: *DGIS, The Netheralnds*

Collaborators: *Mount Makulu Research Station, University of Zambia*

31. Habitat management

The objective of the study was to demonstrate the effect of intercropping sorghum and beans on the stemborer damage and yield of maize (see Table 23).

- The treatments were: Maize pure stand (variety PANNAR 406); sorghum pure stand (variety 'Kuyuma'), maize surrounded by sorghum (sorghum border), maize surrounded by beans (beans border, variety 'Kabulangeti'), maize/beans/sorghum intercropped.

- Plot size was 7.2 x 6 m (effective sample area 6.2 x 5 m). A RCBD with 4 replications was planted at 3 sites (Mount Makulu planted 2nd week December 2003, Sesheke planted 3rd week January 2004 and Luangwa planted 4th week January 2004). All agronomic practices pertaining to the growing of maize were followed.
- Data collected at harvest were: plant height, stem diameter, number of holes, tunnel length, cob weight, stemborer species and parasitoids recovered. Data was subjected to ANOVA using JMP and mean separation using Tukey-Kramer HSD. Differences between treatments were not significant expect for sorghum which had the highest number of holes and cm tunnel bored. As shown by other researchers intercropping maize with sorghum does not reduce borer infestations on either crop.

Table 23. Plant growth and damage variables in mixed cropped maize

Treatments	Stem diameter (cm)	Number of internodes	Number of holes	Tunnel length (cm)	Cob weight (g)
Maize	14.7 ± 2.1 a	15.5 ± 1.86 a	0.04 ± 0.25 a	0.08 ± 0.50	115.9 ± 49.3 a
Maize/sorghum	15.0 ± 2.2 a	11.7 ± 1.56 a	0.14 ± 0.84 a	0.53 ± 1.10 a	121.1 ± 45.1a
Maize/beans	15.1 ± 2.2 a	11.2 ± 1.31 a	0.06 ± 0.46 a	0.09 ± 0.56 a	110.5 ± 50.8 a
Maize/sorghum/beans	15.5 ± 1.8 a	11.1 ± 1.52 a	0.14 ± 0.47 a	0.63 ± 1.97 a	118.1 ± 43.3 a

Means in a column followed by the same letter are not significantly different at $P < 0.05$ (Tukey-test).

32. Establishment of parasitoids

Cotesia flavipes is now established in areas shown in Figure 7. Post-release surveys conducted to determine whether *Xanthopimpla stemmator* has become established have not resulted in any recoveries.

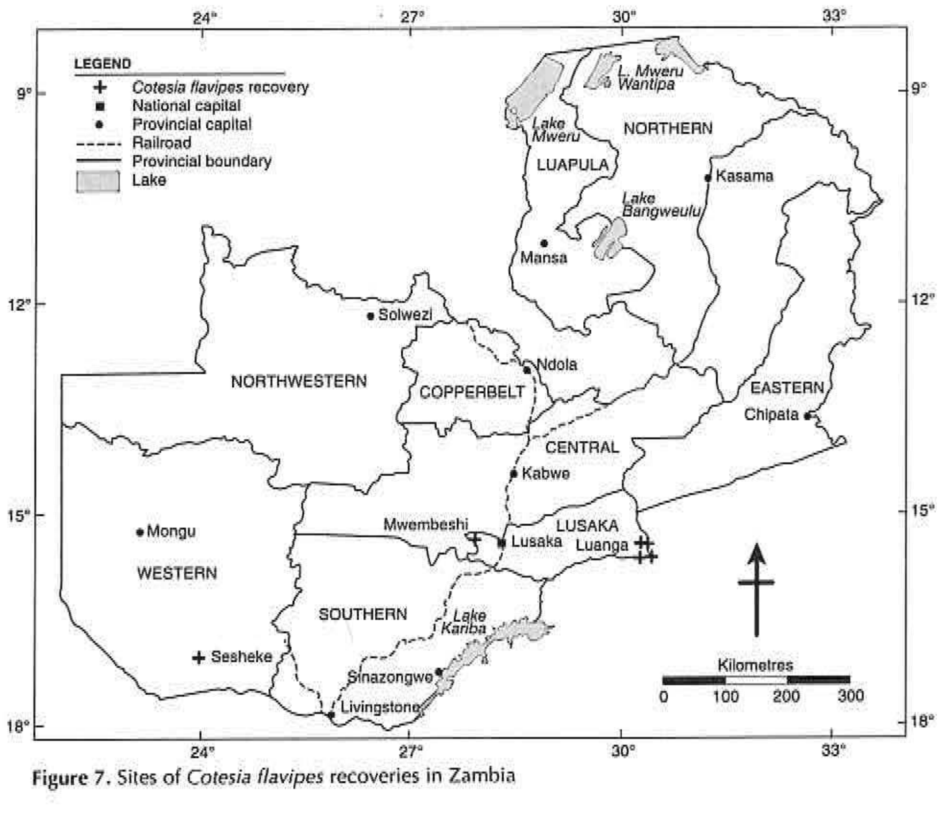


Figure 7. Sites of *Cotesia flavipes* recoveries in Zambia

Zimbabwe

Participating scientists: *P. Chinwada, E. Zitsanga*
Donor: *DGIS, The Netheralnds*
Collaborators: *Plant Protection Research Institute, University of Zimbabwe*

33. Suitability of different stemborer populations for the development of Cotesia flavipes *and an assessment of its establishment in Zimbabwe*

Five populations of *Chilo partellus* (Muzarabani, Sanyati, Musikavanhu, Mamina and Bushu) and one of *B. fusca* (Harare) were tested for their suitability as hosts of *Cotesia flavipes*. Host suitability for the development of *C. flavipes* was assessed by hand-stinging stemborer larvae using naïve 24-hour-old mated female parasitoids. The percentage of stung larvae that produced cocoons, parasitoid developmental time, % adult emergence, brood size and sex ratio, number of parasitoid larvae that exited the host but failed to pupate and the number of parasitoids that died inside cocoons were recorded. For the five *C. partellus* populations, each data set was analysed as a completely randomised design (CRD) with five treatments (borer populations) and four replications. Data on percentages and counts were arcsine- and log (x + 1)-transformed, respectively, before being subjected to ANOVA (Proc GLM, SAS Institute, 1990) followed by the Student-Newman-Keul's (SNK) multiple range test when the F-ratio was significant ($P < 0.05$).

Successful parasitoid development occurred only on *C. partellus* but there were no significant differences ($F = 0.53$, df = 4,15, $P = 0.7151$) in parasitism levels among the five populations. There was complete failure of parasitoid development on *Busseola fusca* due to egg encapsulation. Significantly less parasitoid adult progeny [13.0 adults and 85.4% emergence) were produced on Muzarabani *C. partellus* compared to the Sanyati, Musikavanhu, Mamina and Bushu populations ($P < 0.05$)]. Similarly, the proportion of adult female parasitoids produced on Muzarabani *C. partellus* was lowest (13.5%) compared to the other four populations where females comprised 74.0–77.7% of the adults in each brood.

The egg-larval period of *C. flavipes* was significantly shorter ($F = 3.64$, df = 4,265, $P = 0.0066$) on Muzarabani *C. partellus* than on any of the other four populations. On Sanyati, Musikavanhu, Mamina and Bushu *C. partellus*, egg-larval development was completed in 12.2–12.4 days while on the Muzarabani population, the parasitoid took 11.7 days to emerge from host larvae. A similar result was obtained with pupal periods but in this case, development on Muzarabani *C. partellus* (6.4 days) was significantly longer ($F = 2.70$, df = 4,260, $P = 0.0314$) than on the other four populations (5.9–6.1 days). However, total egg–adult development did not differ among the five populations, ranging from 18.1 to 18.5 days.

34. Field releases of Cotesia flavipes

Unlike pre-2002 releases in which *Cotesia flavipes* was liberated either in cocoon form or as mated adults in cocoon form, in the 2004–2005 season we also experimented with an indirect parasitoid release method through the deliberate infestation of plants using pre-stung *C. partellus* larvae. This technique was tried out at Sanyati, Coburn and Mamina (Table 24). It was felt that

Table 24. *Cotesia flavipes* release locations in Zimbabwe for 2004 and 2005 and approximate number of parasitoids liberated per location

	Approximate number of parasitoid individuals released		
Location	As adults	As cocoons	As pre-stung host larvae
Lowveld (< 600 m)			
Chisumbanje	40,000 (July 2004)	-	-
Middleveld (600–1200 m)			
Bushu	40,000 (Jul 2004) 20,000 (Aug 2004)	- -	- -
Sanyati	10,000 (Dec 2004) -	- -	103 (Dec 2004) 82 (Feb 2005)
Highveld (> 1200 m)			
Coburn Estate	-	-	25 (Feb 2005)
Mamina	1000 (Apr 2005)	20,000 (Apr 2005)	15 (Feb 2005)

Table 25. Percentage stemborer (*Chilo partellus*, *Sesamia calamistis* and *Busseola fusca*) larval parasitism[1] recorded in 2004 and 2005 at different *Cotesia flavipes* release locations

Location	Date of first release	Sampling date	Borer sp.	N	*Cotesia sesamiae*	*Cotesia flavipes*	*Cotesia* sp.
Bushu	1.03.2001	5.02.2004	*C. partellus*	1321	0.1 (1)	3.5 (33)	-
		30.07.2004	*C. partellus*	32	0.0	0.0	-
			S. calamistis	10	0.0	0.0	-
		2.09.2004	*C. partellus*	60	0.0	0.0	-
			S. calamistis	2	0.0	0.0	-
		13.01.2005	*C. partellus*	484	0.0	23.2 (59)	-
			B. fusca	6	0.0	0.0	-
		16.05.2005	*C. partellus*	236	2.7 (3)	?	7.1 (8)
			S. calamistis	4	0.0	0.0	-
Musikavanhu	22.07.1999	4.03.2004	*C. partellus*	670	0.2 (1)	1.8 (9)	-
			S. calamistis	3	0.0	0.0	-
		15.12.2004	*C. partellus*	152	0.0	0.0	-
			B. fusca	5	0.0	0.0	-
			S. calamistis	1	0.0	0.0	-
		10.02.2005	*C. partellus*	853	0.2 (1)	23.1 (107)	-
Muzarabani	3.03.2000	20.02.2004	*C. partellus*	1000	0.0	0.0	-
		27.01.2005	*C. partellus*	284	0.0	3.0 (4)	-
Chisumbanje	23.07.2004	23.07.2004[2]	*C. partellus*	48	0.0	7.5 (3)	-
			S. calamistis	6	0.0	0.0	-
Sanyati	13.12.2004	27.03.2004	*C. partellus*	26	7.7 (2)	-	-
		13.12.2004[2]	*C. partellus*	647	0.0	-	-
			S. calamistis	8	0.0	-	-
		8.02.2005	*C. partellus*	72	8.3 (6)	4.2 (3)	-
		18.05.2005	*C. partellus*	321	0.0	0.0	-
Mamina	9.02.2005	10.12.2004[2]	*C. partellus*	289	2.2 (5)	-	-
			B. fusca	230	0.0	-	-
			S. calamistis	5	0.0	-	-
		9.02.2005[2]	*C. partellus*	96	1.0 (1)	-	-
			B. fusca	68	0.0	0.09	-
		8.04.2005	*C. partellus*	133	30.8 (24)	2.6 (2)	-
			B. fusca	95	21.7 (10)	0.0	-
			S. calamistis	11	0.0	0.0	-

[1]Only medium and large-sized larvae were used in determining % parasitism (number of parasitised larvae in parentheses).
[2]Pre-*C. flavipes* release surveys.

releasing *C. flavipes* through pre-stung method was most effective as one would be assured of initial habitat colonisation as inimical biotic and abiotic factors may kill parasitoids before finding a host.

35. Surveys to determine Cotesia flavipes *establishment*

To date, successful *Cotesia flavipes* establishment in Zimbabwe has been confirmed at Bushu, Musikavanhu, Muzarabani and Chisumbanje (Table 25). Of the four locations, Chisumbanje is the only one at which parasitoid recoveries were made before actual releases had been conducted. Recoveries at Chisumbanje may be due to spread from Musikavanhu (approximately 60 km) where releases were made in July 1999. At Bushu, confirmation of successful *C. flavipes* establishment was first made on 5 February 2004 when cocoons were recovered from 33 *C. partellus* larvae (3.5% parasitism). By 13 January 2005, *C. flavipes* parasitism at Bushu had risen to 23.2% (59 larvae parasitised). At Musikavanhu, successful *C. flavipes* establishment was first confirmed on 4 March 2004 when cocoons were recovered from 9 *C. partellus* larvae (1.8% parasitism). A huge jump in parasitism was recorded the following year on 10 February 2005 when cocoons were recovered from 107 *C. partellus* larvae (23.1% parasitism). At Muzarabani, none of the *C. partellus* larvae sampled in 2004 were parasitised but on 27 January 2005, *C. flavipes* cocoons were recovered from 4 larvae. At Sanyati and Mamina, *C. flavipes* releases were first conducted on 13 December 2004 and 9 February 2005, respectively. In post-release surveys conducted during the same season, *C. flavipes* parasitism was 4.2% at Sanyati (8 February 2005) and 2.6% (8 April 2005) at Mamina.

36. Releases and post-release surveys of Xanthopimpla stemmator

To date, *Xanthopimpla stemmator* has been released at only three sites in Zimbabwe. However, no recoveries of the parasitoid have yet been recorded.

Participating scientists: *F. Schulthess, C. O. Omwega, A. J. Ngi-Song, N. Jiang, R. Ndemah*

Assisted by: *C. Sequeira, E. Muchugu, I. N. Mungai, H. Mwadime, C. Akal, G. Okuku, J. Ochieng, P. Owuor, A. Wanyonyi, C. Kamonjo*

Students: *M. Obonyo (Msc), B. Muli (Msc), C. Gitau (PhD), Y. Bruce (PhD), A. Kipkoech (PhD), T. K. Matama (PhD), D. Cugala (PhD), M. Wale (PhD), S. Gounou (PhD)*

Donors: *Directorate General for International Cooperation, The Netherlands; BMZ, Germany; Kirkhouse Trust, UK*

Collaborators: *IITA, ICRISAT, IRD, NARS/Universities in Kenya, Uganda, Ethiopia, Eritrea, Zambia, Zimbabwe, Malawi, Mozambique and Tanzania-Zanzibar and Mainland; Linnet Gohole, W. K. Yabann (Moi University); Fred Wamunyokoli, Rosabella Maranga, Hellen Kutima (Jomo Kenyatta University of Agriculture and Technology); J. Mbuthi, J. Mueke (Kenyatta University); Stephane Dupas (IRD France)*

Collaborating department: *Molecular Biology and Biotechnology Department*

Collaborating unit: *Arthropod Pathology Unit*

37. *Interspecific competition between* Xanthopimpla stemmator *Thunberg and* Dentichasmias busseolae *Heinrich (Hymenoptera: Ichneumonidae), pupal parasitoids of* Chilo partellus *(Lepidoptera: Crambidae)*

The main objective of this MSc study was to investigate the impact of *Xanthpimpla stemmator* on the efficiency of indigenous pupal parasitoid, *Dentichasmias busseolae*. The specific objectives were to: (1) determine whether females of *X. stemmator* and *D. busseolae* would discriminate between *Chilo partellus* pupae parasitised by the other species and those that are unparasitised, (2) investigate the effect of multiparasitism on *X. stemmator* and on *D. busseolae*, and (3) determine the host searching efficiency of *X. stemmator* and *D. busseolae* female parasitoids on different parts of the maize plant. This report is on the third objective: To determine the host searching efficiency of *X. stemmator* and *D. busseolae* female parasitoids on different parts of the maize plant. The results indicated that the part of maize plant used had no significant effect on the time taken by *D. busseolae* to search for the host (Table 26). Similarly, time taken by *X. stemmator* to search for a host in different parts of the maize plant did not differ significantly. However, while *D. busseolae* successfully searched for and parasitised pupae in stems and cobs, parasitism of pupae in cobs by *X. stemmator* was negligible (Figure 8). Consequently, despite the fact that studies on host discrimination and multiparasitism indicated that both species do not discriminate between parasitised and unparasitised hosts, and that *X. stemmator* was competitively superior to *D. busseolae* when time interval between ovipositions was short, it was concluded that the two species could co-exist because they partly exploit different ecological niches.

Table 26. Mean (± SE) foraging time (sec.), time to open exit window (sec.), and time spent inside pupal chamber (sec.) for *Dentichasmias busseolae* parasitising *Chilo partellus* pupae in different parts of a maize plant

	n	Stem	n	Cob	df	t-value	P
Foraging time	30	131.23 ± 20.74	30	117.40 ± 18.83	58	1.03	0.3057
Time opening exit window	30	257.33 ± 56.60	30	120.77 ±35.20	49	1.27	0.2097
Time inside pupal chamber	30	94.37 ± 22.98	30	229.87 ±65.28	58	2.25	0.02097

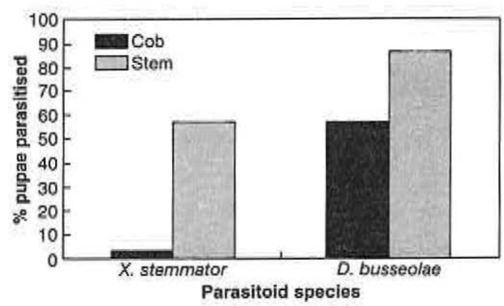


Figure 8. Percent pupae successfully parasitised by *Xanthopimpla stemmator* and *Dentichasmias busseolae* in different organs of the maize plant (n = 30)

38. *Host suitability and interspecific competition of the West African stemborer egg parasitoid* Telenomus isis *Polaszek (Hymenoptera: Scelionidae) in Kenya*

In East and Southern Africa (ESA), the noctuid stemborer *Busseola fusca* (Fuller) and the exotic crambid *Chilo partellus* (Swinhoe) are the most important lepidopteran pests of cereal crops. In western Africa, the scelionid egg parasitoids *Telenomus busseolae* Gahan and *Telenomus isis* Polaszek are the most important biological control agents of noctuid stemborers such as *Sesamia calamistis* Hampson and *B. fusca* while in eastern Africa, egg parasitism is low by comparison. In 1997, International Centre of Insect Physiology and Ecology (*icipe*), jointly with the International Institute of Tropical Agriculture (IITA), initiated a study on control of *B. fusca* in East and Southern Africa. In 2003, the West African species *T. isis* was imported and introduced into the *icipe* quarantine facility for target and non-target species studies. Pre-release suitability studies indicate that West African *T. isis* would establish and could have an impact on stemborer populations in Kenya (Tables 27 and 28). Results showed that *T. isis* would not affect the efficiency of the locally occurring strain of *T. busseolae* and other indigenous parasitoid species of noctuid eggs if released in eastern Africa.

Table 27. Suitability (mean ± SE) of three East African stemborer species in four host ages for *Telenomus isis*

	Species		
	Busseolae fusca	*Sesamia calamistis*	*Sesamia nonagrioides*
% Parasitism			
Age 1	66.7 ± 5.4	63.3 ±5.2	70.7 ± 4.7 a
Age 2	61.8 ± 3.9	61.0 ±6.7	47.3 ± 5.6 b
Age 3	51.1 ± 4.0	55.1 ±8.4	56.7 ± 4.0 b
Age 4	53.3 ± 4.3	54.9 ±4.3	40.9 ± 6.7 b
% Emergence			
Age 1	86.1 ± 4.8 aA	61.9 ±6.4 B	87.1 ± 5.0 aA
Age 2	80.3 ± 4.5 abAB	72.9 ±6.4 A	86.9 ± 1.7 aB
Age 3	76.4 ± 4.5 bA	82.8 ±6.4	62.9 ± 7.4 b
Age 4	71.3 ± 5.9 bA	73.9 ±6.5 a	49.5 ± 9.0 bB
Sex ratio			
Age 1	0.8 ± 0.1	0.7 ±0.1	0.7 ± 0.1
Age 2	0.7 ± 0.1	0.6 ±0.1	0.7 ± 0.1
Age 3	0.7 ± 0.1	0.6 ±0.1	0.7 ± 0.1
Age 4	0.8 ± 0.1	0.7 ±0.1	0.8 ± 0.1
Developmental time (days)			
Age 1	21.1 ± 0.1 A	21.3 ±0.5 aA	18.0 ± 0.3 aB
Age 2	20.3 ± 0.4 A	19.3 ±0.3 abAB	18.0 ± 0.4 bB
Age 3	20.7 ± 0.3	19.8 ±0.3 b	19.0 ± 0.2 c
Age 4	20.8 ± 0.2 A	19.2 ±0.3 bB	22.0 ± 0.2 cC

Means within a row followed by different capital letters and means within a column followed by different lower case letters are significantly different (Student-Newman-Keuls test; $P < 0.05$).

Table 28. Developmental time, parasitism level, total offspring per female, sex ratio (mean ± SE) for *Telenomus isis* at different temperatures and two relative humidity regimes on *Sesamia calamistis*

	Relative humidity	Temperatures (°C)				
		18	21	24	27	30
Developmental time (days)	40–50%	56.0 ± 0.2 A	30.5 ± 0.8 B	24.0 ± 0.4 C	22.0 ± 0.8 aC	15.3 ± 0.1 D
	70–80%	54.0 ± 0.1 A	27.0 ± 0.6 B	23.7 ± 0.6 B	18.2 ± 0.3 bC	15.2 ± 0.2 D
Parasitism (%)	40–50%	16.0 ± 0.3	27.0 ± 0.3	29.0 ± 1.0 a	35.2 ± 0.6 a	22.2 ± 0.9
	70–80%	18.0 ± 0.2 A	27.0 ± 0.1 A	76.0 ± 8.7 bB	48.8 ± 5.8 bB	21.6 ± 0.6 A
Total offspring	40–50%	10.9 ± 0.2	25.0 ± 0.1	29.8 ± 0.5 a	22.8 ± 0.3 a	10.5 ± 0.6
	70–80%	15.0 ± 0.2 A	23.0 ± 0.1 A	60.8 ± 5.5 bB	33.0 ± 5.7 bB	15.1 ± 0.9 A
Sex ratio (%)	40–50%	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	0.6 ± 0.1	0.8 ± 0.1
	70–80%	0.7 ± 0.1	0.6 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.7 ± 0.1

Means within a row followed by different capital letters and means within a column followed by different lower case letters are significantly different (Student-Newman-Keuls test; $P < 0.05$).

39. *Multiparasitism by the pupal parasitoids,* Xanthopimpla stemmator *(Hymenoptera: Ichneumonidae) and* Pediobius furvus *(Hymenoptera: Eulophidae) on African cereal stemborer* Chilo partellus *(Lepidoptera: Crambidae) and* Busseola fusca *(Lepidoptera: Noctuidae)*

The outcome of multiparasitism by two pupal parasitoids, the exotic solitary ichneumonid *Xanthopimpla stemmator* and the indigenous gregarious eulophid *Pediobius furvus* was studied using the invasive crambid stemborer *Chilo partellus* and the indigenous noctuid *Busseola fusca* as hosts. Two parasitism sequences were chosen where *X. stemmator* oviposited before *P. furvus* ('Xs-Pf') and vice versa ('Pf-Xs'). In addition, the effect of time between first and second parasitism on parasitoid emergence, development, sex ratio as the proportion of females, and number of offspring (i.e., 0, 3, 24 and 28 hours) was assessed.

When parasitised by both species, the percentage of pupae producing only *X. stemmator* ranged between 50–100% and 68.4–95.0% with, respectively, *C. partellus* and *B. fusca* as the host, versus 100 and 75%, respectively, when *X. stemmator* parasitised alone. For *P. furvus* the figures were 0–5% and 0–17.6%, respectively, with *C. partellus* and *B. fusca*, and 55 and 40%, respectively, when parasitising alone. Within an oviposition sequence, *X. stemmator* emergence was not affected by time interval between ovipositions, but at 24 and 48 hours with *C. partellus* as the host, it was considerably higher in the Xs-Pf than Pf-Xs sequence, while with *B. fusca* the sequence had no effect. For *P. furvus* emergence, neither the sequence nor time interval had an effect and many treatments did not yield any emergence. Only six out of 16 treatments produced both parasitoids (0 and 3 hours with *C. partellus* as the host, and 0 and 48 hours with *B. fusca*) and the percentage of pupae producing both species was higher with *C. partellus* than *B. fusca* as the host.

In the 'Pf-Xs' sequence, the sex ratio of *X. stemmator* was positively related with the host pupa weight indicating that a higher proportion of fertilised eggs were laid in larger hosts. Developmental time of *X. stemmator* was positively correlated with time interval between parasitism and negatively related with sex ratio; thus, developmental time was longer for males and females. Sex ratio of *P. furvus* was negatively related to pupal weight probably because of a higher number of progeny in larger pupae. In spite of its considerably smaller size, *C. partellus* tended to be the superior host for *X. stemmator* but not so for *P. furvus*.

In general, *X. stemmator* outcompeted *P. furvus* irrespective of if it parasitised first or second, time interval between parasitism and host species. Further studies and especially on host finding capacity of the two parasitoid species are required to determine the competitiveness of the two species under field conditions.

40. *Location of stemborer pupae in various host plants and implications for the performance of natural enemies with emphasis on the pupal parasitoid* Xanthopimpla stemmator *(Hymenoptera: Ichneumonidae)*

To predict host accessibility by the pupal parasitoid *Xanthopimpla stemmator*, four grass species (*Sorghum bicolor, Pennisetum purpureum, Sorghum versicolor* and *Zea mays*) were sampled for stemborer pupae in Kwale, in the low altitudes of southern Kenya, and in Trans-Nzoia, in the high altitudes of western Kenya. The pupal position of *Chilo orichalcociliellus* (Strand), *Chilo partellus* (Swinhoe), *Sesamia calamistis* (Hampson), *Sesamia oriaula* (Tams and Bowden) and *Busseola fusca* (Fuller) in the plant were determined in relation to: (a) distance of pupae from edge of stem (depth), (b) distance between the moth-exit hole and head of the pupa (location) and (c) length of tunnel from moth-exit hole to the base of the tunnel. Pupal depth for *C. partellus* and pupal location for *C. partellus* and *B. fusca* varied significantly in the different plant species tested, and pupae tended to be embedded deeper in cultivated than wild hosts (Table 29). On all host species, the borers were located at a depth less than 0.35 cm. Most *C. orichalcociliellus* and *S. calamistis* pupae were found pupating in ears of maize or upper part of the wild host stem. *Sesamia oriaula* was only collected from lower plant parts and only in *P. purpureum*. For *B.*

fusca, tunnel length varied significantly between plant species and was longer in cultivated hosts. *Xanthopimpla stemmator* has an ovipositor length of about 0.52 cm thus it is anticipated that the parasitoid could easily reach and parasitise pupae in these host species.

Table 29. Depth (a) and location (b) of pupa, and tunnel length (c) (± SE) of several stemborer species in wild and cultivated host plants

Borer species	Region	*Zea mays*	*Sorghum bicolor*	*S. versicolor*	*F*-value	df	*P*-value
(a) *Chilo partellus*	Kwale	0.24 ± 0.01 a	0.20 ± 0.01 b	0.19 ± 0.01 b	4.59	3.528	0.004
C. orichalcociliellus	Kwale	0.20 ± 0.03	0.16 ± 0.01	pa	1.11	1.40	0.29
Sesamia calamistis	Kwale	0.20 ± 0.03	0.20 ± 0.01	pa	0.04	1.34	0.85
F-value		0.46	0.09				
df		2,337	2,241				
P-value		0.63	0.91				
B. fusca	Trans-Nzoia	0.29 ± 0.2	0.27 ± 0.05	ha	0.45	1.39	0.51
(b) *C. partellus*	Kwale	0.90 ± 0.06 aB	0.70 ± 0.1 b	0.70± 0.04 b	4.33	3.528	0.005
C. orichalcociliellus	Kwale	1.70 ± 0.2 A	1.20 ± 0.2	pa	0.93	1.40	0.340
S. calamistis	Kwale	1.30 ± 0.2 A	2.0 ± 0.0	pa	1.14	1.34	0.292
F-value		9.19	3.50				
df		2,337	2,241				
P-value		0.0001	0.0619				
B. fusca	Trans-Nzoia	1.6 ± 0.1	2.0 ± 0.2	ha	6.71	2.141	0.002
(c) *C. partellus*	Kwale	4.10 ± 0.1 B	4.10 ± 0.1 B	4.30± 0.3	1.11	3.528	0.346
C. orichalcociliellus	Kwale	5.70 ± 0.4 A	4.90 ± 0.7 A	pa	0.49	1.40	0.489
S. calamistis	Kwale	4.20 ± 0.3 B	4.80 ± 0.0 A	pa	0.40	1.34	0.531
F-value		7.24	1.19				
df		2,337	2,241				
P-value		0.0008	0.0351				
B. fusca	Trans-Nzoia	5.60 ± 0.2 b	7.60 ± 0.6 a	ha	8.74	2.141	0.003

Means in the same row followed by the same lower case letter(s) are not significantly different. Means in the same column followed by the same upper case letter(s) are not significantly different (Bonferroni comparison test, $P < 0.05$). pa, pupa absent; ha, host plant absent in the region.

41. *Biological control of cereal stemborers in Kenya: A cost–benefit approach*

Lepidopteran stemborers are the key pests of maize in sub-Saharan Africa. In the lowland tropics, dry mid-altitude, dry transitional and the moist mid-altitude zones of Kenya, the invasive crambid *Chilo partellus* causes up to 73% yield loss. The *icipe* started a biological control (BC) programme in 1991 to control stemborers in subsistence agriculture in Africa with emphasis on classical BC of *C. partellus*. The project released the braconid larval parasitoid *Cotesia flavipes* in 1993 in coastal Kenya, where it got established and spread to other regions. This study assesses the economic impact of the introduced parasitoid (Figure 9). Temporal data on percentage parasitism by the introduced parasitoid and on stemborer density were collected between 1995 and 2004. Socio-economic data was collected through administration of questionnaires to 300 farmers. Economic impact of the project was calculated as the value of the yield loss abated by the parasitoid based on a model of expected stemborer density and parasitism level. Average annual parasitism increased linearly from the time of introduction to reach 20% parasitism by 2004. The net reduction in total stemborer density over the last 10 years was 33.7%, thus abating 47.3% of yield loss. The region will accumulate a net present value of US$ 183 million in economic benefits in 20 years since release of the parasitoid. The benefit–cost ratio was estimated at 19:1 when farm gate prices were used, with an internal rate of return of 41%, indicating a high return to investment. Introduction of other parasitoid species targeting the egg and pupal stages of the stemborer life cycle stages would be required for biological control to push yield loss by stemborers to an insignificant level.

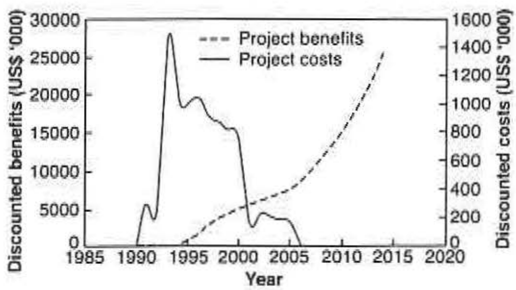


Figure 9. Benefits and costs of the introduction of *Cotesia flavipes* for the control of *Chilo partellus* in Kenya

42. *Stemborer abundance and egg parasitism in Kenya*

Field studies were carried out in 5 sites: Taveta, Kiboko, Mbita (mid altitude area); Eldoret-Kitale transect and Wundanyi (highland altitude areas). Apart from Eldoret and Mbita where the surveys were carried out on a weekly basis for 3 months, other fields were visited once during the short and long rains seasons. During the survey, pre-tasselling maize and sorghum plants were checked and any egg batches recovered were kept in individual vials until the stemborer or parasitoids emergence. In Eldoret and Wundanyi, only *Busseola fusca* eggs were collected, while in Mbita both *B. fusca* and *Sesamia calamistis* eggs were found with *B. fusca* as the dominant species. In Taveta and Kiboko, only *S. calamistis* eggs were recorded. The field results show that there is a high variation in the number of egg batches and number of eggs per batch among the sites surveyed. Most of the infested plants had single egg masses with batch size fluctuating from 22 to 46 among the localities. Egg parasitism varied between 2 and 50% (Table 30). The egg parasitoid species recovered are *Telenomus busseolae, T. thestor, T. bini, Trichogramma bournieri, Trichogramma* nr *lutea, Trichogrammatoidea* sp. and *Trichogramma* sp.

Table 30. Means ± SE of number of maize and sorghum plants, number of batches per field, number of batches per 100 plants, number of eggs per batch, percentage of egg parasitism from five geographic locations in Kenya

	Eldoret	Wundanyi	Taveta	Mbita	Kiboko
No. of plant	962.4 ± 21.9	1150.0 ± 127.5	1114.3 ± 185.7	229.2 ± 30.7	2125.0 ± 61.5
No. of batches/field	17.4 ± 3.8	18.5 ± 3.5	8.0 ± 3.06	1.0 ± 0.3	0.4 ± 0.0
No. of batches/100 plants	10.0 ± 0.2	15.0 ± 0.2	10.0 ± 0.7	0.7 ± 0.0	9.4 ± 1.1
No. of eggs/batch	46.5 ± 1.0	31.8 ± 1.0	22.7 ± 1.0	46.7 ± 4.0	22.8 ± 1.5
Egg parasitism (%)	4.2 ± 0.5	32.4 ± 1.9	49.2 ± 3.2	2.2 ± 1.3	45.9 ± 6.4

43. *Studies on the host range of West African races of* Sturmiopsis parasitica *and the outcome of interspecific competition with* Cotesia sesamiae

The stemborer *Busseola fusca* is a major cereal pest in the East African region while in West Africa it is of minor importance. One of the most common parasitoid species of stemborers in West Africa is the tachinid *Sturmiopsis parasitica*. High parasitism rates were found on *Sesamia calamistis* and *Eldana saccharina*. By contrast, the Zimbabwe race of the tachinid *Sturmiopsis parasitica*, while successfully parasitising the diapausing borer species of *Busseola fusca*, is encapsulated in the non-diapausing *S. calamistis* and *E. saccharina*. Thus, parasitoid populations crash to close to zero during the dry season, when *B. fusca* larvae are in diapause.

In the present study, the host range of West African races of *S. parasitica* and the outcome of interspecific competition with *Cotesia sesamiae* with a view to releasing it against *B. fusca* in Kenya and Cameroon was assessed. Preliminary results showed the parasitoid successfully parasitised the main borer species occurring in East and Southern Africa. Using one planidial egg per borer larva, the rates were 45, 23, 16 and 11% for *S. calamistis, E. saccharina, C. partellus* and *B. fusca* respectively, successfully parasitised by the West African race of *S. parasitica*. Host discrimination and interspecific competition studies are ongoing.

44. *Geographic variation in host acceptance and suitability of* Cotesia sesamiae *Cameron for* Busseola fusca *Fuller in Kenya*

In Kenya, the endoparasitoid *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae) exists as two biotypes that differ in their ability to parasitise the stemborer *Busseola fusca* (Lepidoptera: Noctuidae). *Cotesia sesamiae* from western Kenya completes development in *B. fusca* larvae, hence it is virulent. The coastal *C. sesamiae* biotype does not complete development and eggs that are oviposited get encapsulated in *B. fusca* larvae, and therefore it is avirulent. It is not yet known if intermediate *C. sesamiae* populations exist between western and coastal Kenya. On the other hand, several *B. fusca* biotypes have been described recently and it is not clearly understood whether this host also contributes to variation in *C. sesamiae* parasitism.

The objective of this study was to examine *B. fusca* acceptance and suitability of different populations of *C. sesamiae*. An interaction matrix involving six *B. fusca* populations and six *C. sesamiae* populations collected from six regions in Kenya were used. These locations were Mombasa, Taita, Kitui, Meru, Kitale and Kisumu. All *C. sesamiae* were reared on hosts from which they were collected in the field. The acceptance study showed that the avirulent *C. sesamiae* populations do not have an innate capability to recognise *B. fusca* while the virulent populations possess this trait. Of the 135 avirulent *C. sesamiae* females tested, 94% avoided ovipositing in *B. fusca* larvae within the first 10 minutes of encounter. More than 80% of the *C. sesamiae* females from eastern and coastal *C. sesamiae* populations (Kitui, Taita, Mombasa) rejected *B. fusca* while the western (Kitale, Meru) *C. sesamiae* females equally accepted *B. fusca* (Figure 10). *Sesamia calamistis* was fairly acceptable (> 70%) to all *C. sesamiae* strains (Figure 10). A matrix of various suitability parameters for six *C. sesamiae* populations on their sympatric and allopatric *B. fusca* populations showed a clear East-West divide in virulence. The western *C. sesamiae* populations all completed development in both the sympatric and allopatric hosts. Egg loads of the avirulent *C. sesamiae* females from Taita and Mombasa were significantly higher than those of the virulent Kitale females (Table 31). Results from this study will act as a guide in the selection of the best *C. sesamiae* strain that will be used for augmentative biological control of stemborers in sub-Saharan Africa.

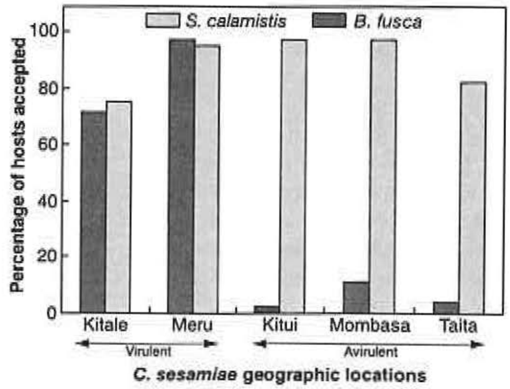


Figure 10. Percentage of *Busseola fusca* and *Sesamia calamistis* that were accepted by two virulent and three avirulent *Cotesia sesamiae* populations in Kenya

Table 31. Mean (± SE) number of eggs in ovaries of *Cotesia sesamiae* females from five geographic locations in Kenya

C. sesamiae location	Taita	Mombasa	Meru	Kitui	Kitale
Mean number of eggs	165 ± 4.3 a (n = 55)	154 ± 4.5 ab (n = 52)	152 ± 4.3 ab (n = 53)	143 ± 3.6 bc (n = 56)	135 ± 3.2 c (n = 55)

Means within the same row followed by the same letter are not significantly different at $P = 0.05$ (Student-Newman-Keul's test). Number of *C. sesamiae* females dissected is shown in parentheses.

45. Geographic variation in the developmental success of Cotesia sesamiae *(Hymenoptera: Braconidae) on* Busseola fusca *Fuller (Lepidoptera: Noctuidae) in Kenya: Coevolutionary dynamics and role of polydnaviruses*

Parasitic microgastrine wasps have polydnaviruses (PDV) in the calyx tissues of their ovaries. The PDV are required for the successful parasitisation of their lepidopteran hosts. On the other hand, parasitoids and their hosts must co-evolve and the genetic interactions in their respective communities must determine which of the two wins the co-evolutionary 'arms race'. In this study, the geographic variations in the successful development of *Cotesia sesamiae* (Cameron) on *Busseola fusca* (Fuller) in Kenya were studied in an interaction matrix using isofemale lines of *C. sesamiae*. The objectives were to establish whether the ability of *C. sesamiae* to parasitise *B. fusca* varies between localities in Kenya and if the origin of variation is due to the host or the parasitoid as well as to analyse the evolutionary factors that may have caused this variation. The polydnavirus *CrV1* gene expressed in *B. fusca* larvae parasitised by avirulent and virulent *C. sesamiae* strains was also examined at the six-hour time point.

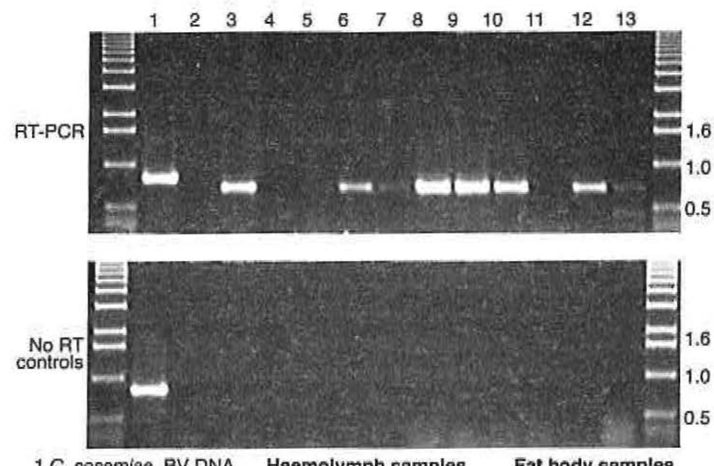
Insects were collected from six geographic locations (from west to coast) of Kenya. These were Kisumu, Kitale, Meru, Kitui, Taita and Mombasa. *Cotesia sesamiae* were reared as isofemale lines for the bioassays.

Cotesia sesamiae from the six geographic locations were allowed to oviposit in *B. fusca* larvae from the sympatric and allopatric locations. Successful development was evident when cocoons formed and unsuccessful development when the parasitised *B. fusca* larvae formed pupae. Results showed a pattern with a clear west-east divide with the three inland western populations (Kitale, Kisumu and Meru) completing development in *B. fusca* and emerged as adults (Table 32). The eastern and coastal populations did not develop on the larvae and eggs oviposited were encapsulated. Analysis on genetic variability and co-evolution showed that *C. sesamiae* has the ability to coevolve more than *B. fusca*. Genetic variation (98%) is explained by the parasitoid locality. Host locality is responsible for 78% of the parasitoids' reproductive success, and 62% by interaction of both. This suggests little potential for co-evolution between the two species, which depends on the species composition. *Cotesia sesamiae* has potential to co-evolve in areas where *B. fusca* is the dominant species.

Table 32. Matrix showing *Cotesia sesamiae* that successfully developed in 6 populations of *Busseola fusca* in Kenya. Figures are percentages of *B. fusca* larvae that were successfully parasitised by *C. sesamiae* from 6 geographic populations. The number of parasitoid isofemale lines tested per interaction, followed by the total number of females used is in parentheses

	C. sesamiae					
B. fusca	Kisumu	Kitale	Meru	Kitui	Taita	Mombasa
Kisumu	100 (1,3)	89 (3,9)	89 (3,9)	0 (1, 3)	0 (2,5)	-
Kitale	-	89 (3,9)	83 (4,12)	0 (2, 6)	0 (1,3)	0 (1,3)
Meru	17 (2,6)	78 (3,9)	50 (4,12)	0 (3, 9)	0 (3,9)	0 (3,9)
Kitui		67 (3,8)	100 (3,9)	0 (2, 6)	0 (2,6)	0 (2,6)
Taita (low)	100 (2,6)	78 (3,9)	75 (4,12)	0 (3, 9)	0 (3,9)	0 (3,9)
Taita (high)	100 (2, 6)	56 (3,9)	75 (4,12)	0 (3, 9)	0 (2,6)	0 (3, 9)
Mombasa	NA	–	–	–	–	–

Busseola fusca larvae were parasitised by the virulent and avirulent *C. sesamiae* females. *Sesamia calamistis* was also parasitised and used as the positive control since it is permissive to both the virulent and avirulent strains. Haemolymph and fat body tissues were extracted from the larvae six hours post-parasitism. RNA was extracted from the tissues and the reverse transcriptase polymerase chain reaction (RT-PCR) carried out using protocol from the RETROscript instruction manual (Ambion). Results showed that the *CrV1* gene is expressed in tissues parasitised by the virulent *C. sesamiae* but not the avirulent *C. sesamiae* (Figure 11).



1 *C. sesamiae* BV DNA

Haemolymph samples
2 Cs Kitale on Sc
3 Cs Mombasa on Sc
4 Cs Kitui on Bf
5 Cs Mombasa on Bf
6 Cs Meru on Bf
7 Cs Kitale on Bf

Fat body samples
8 Cs Kitale on Bf
9 Cs Meru on Bf
10 Cs Mombasa on Sc
11 Cs Mombasa on Bf
12 Cs Kitale on Sc
13 Cs Kitui on Bf

Figure 11. *CrV1* gene expression on haemolymph and fat body tissue six hours post-parasitisation. *Cotesia sesamiae* from Meru and Kitale are virulent while *C. sesamiae* from Kitui and Mombasa are avirulent. (Cs, *C. sesamiae*; Bf, *B. fusca*; Sc, *S. calamistis*)

46. *Predicting spatial patterns of lepidopteran cereal stemborers and their natural enemies under current and future climate scenarios in East and Southern Africa*

The management of both pests and natural enemies requires an understanding of the factors determining their distribution. Statistical models offer methods for formulating the species habitat link and means for predicting where species should occur. This report describes an integrated approach to species habitat mapping in East and Southern Africa region using generalised regression analysis and spatial prediction (GRASP). The approach uses separate statistical models for each stemborer and parasitoid species to predict the species richness and abundance in each grid cell in a geographic information system (GIS). Allocation of these grid cells to species composition allows 'hot-spots' of feasible areas for biocontrol to be defined. Examples of use of this information for pest management are presented. This report explores species habitat under different global climate change scenarios.

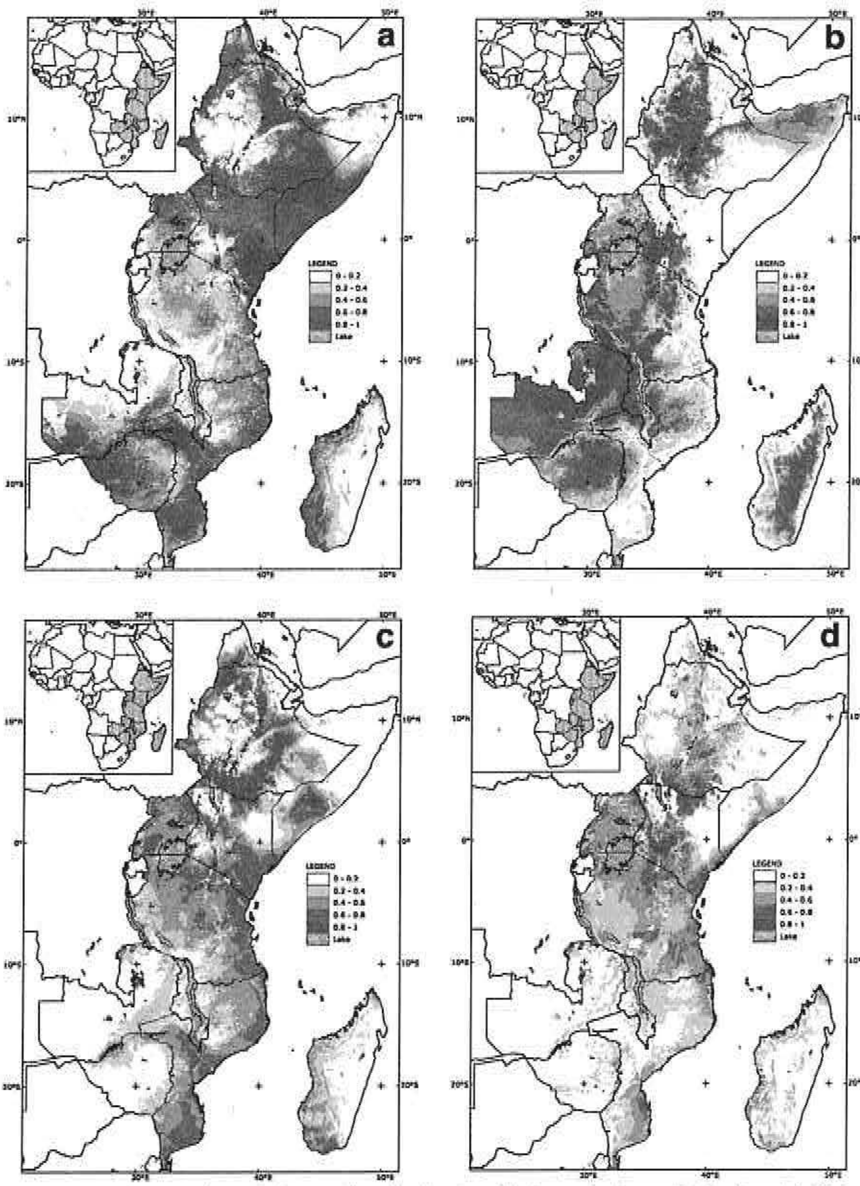


Figure 12. Spatial prediction of (a) *Chilo partellus* distribution, (b) *Busseola fusca* distribution, (c) *Cotesia flavipes* distribution and (d) *Cotesia sesamiae* distribution under current climate conditions in eastern and southern Africa

47. *The temporal correlation and spatial synchrony in the stemborer and parasitoid system of coastal Kenya with climate effects*

The temporal correlation and spatial synchrony of the exotic stemborer *Chilo partellus* and the indigenous *Sesamia calamistis* and *Chilo orichalcociliellus*, the indigenous and introduced larval parasitoids *Cotesia sesamiae* and *C. flavipes*, respectively, was studied using 3-year data collected in coastal Kenya. An autoregressive model was used to study the effect of climatic stochasticity or population density-dependent factors on stemborer populations. It appeared that rainfall did have a direct impact on stemborers in the South Coast, and indirectly in the North Coast. Spatial non-parametric correlation functions (SNCF) and cross-correlation functions (SNCCF) were applied for spatial synchrony analysis. The regional synchrony of *C. partellus* and *S. calamistis* decreased and that of *C. orichalcociliellus* increased after the introduction of *C. flavipes*. The positive cross-correlation coefficient between stemborers and parasitoids suggests a synchrony between the pest and its natural enemy.

Chilo partellus was the dominant stemborer species in both the North and South Coast. By 2005, the average season population density of *C. partellus* in the North Coast was reduced to under 0.5/plant (Figure 13a). Densities of *C. orichalcociliellus* and *S. calamistis* also declined compared to 1998. Parasitism of *C. flavipes* had increased to about 30%, while parasitism of *C. sesamiae* fluctuated with seasons; it was higher during the short than long rainy season. In the South Coast, *C. partellus* declined to 0.6/plant by 2005 (Figure 13b). Densities of the other two indigenous stemborer species did not vary much through the years. Parasitism of *C. flavipes* increased to about 20% during the short rainy season of 2004 and then declined again in 2005. Parasitism of *C. sesamiae* was generally very low.

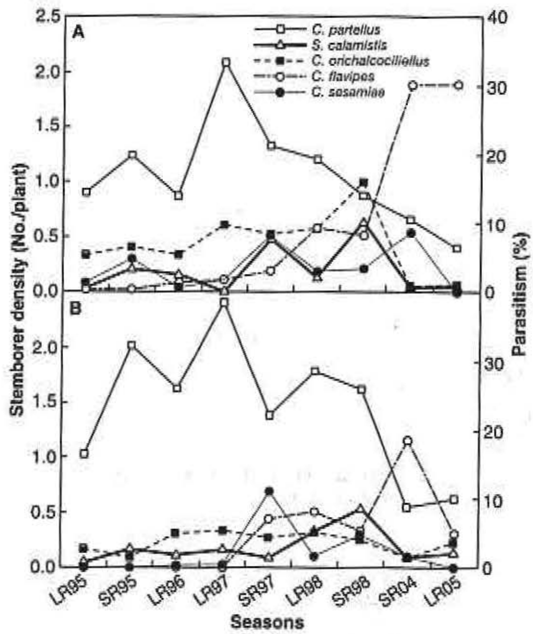


Figure 13. Seasonal population dynamics of stemborers and parasitism in (a) North and (b) South Coast of Kenya

48. *The effect of soil nitrogen and host plant species on the bionomics of* Chilo partellus *and parasitism by* Cotesia flavipes

Studies on several cereal stemborer species in Africa showed that soil nutrient levels, such as nitrogen, greatly influenced nutritional status of the plant and thereby the bionomics of the pest. It is hypothesised that plant nitrogen would also affect the third tropic level, namely the parasitoid. Lab and field trials were conducted to evaluate the effect of plant species (maize, sorghum), plant age (young, middle, old) and four different nitrogen fertilisation levels (N0–N3) on the bionomics of the invasive crambid *Chilo partellus* and the performance of its braconid larval parasitoid *Cotesia flavipes*. Plant nitrogen varied significantly between N0 and N1–N3, but the differences among the latter were not significant. Survivorship, intrinsic rates of increase and net-reproductive rates of *C. partellus* followed the same trends: They were lowest with N0 and similar among the other treatments (Figure 14).

On maize only, mortality of *C. partellus* and parasitism by *C. flavipes* tended to decrease with age of the plant while the percentage of borers reaching adulthood (i.e., pupation) increased. When comparing between host plants, sorghum yielded lower borer mortality and parasitism and higher pupation than maize. On both host plants, percent dry matter content of frass, which could affect ingress of the parasitoid into the borer tunnel, did not vary with nitrogen level. By contrast, it varied with age of the host plants: On maize, it was highest on young plants and on sorghum on old plants. Tunnels were shorter on young maize and sorghum plants; longer tunnels on older plants indicated compensatory feeding by the larva as a result of lower nutritive value of the food source. Consequently, larval weight was lower on older than younger plants. The level of nitrogen fertilisation had no effect on food conversion efficiency of *C. partellus*, expressed as larval weight gained and mg fresh weight of frass produced per cm tunnel bored. N did not affect number of *C. flavipes* progeny while egg load of progeny increased significantly with nitrogen level, on both plant species (Table 33). Differences in egg load between sorghum and maize were mostly not significant. It can be concluded that (a) on depleted soils only, an increase in N via mulching, rotation with a leguminous crop or N fertilisation would increase survival of *C. partellus* on both maize and sorghum; (b) an increase in acreage of maize and in application of nitrogen fertiliser in an area would also increase the parasitism of *C. flavipes*.

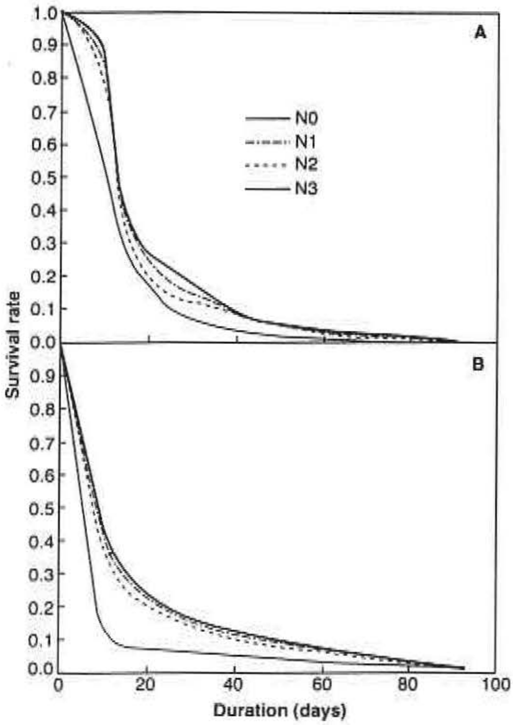


Figure 14. Survival of *Chilo partellus* larvae on maize (A) and sorghum (B) subjected to different nitrogen fertilisation levels (N0–N3)

Table 33. Effect of different nitrogen fertilisation levels (N0–N3) and plant growth stage of maize and sorghum on egg load of *Cotesia flavipes*

	Plant age				
Treatment	Young	Medium	Old	*F*	*P*
Maize					
N0	137.1 ± 4.0 cA	116.0 ± 3.5 bB	118.4 ± 15.6 bB	3.70	0.041
N1	149.5 ± 4.4 bcA	129.5 ± 8.9 bA	151.8 ± 11.2 abA	1.37	0.270
N2	178.0 ± 12.2 bA	150.8 ± 5.3 aB	152.3 ± 5.4 abB	3.81	0.030
N3	209.6 ± 4.6 aA	165.4 ± 6.2 aB	175.5 ± 6.9aB	6.53	0.004
F	11.01	10.36	3.63		
df	3	3	3		
P	<0.0001	<0.0001	0.021		
Sorghum					
N0	125.6 ± 11.8 bA	127.8 ± 8.0 bA	164.0 ± 0.0 aA	0.98	0.400
N1	140.8 ± 10.1 abB	187.4 ±13.7 aA	155.6 ± 7.4 aA	4.41	0.029
N2	N/A	152.0 ± 7.4 bA	125.6 ± 12.4 aA	3.73	0.076
N3	163.5 ± 6.3 aA	153.0 ± 2.9 bA	125.2 ± 9.7 aB	5.84	0.009
F	4.37	7.10	2.5		
df	2	3	3		
P	0.023	0.001	0.109		

Means within a column followed by the same lowercase letter and within a row followed by the same uppercase letter are not significantly different at $P \leq 0.05$ (SNK test).

The effect of maize, cultivated and wild sorghum and Napier grass on the survivorship and weight of parasitised *C. partellus* larvae and on the performance of its larval parasitoid *C. flavipes* were studied under laboratory conditions. *Chilo partellus* larvae were fed on the different plants for 7–8 days before being exposed to *C. flavipes* for parasitisation, and were subsequently kept on the same plant until parasitoid emergence or death of the host larvae. Larval weight before parasitisation, larval survivorship, percent larvae producing cocoons or dying, sex ratio of *C. flavipes* progeny and egg-load in virgin females were assessed in two experiments. In the first (Experiment A), weight of *C. partellus* larvae offered to *C. flavipes* was allowed to vary with host plant species in order to assess both the effect of weight and quality of larvae, as affected by the host plant, on the performance of the parasitoid. In the second (Experiment B), larvae of similar weight across host plant species were selected to enable to separate the effect of weight from that of quality of the larvae. In experiment A, mean weight of larvae successfully parasitised was significantly higher than that of larvae failing to produce cocoons, on the wild host plant species. The mean weight of larvae that produced cocoons was highest on sorghum and lowest on maize and Napier grass. In both experiments, the percentage of larvae producing cocoons and mean progeny size were lower and larvae died faster on wild than cultivated host plants (Table 34). Immature developmental time of *C. flavipes* was greatest in Napier grass in Experiment A, and on wild sorghum in Experiment B. The proportion of female progeny was highest on maize and lowest on the two sorghum species in Experiment A, whereas in Experiment B the sex ratio was similar between the host plant species. Similarly, egg-load of *C. flavipes* offspring was highest on maize and lowest on Napier grass in Experiment A, but it did not vary significantly between host plants in Experiment B. It is suggested that in the coastal region of Kenya, perennial wild sorghum species are vital for the survival of *C. flavipes* during the dry season, when superior plant hosts such as cultivated sorghum and maize are scarce.

Table 34. Percentage of *Chilo partellus* forming cocoons, unexplained larval mortality and *Cotesia flavipes* adult emergence on various host diets

	Cocoon formation		Mortality		Adult emergence	
	A	B	A	B	A	B
Zea mays	42.7 a	38.1 a	57.3 a	60.3 a	97.1 a	91.7 a
Sorghum bicolor	51.2 a	40.3 a	48.8 a	53.7 a	81.8 a	96.3 a
S. arundinaceum	16.7 b	13.6 b	83.3 b	86.4 b	93.7 a	83.3 a
Pennisetum arundinaceum	6.5 b	28.3 ab	93.5 b	71.7 ab	87.5 a	69.2 b

Means within a column followed by the same lowercase letter are not significantly different (SNK test, $P < 0.05$).

49. *The biology and ecology of* Mussidia *spp. and associated natural enemies in Kenya*

The maize ear-borer *Mussidia nigrivenella* is one of the most important pests of maize in West Africa causing yield losses ranging between 5 and 25% in the field and 10% during storage. In addition, it also predisposes maize to pre-harvest and post-harvest infestations by storage beetles, infection by *Aspergillus flavus* and subsequent aflatoxin contamination. *Mussidia nigrivenella* has never been reported as a pest of crops in East Africa though it was found on wild host plants. The aim of the current study was to determine the diversity of *Mussidia* species, associated host plants and natural enemies in Kenya. Field surveys which involved collection of fruits and light trapping were carried out in the lowlands and mid-altitude regions of Kenya. In addition, *Canavalia* spp.—a known host of *M. nigrivenella* in West Africa—was planted at the Kenyan coast to trap the insect. *Mussidia* spp. has been collected from the Eastern lowlands and at the Kenyan coast. *Mussidia* spp. were found on *Canavalia ensiformes, Kigelia africana, Adansonia digitata, Afzelia quanzensis* and *Canavalia carthartica*. The species recovered from the first three hosts is likely to be *Mussidia fiorii* while the species recovered from *Canavalia* spp. is very likely *M. nigrivenella* and from the remaining hosts *M. fiorii*. *Mussidia* spp. recovered from *K. africana* is being successfully reared on artificial diet at *icipe*.

The specimens are identified by Matthias Nuss from the State Museum of Zoology, Dresden, Germany, who is also undertaking a revision of the *Mussidia* genus.

50. *Genetic diversity of* Teretrius nigrescens *Lewis predator of the larger grain borer* Prostephanus truncatus *Horn*

Participating scientists and student: *D. Masiga, F. Schulthess, J. van den Berg[1], D. Bergvinson[2]*

Donor: *Kirkhouse Trust, UK*

Collaborators: *KARI, CIMMYT, Kenya; [1]University of Northwest, South Africa and [2]CIMMYT, Mexico*

The larger grain borer, *Prostephanus truncatus* (Horn), is an exotic invasive post-harvest pest introduced into Africa from Meso-America in the 1970s and 1980s. It has now spread to over 17 countries. It causes severe damage to stored maize and cassava, the most important staple food crops in the continent. In Kenya, *P. truncatus* has recently spread into the breadbasket highland regions of Kenya, threatening the overall maize production in the country. Since the pest exists as on-farm and as wild populations, sustainable control needs to target both environments. Biological control using the predator *Teretrius nigrescens* has shown sustainable success and cost effectiveness in hot-humid but not cool and hot-dry climates in West Africa. This project, therefore, aims at investigating the population genetic structure and climate limitations of different populations of the predator recovered from varied agroecological zones in Mexico and Costa Rica. It also seeks to develop molecular markers for the identification of the strains and their crosses to facilitate monitoring of the performance of the different strains in biological control.

Preserved samples from six populations of *T. nigrescens* have been obtained for molecular studies. A local population of the predator has been similarly acquired and is being reared in the laboratory. Surveys for the pest (larger grain borer) and its predator (*T. nigrescens*) recovered the pest but not the predator from semi-arid forested areas of Eastern Kenya.

The use of RAPD-PCR and amplification of mitochondrial DNA markers in assessing diversity are ongoing. PCR-RFLP of a 1300 bp region of the mitochondrial Cytochrome Oxidase subunit I (mtCOI) gene has revealed some differences between the Benin population (originally Costa

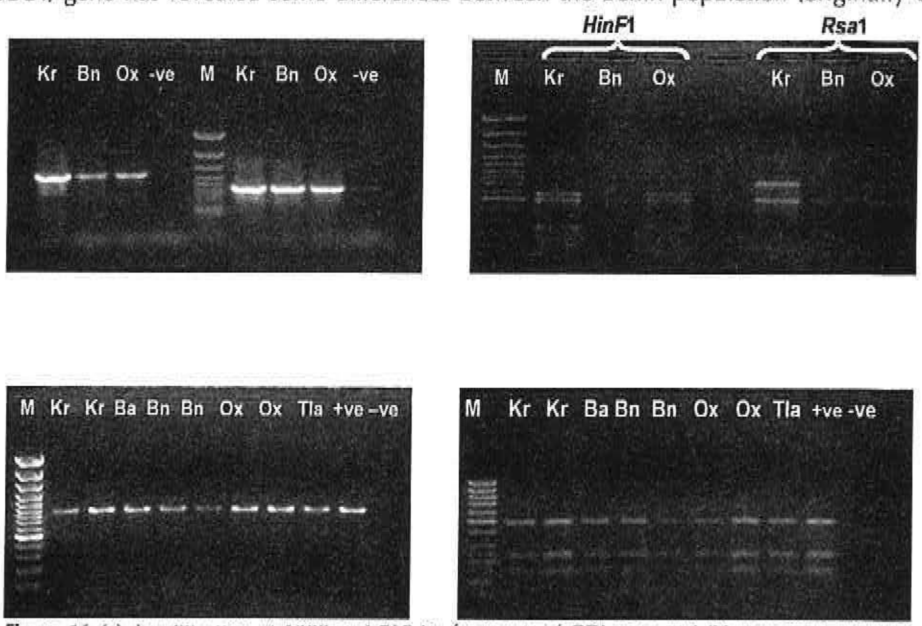


Figure 16 **(a)** Amplification of 1300 and 760 bp fragments of COI gene and **(b)** restriction products of the 1300bp fragment digested with *HinF*1 and *RSa*1 showing differences between Benin and other populations (*RSa*1)

Rica) and the other populations (originally Mexico), but not an 850pb fragment (Figures 15 and 16). We are therefore sequencing whole COI gene to assess the population structure and to develop a diagnostic tool.

51. Isolation and evaluation of local isolates of Bacillus thuringiensis *against the larger grain borer* Prostephanus truncatus, *a postharvest storage pest*

Participating scientist: *N. K. Maniania*

Assisted by: *E. O. Ouna, R. Rotich*

Donors: *icipe core fund donors and USAID*

Collaborators: *KARI, Kenyatta University*

Microorganisms (bacteria, fungi, viruses, nematodes or protozoa) cause diseases in arthropod populations in nature and thereby contribute to natural regulation of pest populations. Consequently, the Arthropod Pathology Unit (APU) is engaged in research into these pathogens to develop them as microbial insecticides or biopesticides.

The larger grain borer (LGB), *Prostephanus truncatus*, is currently the most destructive pest of farm-stored maize, *Zea mays*, and cassava, *Manihot esculenta*, in Africa. In Kenya, yield losses due to LGB have been estimated to KShs 8.4 billion (approx. US$ 100 million) annually. The attack of grains by LGB constitutes the point of entry of mould, thus resulting in production of aflatoxins produced by the fungus *Aspergillus flavus*. Cases of acute aflatoxicosis have been reported in Kenya where people have died after consuming aflatoxin-contaminated maize grains. Chemical control strategies have been implemented with considerable success by large-scale farmers but to a lesser extent by small farmers who practice subsistence farming. The histerid predator *Teretrius nigrescens* was introduced into Africa from South America and has established in some countries. However, this strain of predator appears to be more effective in humid zones than hot-dry areas or cool highlands. In the present study, the use of the entomopathogenic bacterium *Bacillus thuringiensis* (Bt) as potential biological control agent of LGB is investigated. *Bacillus thuringiensis* isolates pathogenic to coleopterans are not common and belong to the subspecies *tenebriosis*, *donegani* and *san diego*. An effective Bt isolate could also be utilised as a source of genes for introduction into maize LGB-resistant crop.

Isolation of **Bacillus thuringiensis**

Samples from soils, grains and insects collected within Kenya yielded 68 Bt isolates out of the 320 samples screened. Out of these, 85.3% were from grains, 11.8% from soil and 2.9% from insects. Grain is, therefore, a good source for isolation of *B. thuringiensis*.

Toxicity of isolates of **Bacillus thuringiensis** *to* **Prostephanus truncatus**

Mortality in the controls was 3.3%, 30 days after treatment. Mortality caused by Bt isolates in adult *P. truncatus* varied between the isolates with Bt isolate 41 recording the highest mortality of 53.3%, 7 days after treatment and 85.0%, 30 days after treatment. *Bacillus thuringiensis* var. *tenebrio*, standard reference isolate, caused mortality of 37%. The lethal time mortality (LT_{50}) values were only calculated for some of Bt. They ranged from 6.6 days to 7.4 days and did not differ significantly. The LT_{50} for the standard reference was 15 days.

Future outlook

The present phase of the project 'Biological Control of Cereal Stemborers in East and Southern Africa (SBCNET)' will end in December 2006, but the work is not over yet. In coastal Kenya, where the *Cotesia flavipes* was first released, it took nearly five years to see a significant impact on pest populations. Eight years later, parasitism rates are still increasing and pest populations decreasing indicating that the system is not yet in equilibrium. In many countries, the parasitoid was released relatively recently, thus it is too early for determining its impact. In addition, the pupal parasitoid *Xanthopimpla stemmator* has been released in some but not all countries. As it attacks a different life stage it should complement the activity of *C. flavipes*. Furthermore, we will get several shipments of the tachinid *Sturmiopsis inferens* in 2006. In Asia, this is a common parasitoid of *Chilo* and *Sesamia* spp. As for every parasitoid species, non-target species effects will have to be studied before releasing it in Africa.

In the future, increasing emphasis will be put on the redistribution BC approach (expansion of the geographic range of indigenous parasitoid species or races of them). The West African egg parasitoid *Telenomus isis* will be released against *Busseola fusca* in Kenya in 2006. Similarly, Kenyan races of *Cotesia sesamiae* will be introduced into Cameroon in 2006. Intensive survey work has shown that in Cameroon *C. sesamiae* is very rare and only found on 'wild' borer species inhabiting grasses. Likewise, *Sturmiopsis parasitica*, which is the most important larval parasitoid of *Sesamia calamistis* and *Eldana saccharina* in West Africa, is completely absent in Cameroon. In addition, *X. stemmator* will be introduced into western Africa as a *new association* candidate to be tested on indigenous borer species. Experiments at *icipe* have already shown that it successfully parasitised the indigenous *S. calamistis*, *B. fusca* and *E. saccharina*.

Survey work in Kenya showed that the speed of action and efficiency of *C. flavipes* varied with ecoregion and location. It is suspected that the degree of habitat fragmentation and abundance and quality of wild habitats, which may affect the performance of parasitoids both negatively or positively depending on their co-evolutionary history, may play a major role. Thus, in future classical BC programmes, more emphasis will be put on the role of wild habitats in the establishment and efficacy of an introduced natural enemy. The present project already started monitoring several other invasive species amenable to classical BC, such as the larger grain borer and the spiralling whitefly. In addition, there are 9 other invasive species, which have been declared as key pests of staple and cash crops by the collaborators in the twelve countries in ESA.

Major thrust in the future will be on the control of post-harvest pests and mycotoxin-producing fungi. LGB has spread over most of East and Southern Africa including the highlands, which often are the food basket in a country. *icipe* is planning to introduce races of the predator *T. nigrescens* adapted to different climates from the laboratories of CIMMYT in Mexico. To date, the Mexican authorities have not granted an export permit. Meanwhile, a PhD student is developing molecular biology tools to allow for identification of the different races which is a requirement for release and follow-up studies. Contamination of grain by aflatoxin produced by *Aspergillus flavus* has often been shown to be related to pre- and post-harvest damage of grain by insects. Hence, the programme is developing a holistic programme, which involves farmers' planting, harvesting and storage practices, and control of insects and fungi, to reduce toxin levels in grain.

Output

Journal articles

Chinwada P., Overholt W. A., Omwega C. O. and Mueke J. M. (2004) Biology of *Sturmiopsis parasitica* (Diptera: Tachinidae) and suitability of three cereal stem borers (Lepidoptera: Crambidae, Noctuidae) for its development. *Annals of the Entomological Society of America* 97, 153–160.

Getu E., Overholt W. A. and Kairu E. (2004) Comparative studies on the influence of relative humidity and temperature on life table parameters of two populations of *Cotesia flavipes* (Hymenoptera: Braconidae). *Biocontrol Science and Technology* 14, 595–605.

Gitau C. W., Ngi-Song A. J., Overholt W. A. and Otieno S. A. (2005) Acceptance and suitability of four lepidopteran stemborers for the development of the pupal parasitoid *Xanthopimpla stemmator* (Hymenoptera: Ichneumonidae). *Biocontrol Science and Technology* 15, 585–600.

Gohole L. S., Overholt W. A., Khan Z. and Vet L. E. M. (2005) Close-range host searching behavior of the stemborer parasitoids *Cotesia sesamiae* and *Dentichasmias busseolae*: Influence of a non-host plant *Melinis minutiflora*. *Journal of Insect Behavior* 18, 149–167.

Gounou S. and *Schulthess F.* (2004) Spatial distribution of lepidopterous stem borers on indigenous host plants in West Africa and its implications for sampling schemes. *African Entomology* 12, 171–178.

Jiang N. and *Schulthess F.* (2005) The effect of nitrogen fertilizer application to maize and sorghum on the bionomics of *Chilo partellus* (Lepidoptera: Crambidae) and performance of its larval parasitoid *Cotesia flavipes* (Hymenoptera: Braconidae). *Bulletin of Entomological Research* 95, 495–504.

Jiang N., Sétamou M., Ngi-Song A. J. and *Omwega C. O.* (2004) Performance of *Cotesia flavipes* (Hymenoptera: Braconidae) in parasitizing *Chilo partellus* (Lepidoptera: Crambidae) as affected by temperature and host stage. *Biological Control* 31, 155–164.

Kalyebi A., Overholt W. A., Schulthess F., Mueke J. M., Hassan S. A. and *Sithanantham S.* (2005) Functional response of six indigenous trichogrammatid egg parasitoids (Hymenoptera: Trichogrammatidae) in Kenya: Influence of temperature and relative humidity. *Biological Control* 32, 164–171.

Kanya J. I., Ngi-Song A. J., Sétamou M., Overholt W., Ochora J. and *Osir E. O.* (2004) Diversity of alternative hosts of maize stemborers in Trans-Nzoia district of Kenya. *Environmental Biosafety Research* 3, 159–168.

Midega C. A. O., Ogol C. K. P. O. and *Overholt W. A.* (2004) Effect of agroecosystem diversity on natural enemies of maize stemborers in coastal Kenya. *International Journal of Tropical Insect Science* 24, 280–286.

Midega C. A. O., Ogol C. K. P. O. and *Overholt W. A.* (2005) Life tables, key factor analysis and density relations of natural populations of the spotted maize stemborer, *Chilo partellus* (Lepidoptera: Crambidae), under different cropping systems at the Kenyan coast. *International Journal of Tropical Insect Science* 25, 86–95.

Muturi J. J., Ngi-Song A. J., Schulthess F., Mueke J. M. and *Sétamou M.* (2005) Location of stemborer pupae in various host plants and implications for the performance of natural enemies with emphasis on the pupal parasitoid *Xanthopimpla stemmator* (Hymenoptera: Ichneumonidae). *International Journal of Tropical Insect Science* 25, 12–18.

Ngumbi E. N., Ngi-Song A. J., Njagi E. N. M., Torto R., Wadhams L. J., Birkett M. A., Pickett J. A., Overholt W. A. and *Torto B.* (2005) Responses of the stem borer larval endoparasitoid *Cotesia flavipes* (Hymenoptera: Braconidae) to plant derived synomones: Laboratory and field cage experiments. *Biocontrol Science and Technology* 15, 271–279.

Niyibigira E. I., Overholt W. A. and Stouthamer R. (2004a) *Cotesia flavipes* Cameron and *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae) do not exhibit complementary sex determination: Evidence from field populations. *Applied Entomology and Zoology* 39, 705–715.

Niyibigira E. I., Overholt W. A. and Stouthamer R. (2004b) *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) does not exhibit complementary sex determination (ii) Evidence from laboratory experiments. *Applied Entomology and Zoology* 39, 717–725.

Sétamou M., Jiang N. and *Schulthess F.* (2005) Effect of the host plant on the survivorship of parasitized *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) larvae and performance of its larval parasitoid *Cotesia flavipes* Cameron (Hymenoptera: Braconidae). *Biological Control* 32, 183–190.

Capacity building

PhD students

M. Wale (Ethiopia) Ecosystems of the Amhara state, Ethiopia. Kenyatta University, Nairobi (ongoing).

T. K. Matama (Uganda) Role of wild host plants in stemborer population dynamics and their parasitoids in Uganda. Kenyatta University, Nairobi (ongoing).

C. Gitau (Kenya) Characterisation of polydnaviruses of the stemborer parasitoid *Cotesia flavipes* and their relation for host suitability. Kenyatta University, Nairobi (completed 2005).

B. Y. Anani (Togo) Host suitability and interspecific competition of the West African stemborer egg parasitoid *Telenomus isis* Polaszek (Hymenoptera: Scelionidae). Kenyatta University, Nairobi (ongoing).

A. K. Kipkoech (Kenya) The economics of biological control of cereal stemborers in Kenya. Moi University, Eldoret (ongoing).

D. Cugala (Mozambique) Impact assessment of natural enemies on stemborers populations and maize yield. Kenyatta University, Nairobi (ongoing).

B. A. Omondi (Kenya) Ecology and population genetic structure of strains of *Teretrius nigrescens* (Coleoptera: Histeridae), predator of *Prostephanus truncatus* (Coleoptera: Bostrichidae). North West University, RSA (ongoing).

B. Muli (Kenya) Biology and ecology of *Mussidia* spp. and associated natural enemies in Kenya. North West University, RSA (ongoing).

S. Gounou (Benin) The performance of new and old association natural enemies on West African cereal stemborer species. Hannover University, Germany (ongoing).

MSc students

A. Tilahun (Ethiopia) Assessment of species diversity and parasitism of parasitoids of maize and sorghum stemborers in the Central Rift Valley of Ethiopia. Alemaya University (completed 2005).

A. Tamiru (Ethiopia) Study on the biology and some ecologial aspects of *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) in relation to its geographical expansion. Addis Ababa University (completed 2005).

G. Kaigani (Uganda) Abundance of egg parasitoids of maize stemborers and their distibution in Central Uganda. Makerere University, Kampala (ongoing).

M. N. Moonga (Zambia) Population studies of *Xanthopimpla stemmator* and *Cotesia flavipes*, natural enemies of the spotted stemborer, *Chilo partellus* in Zambia. University of Zambia (ongoing).

J. J. Muturi (Kenya) Efficacy of *Xanthopimpla stemmator* against selected lepidopteran pests and its interaction with pupal endoparasitoid *Pediobius furvus* in graminaceous plants in Kenya. Kenyatta University, Nairobi (completed 2004).

S. Nyamutukwa (Zimbabwe) Suitability of different populations of maize stemborer species for the development of the parasitoid *Sturmiopsis parasitica* in Zimbabwe. University of Zimbabwe (completed in 2005).

B. Muli (Kenya) Interspecific competition between *Xanthopimpla stemmator* Thunberg and *Dentichasmias busseolae* Heinrich (Hymenoptera: Ichneumonidae), pupal parasitoids of *Chilo partellus* (Lepidoptera: Crambidae). Jomo Kenyatta University of Agriculture and Technology, Kenya (completed 2005).

K. Mushore (Zimbabwe) Suitability of different populations of stemborer species for the development of *Cotesia flavipes* and an assessment of its establishment in Zimbabwe. University of Zimbabwe (completed 2005).

E. O. R. Okoth (Kenya) The bionomics of the egg parasitoid *Telenomus busseolae* (Gahan) (Hymenoptera: Scelionidae) on *Busseola fusca* Fuller and *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) in Kenya. Kenyatta University, Nairobi (completed 2005).

V. Mgoo (Tanzania) Effect of nitrogen on maize yield, stemborer damage and parasitism by *Cotesia flavipes*. Sokoine University, Tanzania (completed 2005).

O. M. Obonyo (Kenya) Performance of *Cotesia flavipes* (Hymenoptera: Braconidae) on stemborer species found on cereal crops and wild grasses. Jomo Kenyatta University of Agriculture and Technology (completed 2005).

A. I. Ali (United Republic of Tanzania) Effect of nitrogenous fertilizer on recovery of *C. flavipes* on stemborers in Zanzibar. Kenyatta University, Nairobi (ongoing).

N. Rashid (United Republic of Tanzania) Egg parasitoids of stemborers in Zanzibar. Sokoine University, Tanzania (ongoing).

L. A. Rasamizafy (Madagascar) Assessment of the composition and distribution of lepidopteran maize stemborers as well as their natural enemies in Madagascar. University of Antananarivo (completed in 2005).

H. J. T. Andrianaivo (Madagascar) Impact of noctuid stemborers on maize yields in the Plateau region of Madagascar. University of Antananarivo (completed in 2005).

J. E. Rakotonirina (Madagascar) Advantages of cultural practices in controlling maize stemborers. University of Antananarivo (completed 2005).

D. M. O. Wanyama (Kenya) The effect of Bt toxins on fitness of *C. partellus* and *X. stemmator*. University of Nairobi (completed 2004).

Y. Tembo (Malawi) The impact of stemborers on yield of maize using exclusion experiments in the Shire valley. University of Malawi (ongoing).

N.-N. Akongnwi (Cameroon) Effect of two grain legumes and tephrosia cover crop rotation with maize on lepidopterous borers attack and yield of maize in the mid altitude of Cameroon. University of Buea, Cameroon (ongoing).

A. Abang (Cameroon) Effect of various chemical nitrogen and phosphorus combinations on lepidopterous borer pests and yield of maize in the high altitude of Cameroon. University of Dschang, Cameroon (ongoing).

O. Omucheru (Kenya) Host range studies of *Sturmiopsis parasitica* (Curran) (Diptera: Tachinidae) and interspecific competition with *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae). Kenyatta University, Kenya (ongoing).

J. Wamaitha (Kenya) Isolation and evaluation of local isolates of *Bacillus thuringiensis* against the larger grain borer *Prostephanus truncatus*, a post harvest storage pest. Kenyatta University, Kenya (submitted). (Based at Arthropod Pathology Unit.)

Habitat Management Strategies for Control of Stemborers and Striga Weed in Cereal-Based Farming Systems

Background, approach and objectives

Maize and sorghum are the principal food and cash crops for millions of the poorest people in the predominantly mixed crop–livestock farming systems of eastern and southern Africa. Stemborers [*Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) and *Busseola fusca* Fuller (Lepidoptera: Noctuidae)] and striga weeds [(*Striga hermonthica* and *Striga asiatica* (Scrophulariaceae)] are the two major biotic constraints to increased maize and sorghum production in eastern Africa.

At least four species of stemborers infest maize and sorghum crops in the region, causing reported yield losses of 20–40% of the potential output. Stemborers are difficult to control, largely because of the cryptic and nocturnal habits of the adult moths and the protection provided by the stem of the host crop for immature stages. The main method of stemborer control, which is recommended to farmers by the governments' ministries of agriculture in the region, is the use of chemical pesticides. However, this is uneconomical and impractical for many resource-poor small-scale farmers.

Parasitic weeds in the genus *Striga* threaten the lives of over 100 million people in Africa and infest 40% of arable land in the savanna region, causing an estimated annual loss of $7 to $13 billion. Infestations by *Striga* spp. have resulted in the abandonment of some arable land by farmers in Africa. The problem is more widespread and serious in areas where both soil fertility and rainfall are low. Unfortunately, subsistence farmers in the region must engage themselves in weeding out striga, which is a time-consuming and labour-intensive activity, mainly delegated to women and children. Recommended control methods to reduce striga infestation include heavy applications of nitrogen fertiliser, crop rotation, use of trap crops and chemicals to stimulate suicidal seed germination, hoeing and hand pulling, herbicide application and the use of resistant or tolerant crop varieties. Effectiveness of all these methods, including the most widely practised—hoe weeding—is seriously limited by the reluctance of farmers to accept them, for both biological and socioeconomic reasons.

The third constraint, poor soil fertility, has also been identified by farmers as a major limiting factor to cereal production. It results from a poor inherent fertility status together with high population pressure and poor management practices. Due to the low inherent fertility status of the soils in the target region, their low buffering capacity and the inability of small-scale farmers to invest in soil fertility management, soils are degrading rapidly and are hardly able to sustain acceptable maize yields. N and P are the major limiting nutrients. Lack of adequate soil management also negatively affects the soil organic matter pool that is responsible for a series of production and environmental service functions essential for sustainable crop production in a healthy environment. The use of inorganic fertiliser to supply plant nutrients by resource-poor farmers is limited. Although many soil fertility restoration technologies such as cereal–legume rotations, biomass transfers, farmyard manure, tree-fallowing and green manure cover crops exist that can redress this situation, their potential for use is greatly influenced by the land size, capital and labour constraints. Striga has been known to cause large losses in maize yields on N limited soils of eastern Africa. In western Kenya and eastern Uganda, widespread P deficiency limits maize yields on high P-fixing soils. Under these conditions, the maize crop responds to moderate applications of P fertiliser when striga weed population is low. However, this response was found to be negligible under high striga infestation and it was concluded that small additions of P fertilisers are not effective under high striga occurrence. It is therefore, recommended that P fertilisation must be combined with effective and sustainable striga control, or else resource-poor farmers would require very high P fertilisation to sustain maize yield increases.

Therefore, reducing the yield losses caused by stemborers and striga and by improving soil fertility through improved management strategies could significantly increase maize and sorghum production, resulting in better nutrition and purchasing power for many producers of these crops. A sustainable solution to these problems can only be provided by a single platform technology that simultaneously addresses these major constraints.

With funding from the Gatsby Charitable Foundation, *icipe* and collaborative partners have developed alternative strategies for stemborer and striga management using technologies appropriate to resource-poor farmers which have shown a high adoption rate by farmers and potential for spontaneous technology transfer within farming communities. This has resulted in significant impact on food security by increased farm productivity in the region. *(See 2002–2003 icipe Annual Scientific Report.)*

The R&D work, undertaken as a joint collaborative effort with KARI, the Ministry of Agriculture (Kenya) and Rothamsted Research in UK, is based on novel strategies that combine a 'push-pull' tactic for controlling stemborers on one hand, and an *in situ* suppression and elimination of striga on the other, in maize-based farming systems. The 'push-pull' tactic involves trapping stemborers on highly attractant trap plants (pull) while driving them away from the maize crop using repellent intercrops (push). The striga control tactic on the other hand is based on the use of intercrops that act through a combination of mechanisms, including seeds that fail to develop and attach onto the host. These strategies undertake a holistic approach to understanding and utilising chemical ecology and agrobiodiversity for stemborer and striga management. These plants also improve soil fertility by fixing nitrogen.

Plants that have been identified as effective in 'push-pull' tactics include Napier grass (*Pennisetum purpureum)*, Sudan grass (*Sorghum vulgare sudanense)*, molasses grass (*Melinis minutiflora)*, silverleaf desmodium (*Desmodium uncinatum*) and greenleaf desmodium (*Desmodium intortum*). Napier grass and Sudan grass have shown potential for use as trap plants, whereas molasses grass and silverleaf desmodium repel ovipositing stemborer moths. Molasses grass, when intercropped with maize, not only reduced infestation on the maize crop by stemborer moths, but also increased stemborer parasitism by a natural enemy, *Cotesia sesamiae*. In addition, desmodium, when intercropped with maize, suppresses and eliminates striga. These plants are of economic importance to farmers in eastern Africa as livestock fodder and have shown great potential in stemborer and striga management in farmer participatory on-farm trials. These innovations have found ready acceptance among the small-scale and medium-scale farmers in East Africa. The adoption of the 'push-pull' technology in high population density areas around the Lake Victoria region is very high and consisted of more than 3500 farmers in 15 districts in the region by the end of 2005 (see Figures 1 and 2). Similarly, more than 600 farmers in 3 districts in central Kenya have also adopted the technology where KARI scientists are implementing a Farm Africa-funded project on this technology.

The major objective of this programme is to reduce poverty by improving the livelihood of resource-poor farmers through increased production of cereal crops, fodder plants and milk.

Participating scientists: *Z. R. Khan, A. Hassanali, C. A. O. Midega*

Visiting scientist (BCED): *M. K. Tsanuo*

Assisted by: *N. Dibogo, D. Nyagol, G. Genga, A. Ndiege, S. Mokaya, N. Otieno, S. Juma, and E. Nyandat, B. O. K. Wanyama (BCED)*

Donors: *Gatsby Charitable Foundation, UK; DFID; Farm Africa, and the Rockefeller Foundation (BCED)*

Collaborators: *Rothamsted Research, Harpenden (UK); Kenya Agricultural Research Institute, Ministry of Agriculture and Rural Development; Ministry of Livestock and Fisheries Development (Kenya); National Agricultural Research Organisation (Uganda); Ministry of Agriculture and Food Security (Tanzania); Sasakawa Global 2000 (Ethiopia); Heifer International; CIMMYT; CIAT-TSBF; ILRI; University of Nairobi and Egerton University, Kenya (BCED)*

Collaborating department: *Behavioural and Chemical Ecology Department*

Work in progress

1. On-farm management of stemborer and striga infestation for increasing maize yield

The habitat management strategies based on the 'push-pull' and striga suppression-elimination tactics, conducted in 15 districts in Kenya have helped more than 3500 participating farmers (Figure 2) to increase their maize yields by an average of 20% in areas where only stemborers are present and by more than 50% in areas where both stemborers and striga are problems (Table 1).

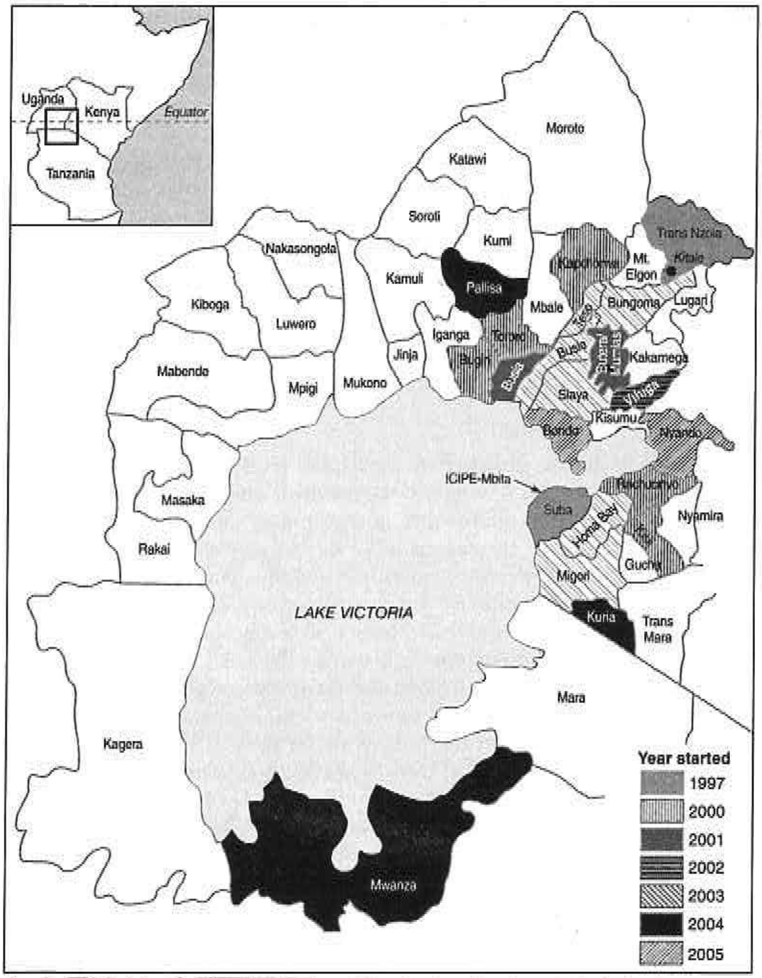


Figure 1. Districts in which the 'push-pull' technology has been adopted

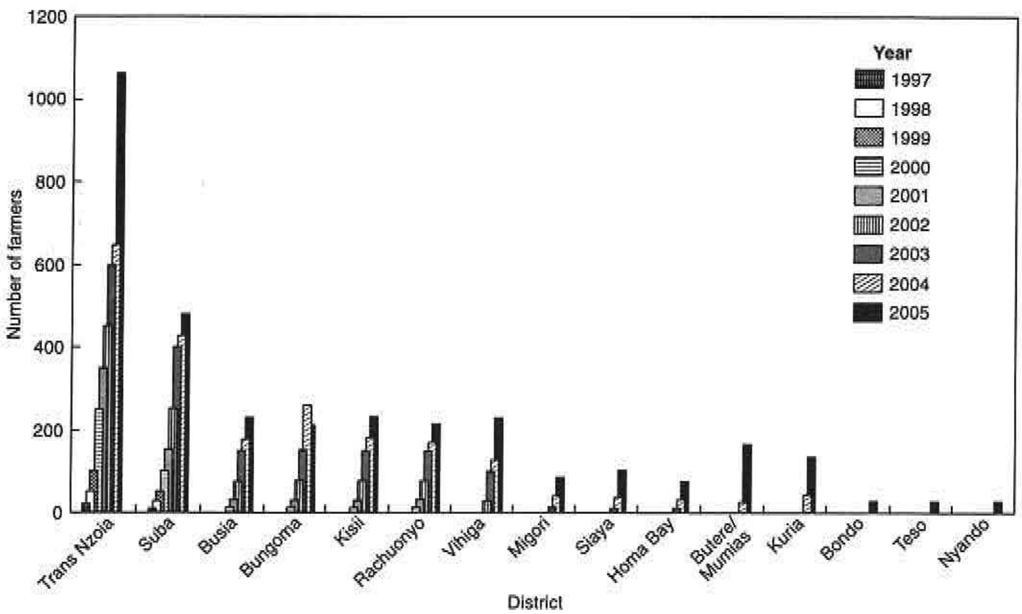


Figure 2. Adoption of the push–pull technology in Kenya, 1997–2005

Table 1. Comparison of stemborer and striga infestation, and yield of maize crop in 'push-pull' and control maize fields in various districts of Kenya in 2004 and 2005

District	No. Push-pull farmers	Stemborer infestation (%)		Striga infestation (Striga/100 maize plants)		Yield (t/ha)	
		Push-pull	Control	Push-pull	Control	Push-pull	Control
2004							
Trans-Nzoia	650	6.8	19.0**	-	-	5.4	4.1*
Suba	430	7.8	22.7**	37.6	266.4**	2.9	1.6**
Kisii	180	5.6	16.3**	2.4	41.5**	2.6	2.0*
Rachuonyo	170	4.7	18.0**	121.5	408.9**	3.7	1.9**
Bungoma	160	5.8	19.6**	4.0	150.6**	4.8	2.1**
Busia	175	4.2	10.3**	26.3	462.7**	4.1	1.9**
Vihiga	125	1.0	2.1*	52.5	393.3**	5.3	3.1**
Migori	40	15.7	31.0**	230.9	1526.4**	4.4	2.7**
Homa Bay	30	12.6	15.5 ns	56.1	125.2*	3.0	1.6*
Butere/Mumias	25	4.3	13.5**	79.2	486.8**	4.7	2.7**
Siaya	35	1.6	4.2**	76.7	875.9**	4.0	2.3**
Kuria	45	5.6	16.3**	1.5	22.6*	2.6	2.0*
2005							
Trans-Nzoia	1065	6.2	18.9**	-	-	5.7	4.1**
Suba	480	3.6	20.5**	8.9	190.5**	3.8	1.6**
Kisii	230	3.3	10.2**	3.4	27.9*	4.4	3.7**
Rachuonyo	215	0.0	2.7*	14.0	283.9**	3.8	1.4**
Bungoma	211	5.6	14.3**	11.2	176.6**	4.5	2.8**
Busia	230	5.1	15.2**	90.0	477.5**	5.6	2.7**
Vihiga	230	7.1	17.2**	87.9	602.4**	4.5	2.6**
Migori	85	5.3	28.0**	59.8	516.4**	3.6	1.7**
Homa Bay	75	4.4	11.7**	74.2	257.3**	4.3	2.2**
Siaya	100	3.0	9.5**	90.8	494.4**	3.1	1.7**
Teso	25	5.1	12.6**	420.1	1384.3**	3.8	1.1**
Butere/Mumias	165	6.2	31.3**	150.1	620.3**	5.6	2.5**
Bondo	25	8.3	14.0**	261.0	610.1**	1.7	0.9*
Kuria	135	4.1	30.9**	6.4	214.5**	4.2	1.7**
Nyando	25	1.2	8.1**	105.9	432.0**	-''	-''

- No striga in Trans-Nzoia district.
''No harvest, crop failure due to drought.
*Difference significant ($P < 0.05$); **difference significant ($P < 0.01$); ns, not significant.

2. Development of habitat management strategies for sorghum

The Project is developing strategies for control of stemborers and striga weed for sorghum farmers. *(See 2002–2003 icipe Annual Scientific Report.)* This technology will be particularly applicable for the arid and semi-arid regions where striga intensity has resulted in the abandonment of arable land by farmers. Higher crop yields and improved livestock production for sorghum and millet producing farmers would support many rural households under existing socioeconomic and agroecological conditions and thus, there would be less pressure for human migration to environments designated for protection.

On-station and on-farm trials were continued during 2004 and 2005 to evaluate effectiveness of greenleaf desmodium, *Desmodium intortum*, in controlling stemborers and striga weed when intercropped with sorghum. *Desmodium intortum* is a drought tolerant species and can fit very well with sorghum and millet. There were highly significant reductions in both *S. hermonthica* emergence and the proportion of stemborer-damaged plants in the intercrop compared to the monocrop in both trials during most of the period. Moreover, grain yields were significantly higher in the former in both trials. These results demonstrate that intercropping sorghum with *D. intortum* offers an effective control of both pests, leading to higher grain yields (Tables 2 and 3).

3. Use of food legumes for the management of striga in maize and sorghum crops

We continued to evaluate different food legumes for use in management of striga in maize and sorghum crops. Several food legumes were intercropped with maize or sorghum in on-station trials, and data on striga emergence and grain yields were collected (Table 4). Intercropping maize or sorghum with desmodium resulted in significantly lower striga infestation and enhanced grain yields than any of the five legumes tested.

Table 2. Use of greenleaf desmodium, *Desmodium intortum*, for management of striga weed and stemborers in sorghum, on-station trials at *icipe*-Mbita, 2004–2005

Cropping season	Treatment	Stemborer damage (%)	No. of striga/ 84 sorghum plants	Yield (t/ha)
2004 Long Rains	Sorghum monocrop	19.6	269.5	1.9
	Sorghum with *D. intortum*	11.9*	0.0**	2.7**
2004 Short Rains	Sorghum monocrop	9.2	130.1	3.2
	Sorghum with *D. intortum*	5.5ns	0.2**	5.7**
2005 Long Rains	Sorghum monocrop	2.9	532.2	2.9
	Sorghum with *D. intortum*	1.9*	1**	4.6**
2005 Short Rains	Sorghum monocrop	9.5	411.7	1.9
	Sorghum with *D. intortum*	2.4**	0.4**	2.9**

*Difference significant ($P < 0.05$); **difference significant ($P < 0.01$); ns not significant.

Table 3. Use of greenleaf desmodium, *Desmodium intortum*, for management of striga weed in sorghum, on-farm trials in Rachuonyo District, Kenya, 2005

Treatment	Stemborer damage (%)	No. of striga/ 84 sorghum plants	Yield (t/ha)
Sorghum monocrop	11.8	349.0	2.2
Sorghum with *D. intortum*	2.7**	78.8**	3.2*

*Difference significant ($P < 0.05$); **difference significant ($P < 0.01$).

Table 4. Use of food legumes for the management of stemborers and striga in maize and sorghum crops, long rains, 2005

Treatment	Mean striga counts/54 plants	Yield (t/ha)
Maize		
Maize + *Desmodium uncinatum*	1.2 c	5.9 a
Maize + *Crotolaria ochroleuca*	57.7 b	3.4 b
Maize + Green gram *(Vigna radiata)*	63.2 ab	2.8 bc
Maize + Groundnut *(Arachis hypogaea)*	80.2 ab	2.5 bc
Maize + Cowpea *(Vigna unguiculata)*	132.0 ab	2.3 c
Maize + beans *(Phaseolus vulgaris)*	149.0 ab	2.3 c
Maize monocrop	307.0 a	2.3 c
Sorghum		
Sorghum + *Desmodium uncinatum*	1.5 c	4.6 a
Sorghum + *Crotolaria ochroleuca*	69.3 b	3.7 b
Sorghum + Green gram	272.5 ab	2.7 c
Sorghum + Groundnut	341.5 ab	2.7 c
Sorghum + Cowpea	306.3 ab	3.0 bc
Sorghum + beans	410.8 ab	3.0 bc
Sorghum monocrop	1124.3 a	3.3 bc

For each crop (maize or sorghum) means within a column followed by different letters are significantly different ($P < 0.05$).

4. *Evaluation of 'push-pull' technology by participating and non-participating farmers*

We undertook an extensive study on perception of 900 'push-pull' participating farmers and 900 visiting farmers in 15 districts in Kenya on the technology. Participating farmers rated their own 'push-pull' fields as compared to their own practice in controlling stemborers and striga, and increasing soil fertility and maize grain yields. The visiting farmers compared the 'push-pull' strategy with control plots during field days organised in each district. The performance of the technologies was rated on a scale of 1–4, where 1 was the least and 4 the best performing.

The key criteria which farmers considered in evaluating the push-pull technology were reduced stemborer damage, reduced striga weed, increased maize grain yields and ability of the technology to improve soil fertility (Table 5). Across the districts and all the criteria, there were significant differences in the performance rating between the push-pull technology and the farmers' practices, except for reduced stemborer rating in Migori, Nyando and Rachuonyo districts as evaluated by participating farmers. Another exception was on striga rating in Bondo and Nyando districts, and also on soil fertility rating and increased maize grain yields in Bondo district by participating farmers. In both participating and non-participating groups the highest score was on reduced striga count followed by stemborer control. In addition, mean scores for increased maize yields and ability of the technology to improve soil fertility were all above 3.0 (Table 5).

5. *Sources of information regarding 'push-pull' and reasons for its adoption by farmers*

Nine-hundred farmers in 15 districts were interviewed on how they obtained information about the 'push-pull' technology and the reasons for adopting it. Farmers in most of the districts, who adopted the technology more than three years ago learnt about it from field days, farmer teachers

Table 5. Rating of 'push-pull' technology as compared to farmers' own practices by participating and visiting farmers in different districts of western Kenya, June 2005

District	Technology	Rating by practising farmers				Rating by visiting farmers			
		Reduced stemborer	Reduced striga	Increased soil fertility	Increased yield	Reduced stemborer	Reduced striga	Increased soil fertility	Increased yield
Bungoma	PP	3.3	3.5	3.4	3.9	3.7	3.6	3.4	4.0
	FP	2.7**	2.8**	2.8**	3.1**	2.2**	1.5**	2.0**	1.8**
Busia	PP	3.5	3.3	3.2	3.8	3.3	3.5	3.2	3.9
	FP	2.7**	2.6**	3.1ns	2.7**	2.2**	2.0**	2.5**	2.5**
Butere/Mumias	PP	3.3	3.1	3.1	3.5	4.0	3.9	3.3	3.9
	FP	2.7**	2.1**	2.0**	2.4**	1.4**	1.6**	1.4**	1.1**
Homa Bay	PP	3.1	3.2	3.4	3.5	3.7	3.9	3.6	3.9
	FP	1.7**	1.5**	1.9**	2.1**	1.9**	1.7**	2.0**	2.0**
Kisii	PP	3.3	2.8	3.0	3.4	3.8	3.9	3.3	4.0
	FP	2.9*	2.4ns	2.6**	2.9*	3.1*	2.6**	2.8**	3.3**
Kuria	PP	3.4	3.3	3.5	4.0	3.7	3.5	3.5	4.0
	FP	2.3**	2.0**	2.1**	2.2**	1.9**	2.2**	2.1**	2.0**
Migori	PP	3.4	3.3	3.3	4.0	3.9	3.8	3.4	4.0
	FP	3.0ns	2.0**	2.1**	2.4**	2.2**	1.3**	1.9**	1.8**
Rachuonyo	PP	3.0	3.0	2.9	3.1	3.8	3.7	3.2	4.0
	FP	2.7*	2.2**	2.3**	2.6*	2.1**	1.6**	2.5*	1.7**
Siaya	PP	3.6	3.5	3.3	3.7	3.5	3.5	3.5	4.0
	FP	2.4**	2.2**	1.8**	2.7**	2.5**	2.2**	1.9**	1.6**
Suba	PP	3.5	3.8	3.2	3.6	-++	-++	-++	-++
	FP	2.7**	2.4**	2.3**	2.7**	-++	-++	-++	-++
Vihiga	PP	3.7	3.8	3.6	4.0	3.7	3.8	3.6	4.0
	FP	1.8**	2.3**	2.1**	1.9**	1.8**	2.3**	2.1**	1.9**
Trans-Nzoia	PP	3.7	-	3.3	4.0	3.7	-	3.3	4.0
	FP	1.6**	-	1.7**	1.6**	1.6**	-	1.7**	1.6**
Bondo*	PP	3.0	1.8	2.6	2.2	3.3	3.4	3.1	4.0
	FP	2.8ns	1.5ns	2.0*	2.1ns	2.3**	1.9**	2.2**	1.5**
Nyando*	PP	2.4	1.9	2.8	2.4	3.5	3.9	3.4	3.8
	FP	2.3ns	1.8ns	2.1**	1.8ns	1.4**	1.8**	1.8**	1.6**
Teso*	PP	3.7	2.9	3.2	3.6	3.8	3.7	3.5	4.0
	FP	2.4**	1.5**	2.1**	1.7**	2.1**	1.7**	1.7**	1.3**

Rating scale of 1–4, where 1 is the least performing and 4 is the best performing technology.
PP, Push-pull technology; FP, Farmer's own practice; *New districts where farmers adopted the push-pull technology in the long rains season of 2005; –, no striga in Trans Nzoia; -++, rating not done; *, difference significant ($P < 0.05$); **, difference significant ($P < 0.01$); ns, difference not significant ($P > 0.05$).

and earlier adopters, whereas the majority of farmers in the three new districts (Bondo, Nyando and Teso) learnt about it mainly from a national radio programme 'Tembea na Majira' (Figure 3). More than 80% of the farmers in Butere/Mumias, Homa Bay, Migori, Suba and Vihiga districts indicated striga control as the main reason for adopting the technology, whereas majority of the farmers in Trans-Nzoia district adopted it for stemborer control (Figure 4). Increased farm productivity was also reported as another reason for adopting the technology by about 25% of the farmers in Bondo, Bungoma, Kisii, Kuria, Siaya and Teso districts (Figure 4). Soil improvement as the primary reason for adopting the technology appeared low.

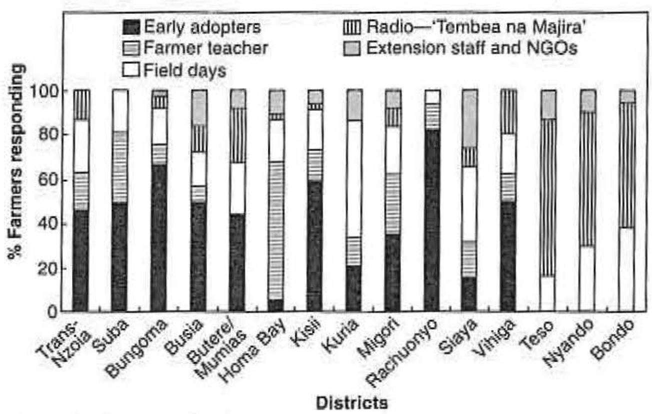


Figure 3. Sources of information on the 'push-pull' technology and proportions of farmers who accessed them before adopting 'push-pull' in different districts

6. *Farmers' perception of benefits realised following adoption of the 'push-pull' technology*

Majority of farmers in 9 out of 10 districts (except Trans-Nzoia) reported a reduction/decrease in striga infestation on their farm after adopting the 'push-pull' technology (Figure 5). About 80% of the farmers in Trans-Nzoia, Homa Bay, Kisii and Suba districts, and more than 50% of those in Bungoma, Butere/Mumias, Migori and Teso districts reported reduced stemborer infestation after adopting the technology. Over 80% of the farmers in Busia district, and over 50% in Bungoma, Migori, Suba and Teso reported an improvement in soil fertility in the 'push-pull' plots as a result of reduced soil erosion and increased nitrogen fixation. Increase in maize and fodder production was reported by majority of farmers in all the 10 districts following adoption of the technology, whereas more than 50% of the farmers in Kisii, Suba and Trans-Nzoia districts reported an increase in milk production due to increased fodder production (Figure 5).

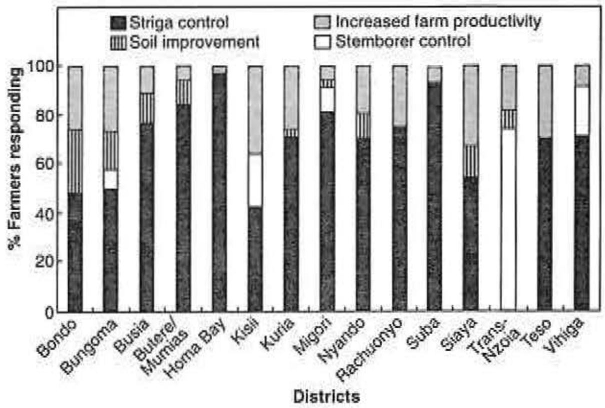
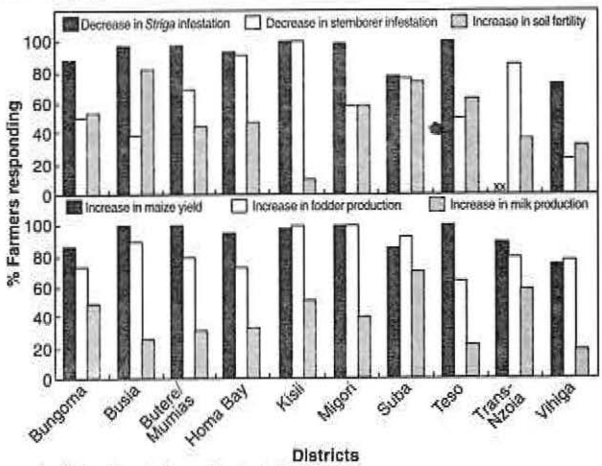


Figure 4. Reasons given by farmers for adopting the 'push-pull' technology in different districts

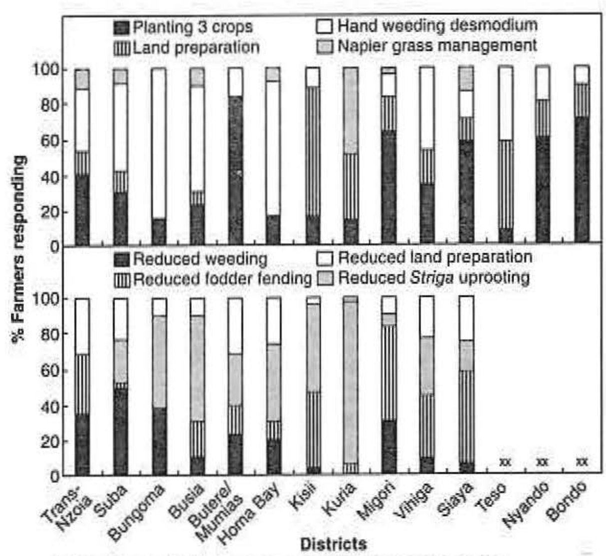


xx No striga in Trans-Nzoia district

Figure 5. The benefits realised by farmers following adoption of the 'push-pull' technology in various districts in Kenya

7. *Farmers' perception about labour issues on adoption of the 'push-pull' technology*

Labour has been an important constraint in the adoption of new technologies. A study was undertaken in 14 districts of Kenya on farmers' perception on labour changes following adoption of the 'push-pull' technology. In all the districts in Kenya, 94–100% of new adopters reported an increase in labour requirement during the first year of establishment of the technology as compared to their own practice. However, 88–100% of 'push-pull' practising farmers reported a decrease in labour requirement in subsequent years in the 'push-pull' plots as compared to their own practice (Figure 6). Farmers in Butere/ Mumias, Migori, Siaya, Nyando and



xx New districts where the push-pull technology was introduced in 2005

Figure 6. Reasons for changes in the labour requirement following adoption of the 'push-pull' technology

Bondo districts reported that labour increase in the first year was mainly due to planting of the 3 crops (maize, Napier grass and desmodium) at the same time (Figure 6). Increase in labour in the first year in Suba, Bungoma, Busia and Homa Bay districts was mainly attributed to hand weeding of young desmodium plants, whereas, farmers in Kisii and Teso districts found land preparation and marking of the field for establishment of the technology as being the most labour intensive. The decrease in labour in subsequent years in established 'push-pull' plots was mainly due to reduced weeding, reduced striga uprooting, reduced fodder fending and reduced labour on land preparation (Figure 6).

8. *Economics of the 'push-pull' technology*

A formal cost–benefit analysis covering six districts in Kenya (Bungoma, Busia, Kisii, Suba, Trans-Nzoia and Vihiga), measured farmers' income, expenditure, use of inputs and labour. Ten farmers were followed from the time they adopted the 'push-pull' technology, and the parameters compared between the push-pull and their conventional cropping system (maize monocrop). Data comprised total variable costs, TVC (labour and non-labour costs), total revenues, TRV (arising from sales of farm produce) and gross benefits (TRV–TVC). The results showed that TVC were significantly higher in 'push-pull' than in traditional maize monocrop plots. However, total gross revenue and gross benefits were also significantly higher with the 'push-pull' technology than with the maize monocrop system, with the benefits outweighing the costs by an average of US$ 530 in the 'push-pull' system but only US$ 140 in the maize monocrop system (Table 6).

Table 6. Economics of 'push-pull' strategy as compared to maize monocrop (control) in six districts in western Kenya, 1998–2004

	Total labour costs ($/ha)		Total variable costs ($/ha)		Total gross revenue ($/ha)		Gross benefits ($/ha)	
District	Push-Pull	Control	Push-Pull	Control	Push-Pull	Control	Push-Pull	Control
Trans-Nzoia **a**	223	128*	493	374*	1290	628**	797	254**
Suba **b**	167	134*	278	250*	679	329**	401	79**
Bungoma **c**	247	222ns	331	300*	867	415**	536	115**
Busia **c**	222	118*	321	243*	862	418**	541	175**
Kisii **c**	184	140*	246	210*	733	334**	487	134**
Vihiga **c**	227	128*	359	331*	423	185**	426	92**

a, b, c represent data averages for 7, 4 and 3 years respectively.
*Difference significant ($P < 0.05$); **difference significant ($P < 0.01$); ns, difference not significant.

9. *'Push-pull' and striga seed depletion*

A long-term study at the *icipe* field station at Mbita Point demonstrated a sharp decline in striga seed count in the 'push-pull' plots over 6 years (Figure 7). In another long-term trial, a comparison of maize–desmodium intercrops with maize monocrop and maize–cowpea intercrop showed significant increases in the striga seed counts in the soil in the maize monocrop and maize–cowpea intercrop, but significant decreases in the maize–desmodium intercrops (Figure 8).

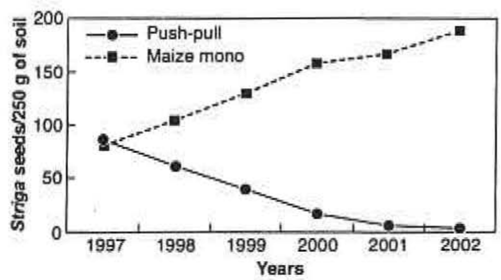


Figure 7. Effect of a long-term push-pull field trial on striga seed density in the soil at *icipe*-Mbita, western Kenya

10. *Enhancing biodiversity through the 'push-pull' technology*

Biodiversity in agroecosystems has greatly been reduced in the last decades as a result of intensification of cereal agricultural systems, while empirical data show that agroecosystems with an enhanced overall biodiversity have relatively fewer pest problems. As a result of this observation it has often been stated that enhancement of biodiversity within agroecosystems can greatly contribute to the development of sustainable crop protection systems, with a reduced reliance on pesticides. Biodiversity has an intricate role in the functioning of natural and agricultural ecosystems since it performs a variety of ecological services thereby mediating processes such as genetic

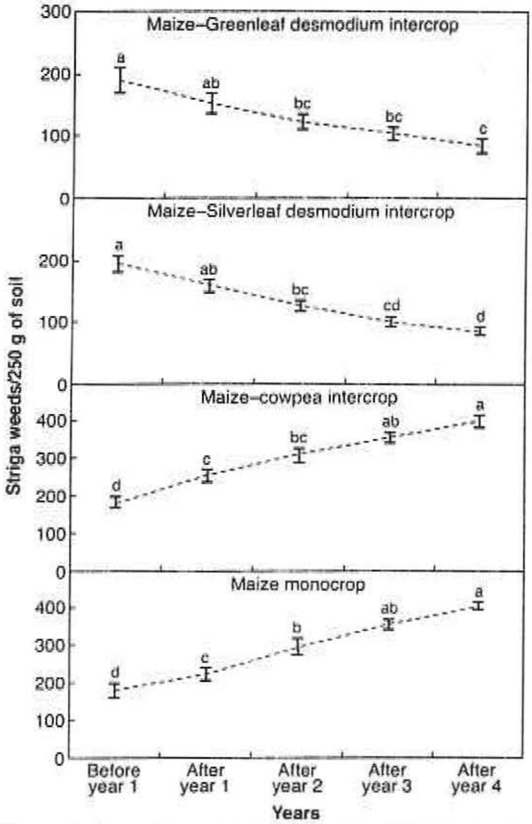


Figure 8. Annual changes in striga soil seed density in different intercrops and maize monocrop. Means marked with different letters within a cropping system are significantly different ($P < 0.05$)

Table 7. Mean (± SE) number of spiders captured per plot in Kenya (Lambwe and Homa Bay) and South Africa (Potchefstroom), 2004

	Kenya		South Africa
Treatment	Lambwe	Homa Bay	Potchefstroom
Maize monocrop	196.5	55.5	19.7
'Push-pull' system	266.2**	103.0**	48.7*

*Difference significant ($P < 0.05$); **difference significant ($P < 0.01$).

introgression, natural pest control, nutrient cycling and decomposition. Farming practices that conserve such biodiversity as ground fauna and pests' natural enemies may be a practical alternative to manage pests in agricultural systems. Our results from Kenya and South Africa, using spiders (Araneae) as an indicator group, indicate that the 'push-pull' strategy is associated with an overall enhancement of ground-dwelling arthropod abundance (Table 7).

11. 'Push-pull' technology and IR maize

In collaboration with CIMMYT, TSBF and national partners, demonstrations with best-bet technologies for the control of striga and stemborers, and enhancement of soil fertility were continued in 2005 in both the long rainy season (March to July) and the short rainy season (September to January) in Kenya and Uganda. *(See 2002–2003 icipe Annual Scientific Report.)* Components of these best-bets were cropping systems (maize intercropped with stemborer moth-repellent *Desmodium* ['push'] with stemborer moth-attractant Napier grass ['pull'] planted around the field ['push-pull' system], continuous maize and rotations with grain [soybean] and herbaceous [*Crotolaria*] legumes). Their effect on suppression of striga and stemborers and soil fertility improvement were compared using two maize varieties (Imidazolinone-resistant [IR] and an improved commercial variety) under two fertiliser levels (no fertiliser and medium fertiliser). Stemborer damage to maize varied substantially between locations and seasons and the 'push-pull' technology was observed to suppress stemborer damage (Figures 9 and 10). The push pull technology consistently suppressed striga emergence in both seasons (Figures 11 and 12). Fertiliser application did not show significant reductions in either stemborer or striga infestations. Striga seed count before and after six cropping seasons showed that the 'push-pull' system and *Crotolaria* rotation were the only systems where there was a decrease in striga seed population while all the other cropping systems resulted in seed density increases (Figure 13).

Farmers' perceptions and evaluation of 'push-pull', IR maize and crop rotation

In collaboration with CIMMYT and KARI, a total of 142 farmers in Siaya and Vihiga districts of western Kenya evaluated these trials using striga and stemborer control, soil fertility enhancement, grain yield, labour saving, crop vigour, fodder supply, soil erosion reduction and overall crop performance as the main criteria. They scored each treatment for each criterion, and an overall score of the treatment, using a scale of 1 (very poor) to 5 (very good). Using ordinal regression analysis, a short model was estimated as $Yj = f(Xj)$, where Y is overall farmer evaluation score from

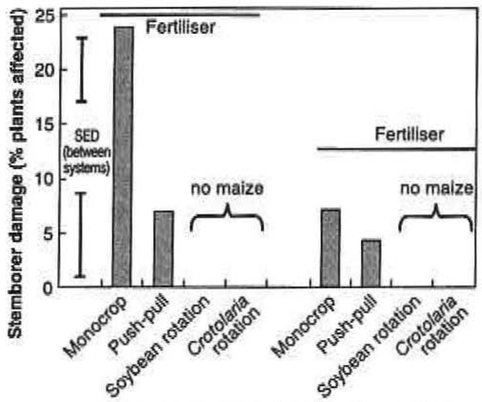


Figure 9. Effect of cropping systems by fertiliser, or lack of, on plant damage by stemborers in Busia District, Uganda

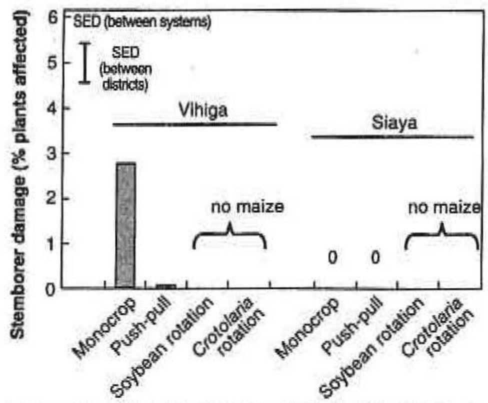


Figure 10. Effect of cropping systems by district on plant damage by stemborers during the long and short rainy season of 2005 in western Kenya

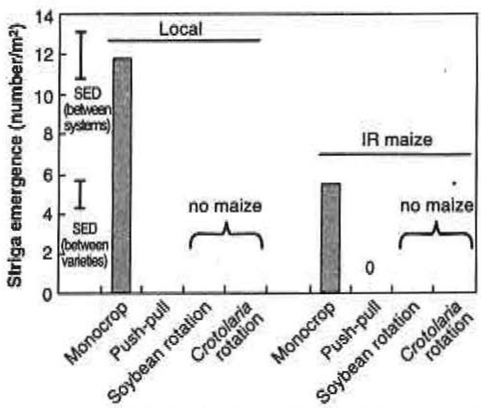


Figure 11. Effect of cropping systems by variety on striga emergence during the long and short rainy season of 2005 in western Kenya

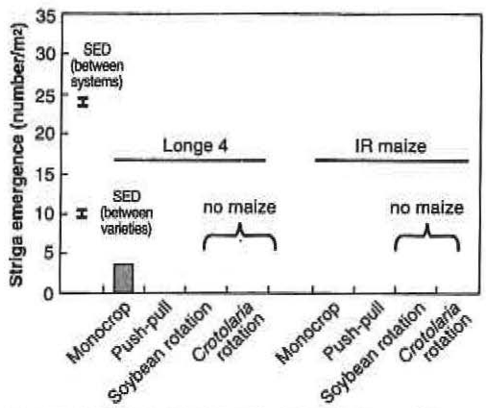


Figure 12. Effect of cropping systems by variety on striga emergence during the long and short rainy seasons of 2005 in Busia District, Uganda

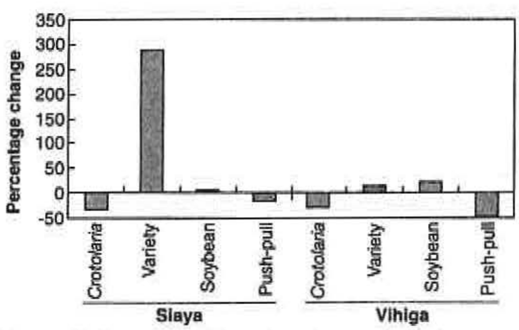


Figure 13. Percentage change in striga seed population in the soil after 6 cropping seasons with different management options in western Kenya

1–5 of treatment Xj. Results showed that treatments were significantly different, with the 'push-pull' trials being generally more preferred (Table 8) than the other technologies.

The estimated 15 coefficients are log-odds ratios compared to the last entry, here the maize monocrop of local variety without fertiliser application. For example, the estimate 1.99 is an exponent and its antilog yields the number of times (7.3) that treatment 1 ('push-pull' with IR-maize and fertiliser) is more preferred compared to treatment 16 (local maize monocrop with no fertiliser application). Overall, the 'push-pull' treatments were generally the most preferred, 4.4 to 7.3 times. The preference of maize–soybean and maize–crotolaria rotations ranged between 1.8 and 5.4 times and 3 and 3.3 times respectively. However, when split, treatments were rated significantly different in the two districts. Farmers in Siaya generally rated the 'push-pull' combinations higher than those in Vihiga, who rated maize–legume rotations higher. The monocrop was rated the lowest in both districts. These results show an overall preference of the 'push-pull' combinations over the other technologies. Further studies are needed over a range of socioeconomic situations and agroecological zones to validate these findings.

Table 8. Appreciation of technologies in general and by district, short rains 2005

	Components of treatment			Estimates of odds ratio			
Treatment	Technology	Maize variety	Fertiliser	Both districts (short model)	Standard error	Vihiga	Cross effect of Siaya
1	Push-pull	IR	yes	1.99***	0.218	0.73**	3.00***
2		IR	no	1.54***	0.216	0.53*	2.42***
3		Local	yes	1.48***	0.216	0.68**	2.00***
4		Local	no	1.63***	0.216	0.64**	2.60***
5	Maize–soybean	IR	yes	1.69***	0.218	1.04**	1.60***
6		IR	no	0.66***	0.215	0.11	1.13***
7		Local	yes	1.11***	0.216	1.29***	-0.48
8		Local	no	0.56**	0.215	1.68***	-2.81***
9	Maize–*Crotolaria*	IR	yes	1.16***	0.217	1.91***	-1.91***
10		IR	no	1.19***	0.216	0.95***	0.57*
11		Local	yes	1.10***	0.216	2.11***	-2.35***
12		Local	no	1.17***	0.216	0.95***	0.47
13	Monocrop	IR	yes	0.08	0.215	-0.02	-0.08
14		IR	no	0.05	0.214	-0.23	0.32
15		Local	yes	0.53**	0.215	1.11***	-1.60***
16		Local	no	0		0	-0.35
Log likelihood					1115.8	431.54	
χ^2					246.02	234.49	

***significant at 1%, **significant at 5%, *significant at 10%.

12. Benefits of incorporating the Bt-technology into the 'push-pull' strategy

Transgenic (Bt-maize) maize cultivars have been developed to control cereal stemborers. These have a foreign gene from *Bacillus thuringiensis* (Bt), a bacterium that produces insecticidal crystalline proteins during sporulation, incorporated into the DNA of maize making it toxic to some species of lepidopteran pests that feed on it. The usefulness of the cultivars may be cut short should the target pests develop resistance to them. Our studies have indicated that the 'push-pull' strategy significantly reduces stemborer infestations in the main crop. Any tactic that appreciably reduces the number of individuals of the target pest getting exposed to the Bt-toxin is desirable in an integrated resistance management strategy. Our studies in South Africa show that incorporating push-pull into the Bt-technology significantly reduces infestation of the maize by the stemborers (Figure 14), significantly enhances predator populations (Figure 15) and

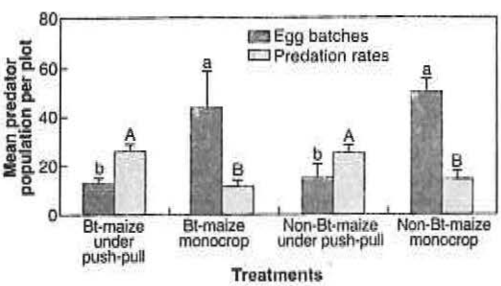


Figure 14. Mean number of *Chilo partellus* egg batches and % egg predation rates per plot at Potchefstroom, South Africa, 2004

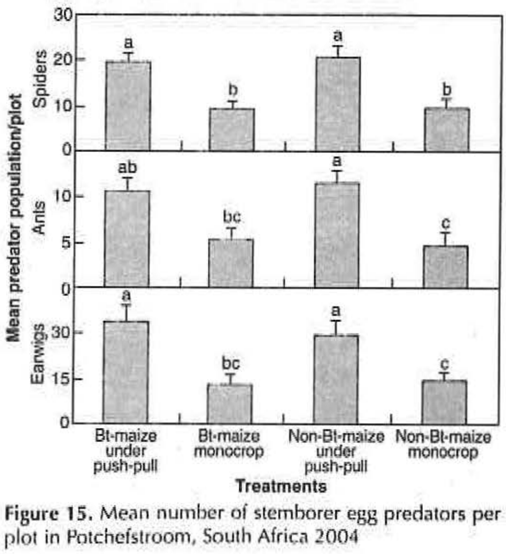


Figure 15. Mean number of stemborer egg predators per plot in Potchefstroom, South Africa 2004

their efficacy on *C. partellus* eggs (Figure 14). Our studies indicate a potential role of the system becoming a component in Bt-resistance management for the pest. Further studies are needed to elucidate the socioeconomics of the system compared with 'push-pull' based on non-Bt maize.

13. Ability of the 'push-pull' strategy to sustain its benefits in a different environment

The 'push-pull' system is expanding in East Africa and trials are also ongoing in South Africa following an extensive survey of wild hosts of stemborers and studies on colonisation, growth and survival of stemborers in indigenous grasses in the country. Studies conducted in Kenya have consistently shown the system's effectiveness in controlling the pests and enhancing grain yields. It was thus desirable to assess whether the strategy would offer similar levels of benefits in a different environment. This is important as the pest management mechanisms of the 'push-pull' strategy may vary regionally/locally because herbivore assemblages may differ as well as characteristics of the plants. We therefore carried out a step-wise assessment of the impact of this system on maize stemborer colonisation, crop damage and yield in the dominant maize production systems of Kenya and South Africa. Results established that *C. partellus* and *B. fusca* were the main stemborer species at all sites, with the former being relatively more abundant in Kenya while the latter was relatively more abundant in South Africa. The numbers of egg batches of both species were significantly higher in the maize monocrop than the 'push-pull' systems in both countries. The incidence of the larvae and pupae (combined for both species) was significantly higher in maize monocrop than 'push-pull' systems in both countries (Table 9). There was significantly more plant damage (number of entry/exit holes per plot, the percentage number of plants with leaf damage and plants with broken stems) caused by stemborer larval feeding in the maize monocrop than in the 'push-pull' plots in both countries (Table 10).

Table 9. Average (± SE) number of stemborer egg batches and larvae and pupae per plot in Kenya (Lambwe and Homa Bay) and South Africa (Potchefstroom), 2004

Stemborer life stage		Kenya		South Africa
		Lambwe	Homa Bay	Potchefstroom
Chilo partellus egg batches/ plot	Monocrop	27.1	19.4	16.5
	Push-pull	11.2**	7.9**	4.2**
Busseola fusca egg batches/ plot	Monocrop	20.2	16.6	19.0
	Push-pull	8.1**	5.1**	5.2**
Larvae and pupae/plot	Monocrop	54.7	37.2	39.7
	Push-pull	20.1**	20.8*	16.2**

*Difference significant ($P < 0.05$); **difference significant ($P < 0.01$).

Table 10. Mean (± SE) maize plant damage levels per plot in Kenya (Lambwe and Homa Bay) and South Africa (Potchefstroom), 2004

Damage parameter		Kenya		South Africa
		Lambwe	Homa Bay	Potchefstroom
% plants with foliar damage	Monocrop	32.9	26.7	44.3
	Push-pull	12.1**	5.8**	11.1**
% dead plants	Monocrop	3.9	4.0	1.4
	Push-pull	1.2**	1.0**	1.2ns
Stemborer entry/ exit holes	Monocrop	15.5	14.6	14.9
	Push-pull	8.1**	6.7**	8.9*
% plants with broken stems	Monocrop	4.7	4.2	3.6
	Push-pull	0.8**	0.9**	1.5*

*Difference significant ($P < 0.05$); **difference significant ($P < 0.01$); ns, difference not significant.

14. Electrophysiological responses of stemborers to the volatiles from wild and cultivated host plants

Volatiles released by two cultivated hosts, sorghum and maize (*Sorghum bicolor* and *Zea mays*), and two wild grass hosts (*Pennisetum purpureum* and *Hyparrhenia tamba*), were collected by air entrainment. Electrophysiologically active components in these samples were located by coupled gas chromatography-electroantennography (GC-EAG) and the active peaks identified by gas chromatography-mass spectrometry and co-injection with authentic standards. A total of 41 compounds were identified from the four plant species, all of which, as well as two unidentified compounds, elicited an electrophysiological response from one or both of the stemborers. The compounds included a number of greenleaf volatiles and other aliphatic aldehydes, ketones and esters, mono- and sesquiterpenoids and some aromatic compounds (Figure 16).

EAG studies with authentic samples, conducted at two discriminating doses for all compounds, and dose-response curves for 14 of the most highly EAG-active compounds, showed significant differences in relative responses between species. The compounds which elicited large responses in

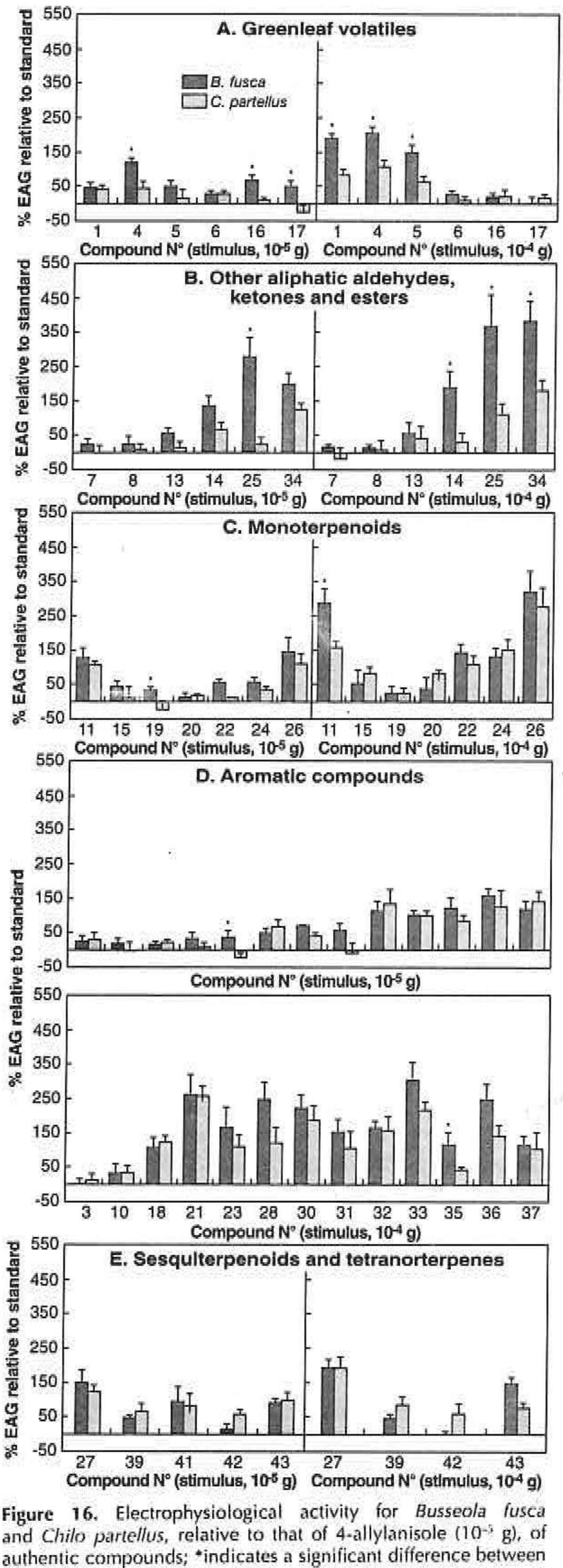


Figure 16. Electrophysiological activity for *Busseola fusca* and *Chilo partellus*, relative to that of 4-allylanisole (10^{-5} g), of authentic compounds; *indicates a significant difference between the responses of the two species ($P < 0.05$)

both species of moth included linalool, acetophenone and 4-allylanisole, while a number of compounds such as the aliphatic aldehydes octanal, nonanal and decanal elicited a large response in *Busseola fusca*, but a significantly smaller response in *Chilo partellus* (Table 11). Furthermore, the wild hosts produced significantly higher levels of physiologically active compounds, overall, compared with either of the cultivated hosts. This study provides insights into possible host location kairomones used by these two species of stemborers and into the differential attraction/oviposition between cultivated and wild hosts observed in the field. In particular, it provides some essential scientific input required for sustainability of the 'push-pull' strategy.

15. Mechanisms of striga suppression by *Desmodium uncinatum*

It has been demonstrated that a combination of two allelochemicals (germination stimulant and post-germination radicle inhibition) is responsible for continual elimination of striga seeds observed in maize–*Desmodium* intercrops. *(See 2002–2003 icipe Annual Scientific Report.)* Bioassays of different chromatographic fractions of adsorbent-trapped collections of *Desmodium* root exudates had indicated that different sets of constituents are associated with the two activities and that the most potent radicle inhibitors are located in the polar region of the complex exudate blend.

Follow-up efforts to isolate active allelochemicals from the root exudates of *Desmodium* led to the characterisation of three novel structurally related isoflavanoids of medium polarity, one with uncyclised and the other two with cyclised (furanoid) isopropenyl moiety in ring A. The two with isoproprenylfurano rings were active, one as a striga germination stimulant (**I**) and the other (**II**), with one of the phenoxy OH group methylated, as a moderate radicle inhibitor of the germinated seeds. In addition, a polar

Table 11. Quantities (ng) of EAG-active components in the volatiles[1] from host plants of the stemborers *Chilo partellus* and *Busseola fusca*

Compound	*Pennisetum purpureum* (N = 5)	*Hyparrhenia tamba* (N = 3)	*Sorghum bicolor* (N = 4)	*Zea mays* (N = 2)
Green leaf volatiles and other aliphatic compounds				
1 (*E*)-2-pentenal	0.2 ± 0.1	0.5 ± 0.1	0.4 ± 0.2	nd
4 hexanal	5.0 ± 5.0	1.3 ± 0.4	0.9 ± 0.1	0.3 ± 0.3
5 (*E*)-2-hexenal	4.7 ± 3.8	0.9 ± 0.5	0.3 ± 0.1	1.2 ± 0.2
6 (*Z*)-3-hexen-1-ol	12.3 ± 11.3	3.3 ± 3.0	1.7 ± 0.4	1.3 ± 0.4
7 3-methylbutyl acetate	0.4 ± 0.2	1.9 ± 1.0	0.4 ± 0.1	0.8 ± 0.0
8 pentyl acetate	0.4 ± 0.4	0.5 ± 0.3	0.3 ± 0.2	nd
13 6-methyl-5-hepten-2-one	2.4 ± 1.1	3.9 ± 2.3	1.2 ± 0.7	1.2 ± 0.5
14 octanal	3.4 ± 2.0	14.7 ± 10.2	2.0 ± 1.1	5.8 ± 2.3
16 (*Z*)-3-hexen-1-yl acetate	120.0 ± 117.0	23.1 ± 8.6	3.3 ± 1.5	1.3 ± 0.7
17 hexyl acetate	1.6 ± 0.8	3.4 ± 2.0	1.3 ± 0.6	2.2 ± 0.1
25 nonanal	4.5 ± 3.6	9.4 ± 6.7	5.4 ± 3.5	<0.1
34 decanal	8.7 ± 7.2	8.0 ± 6.8	7.7 ± 5.8	<0.1
Aromatic compounds				
3 toluene	0.4 ± 0.3	0.7 ± 0.1	2.0 ± 0.6	1.7 ± 0.4
10 benzaldehyde	0.3 ± 0.3	3.5 ± 1.9	0.1 ± 0.1	0.7 ± 0.1
12 propylbenzene	1.2 ± 0.8	3.6 ± 3.1	0.4 ± 0.2	2.7 ± 0.6
18 phenylacetaldehyde	1.7 ± 1.3	11.9 ± 6.1	0.2 ± 0.1	1.1 ± 0.4
21 acetophenone	3.0 ± 1.8	1.1 ± 1.1	0.3 ± 0.3	3.2 ± 3.2
23 methyl benzoate	0.9 ± 0.5	3.3 ± 2.0	1.0 ± 0.5	0.9 ± 0.5
28 2-ethylbenzaldehyde	nd	0.3 ± 0.3	nd	nd
29 3-ethylbenzaldehyde	2.0 ± 0.9	3.2 ± 1.8	4.4 ± 2.9	0.3 ± 0.3
30 4-ethylbenzaldehyde	0.1 ± 0.1	0.5 ± 0.5	0.6 ± 0.2	6.9 ± 6.9
31 naphthalene	0.8 ± 0.6	2.9 ± 2.2	0.8 ± 0.4	nd
32 methyl salicylate	3.2 ± 2.1	12.3 ± 8.3	0.8 ± 0.4	10.5 ± 10.5
33 4-allylanisole	0.1 ± 0.1	0.4 ± 0.2	0.2 ± 0.2	nd
35 indole	27.1 ± 20.7	1.6 ± 0.8	0.2 ± 0.2	2.7 ± 2.7
36 4-ethylacetophenone	3.5 ± 1.9	1.3 ± 0.7	nd	2.3 ± 2.3
37 eugenol	0.6 ± 0.2	0.3 ± 0.3	0.3 ± 0.3	nd
Terpenoids				
11 α-pinene[2]	1.8 ± 1.1	1.8 ± 1.3	0.3 ± 0.2	5.1 ± 0.1
15 myrcene	0.7 ± 0.7	2.2 ± 1.9	0.3 ± 0.1	1.8 ± 1.8
19 1,8-cineole	nd	1.8 ± 1.3	nd	1.5 ± 0.2
20 limonene[2]	1.4 ± 0.7	4.1 ± 2.3	2.7 ± 1.6	2.0 ± 0.7
22 (*E*)-ocimene	0.6 ± 0.3	1.7 ± 1.3	nd	6.2 ± 1.4
24 α-terpinolene	nd	0.1 ± 0.1	nd	nd
26 linalool[2]	1.5 ± 0.9	14.2 ± 9.8	2.0 ± 0.9	0.6 ± 0.1
27 (*E*)-4,8-dimethyl-1,3,7-nonatriene	55.3 ± 19.1	21.0 ± 10.8	39.6 ± 11.6	2.9 ± 2.1
38 α-copaene[2]	0.4 ± 0.4	1.1 ± 1.0	0.7 ± 0.4	1.4 ± 1.4
39 β-caryophyllene[2]	21.5 ± 14.1	5.7 ± 2.7	19.5 ± 6.3	0.4 ± 0.4
40 bergamotene[2]	0.9 ± 0.8	0.3 ± 0.1	2.3 ± 0.6	0.4 ± 0.2
41 (*E*)-β-farnesene	0.3 ± 0.3	1.3 ± 0.1	4.4 ± 1.5	0.2 ± 0.2
42 α-humulene	1.3 ± 0.9	0.5 ± 0.3	0.8 ± 0.3	nd
43 (*E,E*)-4,8,12-trimethyl-1,3,7,11-tridecatetraene	3.0 ± 0.5	14.5 ± 5.7	0.8 ± 0.1	1.35 ± 1.35
Unknowns				
2 KI = 743	0.5 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	nd
9 KI = 911	nd	1.6 ± 1.0	0.3 ± 0.2	nd
Total volatiles	294.8	186.5	103.4	70.3

[1]Compound numbers refer to the order in which they were eluted from an HP-1 GC column.
[2]The optical isomers of these compounds were not characterised.
Samples were collected for 10–12 h (starting from the 4th hour of the photophase).
The amounts of volatiles are estimates based on the total area under the reported peaks compared with the peak area of the internal standard (100 ng).
nd, below the detection limits of 0.05 ng.

post-germination inhibitor was isolated and shown to be a di-glycosyl flavone (**III**). These results suggested relatively strict structural requirements for striga germination and its post-germination inhibition, respectively. *(See 2002–2003 icipe Annual Scientific Report.)*

The focus during the last two years has been on comprehensive isolation and characterisation of candidate allelochemicals from *Desmodium* root extracts and evaluation of their bioactivities individually and in blends. Identification of active constituents of these fractions and if they act additively or synergistically would provide a useful basis of assessing the biotechnological potential of *Desmodium* genomics and the possible course such a venture could take.

The effect of the bulk organic extracts of *Desmodium* roots on *Striga* was compared with that of the aqueous root exudates. The polar MeOH extract, like the aqueous root exudates, was found to exhibit low striga germination stimulation activities but high post-germination inhibition. Acetone extract was found to be relatively active both as a germination stimulant and a post-germination radicle inhibitor, whereas the dichloromethane extract exhibited striga germination stimulation activities but did not inhibit the post-germination growth of striga (Figures 17 and 18). The results confirmed the previously observed pattern, with germination stimulation associated largely with the less polar extracts and post-germination inhibition with the more polar region.

Fractionation of the CH_2Cl_2 extract of *D. uncinatum* roots (vacuum liquid chromatography on silica gel and eluting with hexane-acetone mixtures with increasing proportion of acetone) yielded four fractions (A, B, C and D). Fractions A, B, C and D were eluted with 100% n-hexane; 5% acetone-hexane; 20% acetone-hexane and 50–100% acetone-hexane respectively. These fractions were tested for germination stimulation of *S. hermonthica* seeds (Table 12).

Fractionation of the acetone root extract by *D. uncinatum* by vacuum liquid chromatography on C-18 reverse phase silica, yielded fractions ACF1 to ACF5 by eluting with 50% $MeOH/H_2O$, 75% $MeOH/H_2O$, 90% $MeOH/H_2O$, 100% MeOH and 100% acetone, respectively. The fractions were tested for their effects on germination and post-germination growth of *S. hermonthica* (Tables 13 and 14).

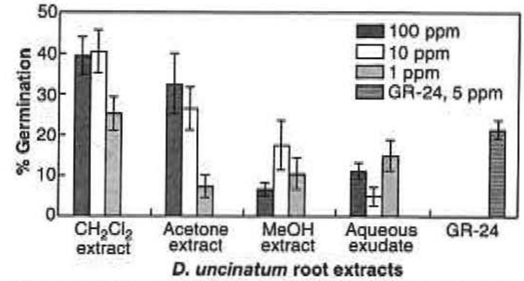


Figure 17. Germination response of *Striga hermonthica* seeds to *Desmodium uncinatum* root extracts at varying concentrations (values are means ± SE, n = 10)

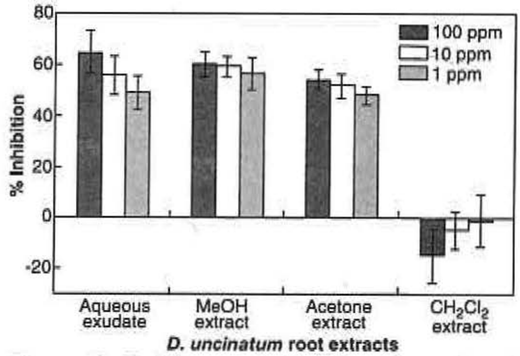


Figure 18. Radicle growth inhibition of germinated *Striga hermonthica* seeds exposed to the root extracts of *Desmodium uncinatum* at varying concentrations (values are means ± SE, n = 10)

Table 12. Germination response of *Striga hermonthica* seeds to fractions of CH_2Cl_2 extract of *Desmodium uncinatum* roots at varying concentrations

	Percentage mean germination (± SE), n = 10		
Fraction	100 ppm	10 ppm	
A	0.63 (0.63) d	0.4 (0.24) d	
B	46.23 (1.88) bc	42.61 (1.25) c	
C	57.64 (3.98) ab	50.22 (2.82) bc	
D	67.80 (3.65) a	53.83 (4.30) bc	
GR-24, 5 ppm			50.17 (4.66) bc

Means with the same letter are not significantly different ($P \leq 0.05$, Tukey's studentised range test).

Table 13. Germination response of *Striga hermonthica* seeds to fractions of acetone extract of *Desmodium uncinatum* roots at varying concentrations

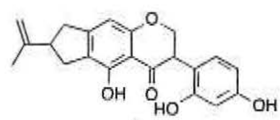
	Percentage mean germination (± SE), n = 16			
Treatment	100 ppm	10 ppm	1 ppm	
ACF1	29.58 (1.85) cd	1.78 (1.20) f	0.00 (0.00) f	
ACF2	46.66 (3.99) a	40.88 (3.03) ab	33.25 (3.34) bcd	
ACF3	34.42 (3.56) bc	22.99 (2.64) de	23.47 (2.99) cde	
ACF4	0.00 (0.00) f	2.46 (1.92) f	0.37 (0.37) f	
ACF5	4.13 (1.53) f	2.79 (1.02) f	0.00 (0.00) f	
GR-24, 5 ppm				16.97 (2.49) e

Means with the same letter are not significantly different ($P \leq 0.05$, Tukey's studentised range test).

Table 14. Radicle growth inhibition of germinated *Striga hermonthica* seeds exposed to fractions of acetone extract of *Desmodium uncinatum* roots at varying concentrations

Treatment	Concentration (ppm)	Radicle length (mm) (n = 16)	Percentage radicle length reduction
ACF1	100	0.20 (0.01) e	72.60
	10	0.27 (0.02) e	63.01
	1	0.36 (0.03) de	50.68
ACF2	100	0.31 (0.03) e	57.53
	10	0.58 (0.03) abc	21.23
	1	0.76 (0.03) ab	-3.42
ACF3	100	0.38 (0.03) cde	47.95
	10	0.56 (0.03) bcd	23.97
	1	0.71 (0.05) ab	2.74
ACF4	100	0.67 (0.05) ab	8.22
	10	0.75 (0.06) ab	-2.05
	1	0.74 (0.05) ab	-0.68
ACF5	100	0.73 (0.04) ab	0.68
	10	0.77 (0.04) a	-4.79
	1	0.76 (0.06) ab	-3.42
GR-24	5	0.73 (0.06) ab	0.00

Means with the same letter are not significantly different ($P \leq 0.05$, Tukey's studentised range test).



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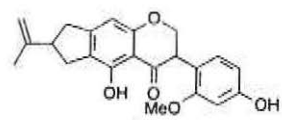

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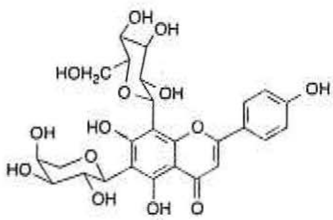

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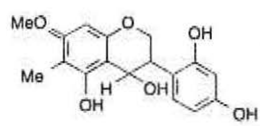

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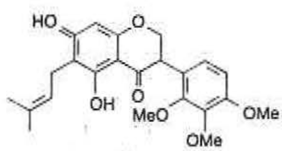

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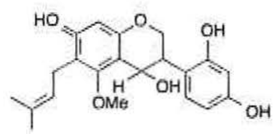
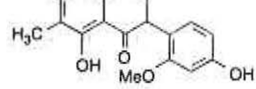
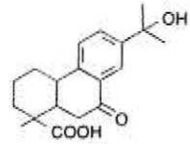


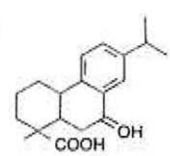
VI



VII

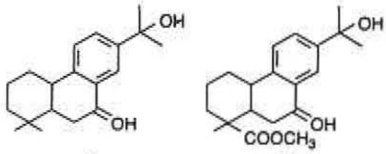


VIII



IX

Fractionation of fractions from CH_2Cl_2 extract on silica gel column chromatography followed by further purification on a semi-preparative HPLC on Ultrasphere C-18 column yielded four new isoflavonoids (**IV–VII**), which were characterised by 2D-NMR and mass spectroscopy, together with known abietane diterpenes, 7-oxo-15-hydroxydehydroabietic acid (**VIII**) and 7-hydroxycallitrisic acid (**IX**).



X **XI**

The most polar ACF1 fraction has been the major focus of sub-fractionation cycles involving semi-preparative HPLC (using C-4 reverse-phase column). A series of partially purified isolates have been obtained. Isolation of pure components from these has been a major challenge. Currently, we are using analytical C-4 reverse phase column to isolate pure compounds. So far, two compounds (**X** and **XI**) have been isolated and characterised, and are being assayed.

Two structural variants have so far been shown to be associated with post-germination activities: a moderately polar *O*-methylated isoflavanone (**II**) and a polar diglycosyl flavone (**III**). In all probability the most active ACF1 fraction of acetone extract also contains a series of glycosylated flavones or isoflavanones. The minor difference in their polarity has made their separation a very challenging task. We are currently deploying a combination of semi-preparative and analytical HPLC using C-4 bonded silica columns to build up enough stock of target compounds for spectral analysis and bioassays.

16. Commercial production of Desmodium *seed*

The Western Seed Company Limited in Kitale, Kenya in collaboration with *icipe* and its partners is undertaking a major drive for commercial seed production through smallholder farmers and local community groups. Farmers and communities were asked to select participating farmers and groups interested in income generation through seed production to become contract seed producers for the seed company. A planning workshop, attended by farmers' representatives, frontline extension staff and area chiefs was organised by Western Seed Company in collaboration with *icipe*, Rothamsted Research and KARI to lay down strategies for implementing the project. In-depth training to participating farmers from each location in cultivation of silverleaf, *D. uncinatum*, and greenleaf, *D. intortum*, and processing of seed materials was offered.

In the second year of the commercialisation of the seed project (2004), the seed company provided 250 g seed to each of 600 trained farmers in two districts of Kenya (Bungoma and Trans-Nzoia) for planting. The Western Seed Company guaranteed it would purchase the desmodium seed from the 600 contract farmers. The company cleaned the seed, checked germination and viability, and properly packed it. In 2005 Western Seed produced 3 tonnes of high quality desmodium seed. The company will continue purchasing desmodium seed from the contract farmers and cleaning and packing them for sale at an affordable price.

The seed company also checks germination viability of the seeds from time to time. Depending on demand, the seed company will expand the number of participating farmers. The Kenya Plant Health Inspectorate Service (KEPHIS) is responsible for quality control of the seed and planting material. Rothamsted analyses the airborne volatiles of these plants from selected samples from time to time using GC and GC-MS to establish that the quality of the product is maintained in terms of appropriate production of semiochemicals. Behavioural studies with stemborer females and parasitoids are also being conducted to ensure that the plants continue to produce volatile chemicals to repel stemborers, and that there is no genetic drift in seeds multiplied by farmers. Similarly, quality control of the striga-inhibiting effects of desmodium seed samples are being undertaken by *icipe*.

During the last five years two other pathways for propagation of desmodium have emerged: vegetative propagation among smallholder farmers and community-based seed production initiatives. These could evolve into important mechanisms for horizontal diffusion of the 'push-pull' technologies among resource-limited farming communities.

Future outlook

The habitat management 'push-pull' project is quite unique in the way that it has developed from the basic science to technology transfer, to farmer take-up, and spontaneous technology transfer between farmers. Although the experience to date has been restricted to maize-based farming systems and on-station sorghum-based farming systems, we believe that the general approach is applicable to a much wider range of pest problems, in a variety of crops (such as millet) and will be a model for other researchers in their efforts to minimise pest-induced yield losses in an economically and environmentally sustainable manner.

The 'push-pull' approach described here is now expanding into Kenya, Uganda and Tanzania. In Kenya, a farmer teacher programme has been initiated, where each trained farmer has to teach 5 new farmers each year. Sasakawa Global 2000, an international NGO, is helping to expand the 'push-pull' programme in Ethiopia. A pilot programme had been initiated in southern Africa, addressing stemborer control in the arid and semi-arid areas of the Northern Province of South Africa. Each region has, in addition to varying climate conditions and use of alternative cultivars, and some differences in crops that must be taken into account, gained considerable experience in this aspect by the pilot studies in various countries. However, wherever these approaches are developed for the specific needs of local farming practices and communities, it is essential that the scientific basis of the modified systems should be completely elucidated, otherwise there might be a drift from effectiveness to justifiable dissatisfaction on the part of the practising farmers. Every effort will be made to ensure that technology transfer follows the incorporation of these practices into other regions of Africa.

The 'push-pull' project is expanding in eastern Africa via smallholder farmers. However, the major constraint to widespread technology transfer has been availability of desmodium seed. Several pathways have emerged including involvement of a private seed company, community-based seed production, and vegetative propagation among farmers adopting 'push-pull' technologies. The relative merits of these pathways in stimulating autonomous diffusion of the technologies need to be analysed and compared. In addition, the role of different reinforcing interventions such as mass media, information bulletins, field days, farmer teachers, farmer field schools etc. need to be evaluated and the most cost-effective ones identified. The relationship between household socioeconomic status and land–labour ratio in different districts, and the performance of different diffusion mechanisms needs to be clarified.

Several new science-led maize production and protection technologies (IR maize, Bt maize and QP maize) have been developed by other research institutes, the effectiveness and sustainability of which need to be compared with 'push-pull' strategies over a longer time scale. Questions relating to potential integration of these technologies or their complementarities have been raised and need to be evaluated in continued collaboration with other centres. Demonstrations of the relative productivity of integrated approaches and their socioeconomics, including possibility of forward linkages, will be an important objective of the future project as well as collaborative undertakings with other institutions.

For long-term sustainability of the 'push-pull' system and its placement on a strong scientific foundation, there is a need to: (i) develop tools for quality control of the performance of the 'push' and 'pull' components, (ii) enhance understanding of soil nutrient dynamics in long-term 'push-pull' fields, and (iii) study and solve emerging problems of a previously unrecognised pest (a pollen beetle attacking desmodium) and a disease of the companion crops (phytoplasma disease of Napier grass). Studies in these areas will be undertaken and tools that emerge will be optimised and incorporated into the 'push-pull' dissemination activities.

Output

Journal articles

Gohole L. S., Overholt W. A., Khan Z. R. and Vet L. E. M. (2005) Close-range host searching behavior of the stemborer parasitoids *Cotesia sesamiae* and *Dentichasmias busseolae*: Influence of a non-host plant *Melinis minutiflora*. *Journal of Insect Behavior* 18, 149–169.

Midega C. A. O., Khan Z. R., Van den Berg J. and Ogol C. K. P. O. (2005) Habitat management and its impact on maize stemborer colonization and crop damage levels in Kenya and South Africa. *African Entomology* 13, 333–340.

Mohamed M. H., Khan Z. R., Overholt W. A. and Elizabeth D. K. (2004) Behaviour and biology of *Chilo partellus* (Lepidoptera: Pyralidae) on maize and wild gramineous plants. *International Journal of Tropical Insect Science* 24, 287–297.

Book chapter

Khan Z. R. and Pickett J. A. (2004) The 'push-pull' strategy for stemborer management: A case study in exploiting biodiversity and chemical ecology, pp. 155–164. In *Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods* (Edited by G. M. Gurr, S. D. Wratten and M. A. Altieri). CSIRO, Australia and CAB International, UK.

Research proposal

Promotion and dissemination of integrated pest and soil fertility management strategies to combat *Striga*, stemborers and declining soil fertility in the Lake Victoria basin (2005–2006). Funded.

Capacity building

PhD students

C. Midega (Kenya) Impact of a habitat management system and Bt-maize on stemborer natural enemies and biodiversity of ground-dwelling arthropods and soil fauna in Africa. Kenyatta University, Kenya (completed).

E. Njuguna (Kenya) Push-pull technology for the control of stemborers in the Lake Victoria region: Hidden impacts on the farming systems. University of Nairobi, Kenya (ongoing).

L. Lebesa (Lesotho) Towards development of traps for the control of blister beetles on desmodium: Studies on volatile profiles of the host plant and pests, and their influence on beetle behaviour. University of Pretoria, South Africa (ongoing).

S. Guchu (Kenya) Studies on *Desmodium* species for the allelochemicals involved in *Striga* suppression. University of Nairobi, Kenya (ongoing). (Based at Behavioural and Chemical Ecology Department.)

MSc student

S. R. Kiambi (Kenya) Comparison of biological effects and chemistry of soybean and desmodium root exudates on *Striga hermonthica*. Egerton University, Kenya (completed 2004, Behavioural and Chemical Ecology Department).

Impact

- Over 3500 'push-pull' farmers have at least doubled their maize yields and increased milk production by 50%.
- Fodder production by 3000 'push-pull' farmers contributes in production of 1.5 million litres of milk annually.
- More than 600 smallscale farmers produce desmodium seed for income generation and are linked to a private seed company.
- Extra income from 'push-pull' fields has helped at least 500 farmers to send one child to a secondary school.
- By the end of 2009 at least 15,000 farmers will benefit from the 'push-pull' strategy.
- At least 3 tonnes of certified desmodium seed will be produced annually by 1000 smallscale farmers.

B. Horticultural Crops Pests

Expanding Biological Control of the Diamondback Moth, *Plutella xylostella* L. in East and Southern Africa

Background, approach and objectives

Among the most important vegetables for home consumption and local markets in East and Southern Africa are crucifers. However, they play a very different role in different countries. In East Africa, cabbage, *Brassica oleracea* var. *capitata* (L.) Alef. (Brassicaceae) and especially kales ('sukuma wiki'), *B. oleracea* var. *acephala* (L.) have a dominant place in the national diet of Kenyans. Ethiopian kale is part of almost every meal in Ethiopia and Mozambican kale ('tronchuda'), *B. oleracea* var. *costata*, is an important smallholder subsistence crop in Mozambique and Zimbabwe. Cabbage, cauliflower and broccoli are grown predominantly for urban markets in all countries of East Africa; limited amounts of the latter two and Brussels sprouts are also exported to Europe.

All these crops are attacked by the diamondback moth (DBM), *Plutella xylostella* (L.) (Lep.: Plutellidae), the most injurious insect pest of crucifers worldwide. The pest has developed resistance to a wide range of synthetic insecticides including *Bacillus thuringiensis* (Bt) based products and other biopesticides. To rectify the situation, countries in Southeast Asia developed and implemented biocontrol-based IPM strategies, which have proved successful. In contrast, research towards the control of DBM in Africa is rare considering the size of the continent. An analysis of plant protection research on crucifers in national research institutions of East and Southern Africa, conducted during 1980–1995, clearly showed that emphasis has been on pesticide screening. In addition, in many countries horticultural research is generally under-funded and the number of qualified staff assigned to vegetable research, and particularly to plant protection, is low. Therefore, regional cooperation and networking is imperative to make optimal use of available manpower and finances. Such collaborative efforts to implement biological control of diamondback moth in East and Southern Africa have been ongoing since 1994 and in 2000, *icipe* embarked on a research project towards biological control of the diamondback moth. The project laid the scientific basis for a successful implementation of biological control through surveys in the four project countries: Ethiopia, Kenya, Tanzania and Uganda. The surveys yielded information about the seriousness of the DBM problem and the locally available natural enemies and their prevalence. In general, the DBM problem was rated as serious mainly in commercial cabbage production while subsistence vegetable crops like kales (*Brassica oleracea* var. *acephala* and Ethiopian kale *Brassica carinata* L.) were less affected. The indigenous natural enemy fauna was very scarce (7 species), compared to South Africa (33 species) or Romania (27 species) and the prevalence was generally low with the exception of some areas of Ethiopia. As a consequence of these results, the decision was taken to import an exotic parasitoid known from earlier biocontrol efforts in Asia, *Diadegma semiclausum* (Hellen) (Hymenoptera: Ichneumonidae), a larval parasitoid adapted to temperate highland growing conditions. As leafy cabbage (kale) is an important subsistence crop in lowland semi-arid conditions, another parasitoid, *Cotesia plutellae* (Kurdjumov) (Hymenoptera: Braconidae), was studied for three years in cooperation with the Plant Protection Research Institute of South Africa and eventually also imported to Kenya. The former was released in Kenya and Tanzania in pilot sites in 2001 and its establishment and impact studied. *Cotesia plutellae* was released in Uganda for the first time in late 2003.

Participating scientists: *B. Löhr, D. Mithöfer, A. Rossbach*

Assisted by: *G. Gichini, N. Mwikya, F. Nyamu, I. Macharia*

Donors: *German Federal Ministry of Economic Cooperation and Development with two grants through the German Agency of Technical Cooperation*

Collaborators: *KENYA: Kenya Agricultural Research Institute, National Biological Control Centre, Muguga, Dr Charles Kariuki, Mr John Obiero; District Agricultural Office, Taita Taveta District, Mr Paul Onano, Mr Shadrack Juma; Ministry of Agriculture and Rural Development, Division Horticulture Officers and Frontline Extension Workers in South Kinangop, Kieni East, Kieni West, Kikuyu and Limuru Divisions. TANZANIA: Ministry* *of Agriculture and Food Security, Plant Health Services, Kibaha Biocontrol Centre, Mr Oscar Mfugale, Mr William Riwa (IPM Coordinator), Ms Salome Munisi (Plant Protection Coordinator, Northern Zone), Mr Livin Mahoo (Horticultural Officer, Lushoto). UGANDA: National Agricultural Research Organisation, Namulonge Agriculture and Animal Research Institute, Biocontrol Unit, Dr James Ogwang, Ms Florence Nagawa. FRANCE: Centre Nacional de Recherche Scientifique, CNRS Laboratoire Populations Génétique et Evolution, Gif sur Yvette, Mrs Claudia Rincón. GERMANY: University of Hannover: Institut für Pflanzenkrankheiten und Pflanzenschutz, Prof. H.-M. Pöhling; Betriebswirtschaftliche Fakultät, Prof. Hermann Waibel; University of Göttingen: Inst. für Pflanzenpathologie und Pflanzenschutz, Prof. Stefan Vidal, Andrea Rossbach (Visiting Scientist); Max Planck Institut für Chemische Ökologie, Jena, Prof. David Heckel. THE NETHERLANDS: University of Amsterdam, Prof. Peter Roessingh. SYRIA: University of Aleppo, Prof. Radwan Yakti, Dr Walid Idraw. CHINA: World Vegetable Centre, Dr S. Srinivasan*

Work in progress

Kenya

1. Diadegma semiclausum *establishment and impact*

The parasitoid established well in all pilot release areas, even though only very low numbers (5 release fields, 25 females/field) were released. Monitoring of the biological impact of *Diadegma semiclausum* on DBM populations and indigenous parasitoids was continued at the two pilot sites in Kenya throughout the year (2004/5). Diamondback moth populations have continued to decline and the diamondback moth damage has declined so much that many farmers have stopped spraying against DBM. Parasitism has passed 60% level at Nyathuna (the area where *D. semiclausum* had difficulties in getting established) as well and continues to be high in the Taita Hills. Cage exclusion studies conducted in 2004/5 at the two pilot release sites about half a year and one year after release showed the increase in mortality caused by the introduced parasitoid (Tables 1 and 2). In season-long field collections it could also be shown that the introduced parasitoid outcompeted the indigenous species while it brought DBM populations down (Tables 3 and 4).

Table 1. Mortality factors of diamondback moth (*Plutella xylostella*) larvae and pupae in cage exclusion experiments seven and twelve months after the release of an exotic parasitoid. Werugha, Wundanyi Division, Coast Province of Kenya

Exclusion treatment	Larvae per plant		% survival	% mortality due to			
	Infested	Recovered		*Diadegma semiclausum*	*Oomyzus sokolowskii*	Disease	Not identified
Seven months after release							
Caged and glued	60	30.8 ± 3.8 a	85.2 ± 1.3 a	3.8 ± 1.5 b	0.8 ± 0.8 a	4.2 ± 2.5 ba	6.0 ± 1.2 a
Caged only	60	28.0 ± 4.5 a	90.3 ± 3.7 a	3.2 ± 1.4 b	0.7 ± 0.7 a	0.8 ± 0.8 b	5.0 ± 2.3 a
Glued only	60	24.5 ± 2.6 a	61.5 ± 2.3 b	18.0 ± 2.0 a	3.9 ± 2.6 a	10.2 ± 3.9 a	5.8 ± 2.3 a
Control	60	29.0 ± 2.7 a	60.2 ± 8.1 b	16.5 ± 5.1 a	6.7 ± 2.0 a	6.7 ± 0.9 ba	10.0 ± 4.8 a
Twelve months after release							
Caged and glued	60	35.0 ± 1.1 a	90.1 ± 2.5 a	0 b	0 a	4.9 ± 1.2 a	2.1 ± 2.1 a
Caged only	60	27.5 ± 5.0 ba	88.0 ± 5.2 a	2.3 ± 2.3 b	0 a	4.9 ± 3.2 a	4.9 ± 2.1 a
Glued only	60	17.0 ± 3.0 b	25.4 ± 4.4 b	65.0 ± 2.2 a	0 a	6.2 ± 2.5 a	3.4 ± 2.0 a
Control	60	17.3 ± 0.9 b	26.2 ± 3.8 b	54.3 ± 7.1 a	0 a	12.5 ± 6.0 a	7.1 ± 2.6 a

Means within the same column followed by the same letter are not significantly different at $P < 0.05$, Student-Newman-Keuls test for comparison of means.

Table 2. Mortality factors of diamondback moth (*Plutella xylostella*) larvae and pupae in cage exclusion experiments seven and twelve months after the release of an exotic parasitoid. Tharuni, Limuru Division, Central Province of Kenya

Exclusion treatment	Larvae per plant		% survival	% mortality due to			
	Infested	Recovered		*Diadegma semiclausum*	*Oomyzus sokolowskii*	Disease	Not identified
Seven months after release							
Caged and glued	60	33.0 ± 2.9 a	89.2 ± 2.4 a	0 b	0 a	2.0±1.2 a	8.7 ± 2.2 a
Caged only	60	32.0 ± 3.2 a	80.2 ± 4.8 a	0 b	0 a	5.9 ± 2.8 a	13.9 ± 4.8 a
Glued only	60	31.3 ± 2.9 a	78.1 ± 2.2 a	8.0 ± 1.6 a	0 a	3.8 ± 1.8 a	10.1 ± 2.0 a
Control	60	29.5 ± 0.9 a	76.9 ± 6.9 a	9.2 ± 2.7 a	0 a	6.1 ± 2.3 a	7.8 ± 3.1 a
Twelve months after release							
Caged and glued	60	32.0 ± 3.5 ba	95.3 ± 0.8 a	1.1 ± 1.1 b	0 a	1.3 ± 0.8 a	2.3 ± 1.6 a
Caged only	60	42.3 ± 4.5 a	95.1 ± 1.7 a	0 b	0 a	1.8 ± 0.6 a	3.2 ± 1.5 a
Glued only	60	24.0 ± 4.8 b	77.8 ± 4.8 b	18.1 ± 4.4 a	0 a	2.6 ± 1.7 a	1.5 ± 1.5 a
Control	60	24.3 ± 1.7 b	77.0 ± 2.0 b	16.0 ± 3.4 a	0 a	2.1 ± 1.2 a	4.9 ± 2.4 a

Means within the same column followed by the same letter are not significantly different at $P < 0.05$, Student-Newman-Keuls test for comparison of means.

Table 3. Changes in diamondback moth parasitoid guild composition of field-collected larvae seven and twelve months after the release of an exotic parasitoid. Werugha, Wundanyi Division, Coast Province, Central Province of Kenya

	January–April 2003			April–July 2003		
	No. collected	% emergence	% of total parasitism	No. collected	% emergence	% of total parasitism
Plutella xylostella larvae/pupae	1103			577		
Plutella xylostella adult emerged	533	48.3		276	47.8	
Diseased/unidentified	163	14.8		22	3.8	
Parasitised	407	36.9		279	48.4	
Parasitoid species						
Diadegma semiclausum	351	31.8 ± 1.9 a	86.2	276	47.8 ± 1.9 a	98.9
Diadegma mollipla	5	0.5 ± 0.2 c	1.2	0	0.0 ± 0 b	0.0
Oomyzus sokolowskii	35	3.2 ± 0.9 b	8.6	3	0.5 ± 0.7 b	1.1
Apanteles spp.	5	0.5 ± 0.2 c	1.2	0	0.0 ± 0.0 b	0.0
Brachymeria spp.	4	0.4 ± 0.4 c	1.0	0	0.0 ± 0.0 b	0.0
Itoplectis spp.	7	0.6 ± 0.2 c	1.7	0	0.0 ± 0.0 b	0.0

Means within the same column followed by a common letter are not significantly different at $P < 0.05$, Student-Newman-Keuls test for comparison of means.

Table 4. Changes in diamondback moth parasitoid guild composition of field-collected larvae seven and twelve months after the release of an exotic parasitoid. Tharuni, Limuru Division, Central Province of Kenya

	January–April 2003			April–July 2003		
	No. collected	% occurrence	% of total parasitism	No. collected	% occurrence	% of total parasitism
Plutella xylostella larvae/pupae	1202			1034		
Plutella xylostella adult emerged	850	70.7		768	74.2	
Diseased/unidentified	103	8.6		27	2.6	
Parasitised	249	20.7		239	23.1	
Parasitoid species						
Diadegma semiclausum	27	2.2 ± 0.5 b	10.8	232	22.4 ± 1.7a	97.1
Diadegma mollipla	12	1.0 ± 0.3 cd	4.8	4	0.4 ± 0.4 b	1.7
Oomyzus sokolowskii	168	14.0 ± 0.3 a	67.5	0	0 b	0
Apanteles spp.	22	1.8 ± 0.4 cb	8.8	0	0 b	0
Brachymeria spp.	20	1.7 ± 0.6 cb	8.0	3	0.3 ± 0.4 b	1.3
Itoplectis spp.	0	0 d	0	0	0 b	0

Means within the same column followed by a common letter are not significantly different at $P < 0.05$, Student-Newman-Keuls test for comparison of means.

Rearing and release operations in Kenya were handed over to KARI at the beginning of 2004 and several releases of combined (>5000) parasitoids have so far been made. Releases concentrated in western Kenya and the Rift Valley areas in Central Kenya were left until late 2005 when data collection for impact assessment had been finalised. Rearing and release operations for *Diadegma semiclausum* in Kenya, entirely managed by KARI, were terminated at the end of the year as all areas suitable for the parasitoid had been covered. The first monitoring survey was conducted by the KARI team. *Diadegma semiclausum* was found everywhere and DBM populations were under good control. Preparations were made to shift the rearing activities at KARI to produce *Cotesia plutellae*.

Tanzania

A monitoring survey was conducted in the *D. semiclausum* release area at Ilikidinga, Tanzania. Parasitism increased from an initial <10 to 36% in late 2003 and 58% in December 2004. The damage has decreased substantially in the area where farmers were educated about the release operations and about how to deal with their pest problems in the presence of the biocontrol agent. The survey also showed, however, that farmers in neighbouring areas, where the parasitoid had immigrated through natural dispersal, continued to spray heavily and their whole crop was destroyed nevertheless. This shows that farmer education is very important and has to be given more attention. The Ilikidinga experience was used to plan and execute the ToT in Tanzania, and this proved very useful to the trainer and the course participants.

Cameroon

Upon invitation of the Cameroonian–German Plant Protection Project, *icipe* team member A. Rossbach went for three weeks to Cameroon to help the Plant Protection Service in a survey to assess the DBM problem and the chances to expand the work done in Kenya to the benefit of Cameroon. The survey showed a similar picture to the one observed in East Africa: Cabbage production mainly in mid-altitude areas and regular use of pesticides (Table 5). In the higher areas, *D. mollipla* was the prevalent parasitoid and parasitism was similarly low as in East Africa. In low-lying areas, the most common parasitoid was *Oomyzus sokolowskii*, also at levels that could not exert economic control of the pest (Table 6). It was agreed that a technician would be sent from Cameroon to *icipe* to learn rearing of DBM and parasitoids. An introduction and release programme would then be implemented by the Cameroonian national programme, if necessary with back-up from Nairobi.

Table 5. Site characteristics and cabbage growing practices of three cabbage growing areas in Cameroon

	Area characteristics			Production practices		
Growing area	Altitude (m)	Temp. (°C)	Rainfall (mm)	Cabbage variety	Pesticide used	Application frequency
Dschang	1470–1600	20.5–21.0	134–304	Green Coronet, Omphalox	Cypermethrine, Isoproturon	Bi-monthly Monthly
Babadjou	1625–1850	18.5–19.5	154–160	Green Coronet	Cypermethrine, Dimethoate	Weekly Weekly
Santa	1820–1980	18.3–19.1	329–423	Globemaster, Tropical	Alphamethrine, Cypermethrine	Bi-weekly Bi-weekly

Table 6. Diamondback moth population and parasitoids in three cabbage growing areas in Cameroon

		Number of parasitoids collected			
Growing area	DBM/ Plant	*Oomyzus sokolowskii*	*Diadegma mollipla*	Unidentified Ichneumonidae	% overall parasitism
Dschang	1.3	68 (547)	18	1	13.6
Babadjou	2.6	96 (106)	87	0	18.1
Santa	1.2	25 (0)	25	0	14.1

Uganda

In Uganda, the spread of *D. semiclausum* was assessed in the Kabale release area about 18 months after the release was made. *Diadegma semiclausum* is well established and has spread all over the cabbage growing area in Kabale District. However, farmer awareness about the natural enemy and its potential was not sufficient to convince the farmers to stop spraying. A refresher course was therefore planned for the local extension staff.

2. *Complementary parasitoids introduced, studied and released in pilot areas*

When introducing biological control agents, the broadest genetic base possible is recommended by biological control workers as the best guarantee for success. In light of this, multiple introductions of the same species of different proveniences seem to be the best recipe. Our investigations show that this can actually be a roadmap to failure. In the case of *Cotesia plutellae*, several introductions have been listed as failures. Upon close examination, many of these failures might be attributed to reproductive incompatibility of the strains selected for introduction or of the introduced strain with an already present one.

The Project introduced two biotypes of *C. plutellae* with the intention to have a broad genetic base for the releases. Fortunately, we performed some preliminary tests on compatibility between the biotypes and we found almost complete reproductive incompatibility. With the aim of gaining better understanding to manage introductions of *C. plutellae*, the reproductive compatibility between five populations native from different geographic areas—including our two biotypes—were examined. This was done by Claudia Rincón at the Centre Nacional de Recherche Scientifique in France with Project support. Morphological (antennae and body length and antennae/body ratio) (Table 7) and two molecular characters (sequence of a Cyt B fragment and infection status by *Wolbachia*) were investigated for their potential to predict the reproductive compatibility between populations. Results from three areas (morphology, DNA sequences and infection status by *Wolbachia*) were evaluated collectively in a generalised linear model of reproductive compatibility. The study led to the conclusion that these five *C. plutellae* populations form two partially to highly incompatible aggregates (Table 8), which are morphologically and molecularly distinguishable. Morphometric divergences, molecular distances (Cyt B), and infection status by *Wolbachia* are all good predictors of compatibility.

After this discovery, the *C. plutellae* culture from Taiwan was discontinued and the culture of the South African biotype was transferred to a screenhouse on the *icipe* campus. Rearing the SA biotype had been very difficult in the laboratory but the transfer to the screenhouse solved this problem with immediate effect: The wasps do much better in these quasi-natural conditions than in the cage.

Table 7. Morphometric differentiation between adults of five *Cotesia plutellae* populations

Body size parameters	Origin of *C. plutellae*: South Africa ♀	South Africa ♂	Benin ♀	Benin ♂	Martinique ♀	Martinique ♂	Reunion ♀	Reunion ♂	Taiwan ♀	Taiwan ♂
Antennal length	2.37 ± 0.19 f	2.82 ± 0.22 c	2.44 ± 0.10 e	2.89 ± 0.16 b	2.55 ± 0.12 d	3.01 ± 0.13 a	2.35 ± 0.20 f	2.78 ± 0.25 c	2.39 ± 0.17 ef	2.79 ± 0.23 c
Body length	2.32 ± 0.19 d	2.33 ± 0.21 d	2.64 ± 0.12 a	2.46 ± 0.15 c	2.50 ± 0.13 bc	2.49 ± 0.17 bc	2.56 ± 0.23 b	2.36 ± 0.23 d	2.56 ± 0.19 b	2.32 ± 0.24 d
Antenna/body ratio	1.03 ± 0.05 c	1.22 ± 0.07 a	0.92 ± 0.03 d	1.18 ± 0.06 b	1.02 ± 0.05 c	1.21 ± 0.08 a	0.92 ± 0.04 d	1.20 ± 0.06 a	0.93 ± 0.04 d	1.21 ± 0.07 a
Female/Male body length ratio	0.9957		0.9311		0.9960		0.9206		0.9075	

Values of 'female/male body length ratio' are ratios between averages calculated on 80 individuals. Means in the same line followed by the same letter are not statistically different (Student-Newman-Keuls 5 %).

Pre-release studies were initiated in two semi-arid pilot areas. One site is along Athi River, about 30 km southeast, the other one about 50 km northeast of Nairobi. Both areas concentrate on the production of leafy cabbage ('sukuma wiki'), the former along a river on black cotton soil, the latter in an irrigation scheme with sandy loam soil. Observations were initiated in May (Athi River) and June 2004 (Yatta) and one year of observations were completed before a release was made. The information gathered thus far indicates a very different situation from the highlands. Local parasitoids are seasonally abundant (up to 60% parasitism) but nevertheless unable to keep DBM populations below the damage threshold. A release of *C. plutellae* was made in both areas in May/June 2005 and resulted in initial establishment; however, towards the end of 2005, recoveries declined. *Diadegma semiclausum* has invaded the release area through natural expansion of its range and seems to be one of the reasons preventing establishment of *C. plutellae*.

Table 8. Reproductive compatibility of five populations of *Cotesia plutellae*, parasitoid of the diamondback moth

Cross	Compatibility rate [a]	Number of wasps produced	Overall sex ratio (proportion females)	Sex ratio of compatible couples
SA-B	0.5	6.20 ± 1.55	0.34 ± 0.38	0.66 ± 0.24
SA-M	0.4	5.10 ± 2.13	0.23 ± 0.38	0.58 ± 0.41
SA-R	0.1	4.50 ± 1.96	0.09 ± 0.28	0.89
SA-T	0.4	4.40 ± 1.35	0.27 ± 0.37	0.65 ± 0.28
B-SA	0.3	7.20 ± 1.62	0.19 ± 0.35	0.65 ± 0.32
B-B	1	**7.90 ± 3.49**	**0.49 ± 0.17**	**0.49 ± 0.17**
B-M	0	6.30 ± 1.77	0	
B-R	0.6	6.60 ± 2.07	0.36 ± 0.40	0.61 ± 0.33
B-T	1	6.40 ± 1.07	0.41 ± 0.20	0.41 ± 0.20
M-SA	0.9	6.20 ± 1.14	0.63 ± 0.28	0.69 ± 0.19
M-B	0	5.90 ± 1.60	0	
M-M	0.9	**7.40 ± 1.90**	**0.5 ± 0.33**	**0.55 ± 0.29**
M-R	0	5.10 ± 1.91	0	
M-T	0.3	5.60 ± 1.51	0.20 ± 0.37	0.68 ± 0.33
R-SA	0.3	5.10 ± 1.91	0.25 ± 0.42	0.85 ± 0.15
R-M	0.3	4.30 ± 1.57	0.16 ± 0.29	0.54 ± 0.24
R-B	0.1	5.90 ± 1.37	0.05 ± 0.16	0.5
R-T	0.9	5.80 ± 1.69	0.55 ± 0.33	0.62 ± 0.28
T-SA	0.2	5.30 ± 1.83	0.19 ± 0.30	0.71 ± 0.06
T-B	0.7	5.20 ± 1.4	0.58 ± 0.43	0.82 ± 0.22
T-M	0.1	4.30 ± 1.7	0.05 ± 0.16	0.5
T-R	0.6	5.60 ± 1.96	0.32 ± 0.39	0.55 ± 0.36
Intra-groups[b]	0.73 ± 0.25	6.05 ± 1.09	0.42 ± 0.15	0.59 ± 0.11
Inter-groups[c]	0.19 ± 0.17	5.48 ± 0.87	0.14 ± 0.12	0.68 ± 0.13
Glm P-value	3.576e-16	0.055	7.019e-30	0.022

Origin of parasitoids: SA: South Africa; B: Benin; M: Martinique; R: Reunion; T: Taiwan. SA-B refers to cross between South Africa and Benin. In all crosses, the first letter represents the mother and the second the father. Values are means ± SE. (a) Proportion of couples producing female progeny, (b) crosses within interbreeding groups, (c) crosses between interbreeding groups.

In Uganda, the spread of *C. plutellae* was assessed in the Wakiso release area about 18 months after the release was made. The parasitoid was found in all fields inspected and has spread widely from the release area. The furthest recovery from a release point was 68 km. In some fields, 100% of the collected DBM samples were parasitised and the DBM populations were very low in all surveyed fields.

3. *Economic impact assessment*

Project activities commenced in March 2005. To assess the ex post economic impact of the biological control of the diamondback moth in cabbage in Kenya and assess factors that contribute to the success of the biological control strategy, surveys were carried out for two cabbage crops: the crop planted during the hot season (October 2004–February 2005) and the crop planted during the rainy season (March 2005–July 2005) in Kenya, Central Province, and Tanzania, Northern Zone. The research project applies the ex post facto study design, i.e. surveys were carried out in areas, where the biological control agents had been released ('with' = W), as well as in areas where it had not been released ('without' = W/o) (Table 9). These surveys included cabbage production data and direct health effects of pesticides.

Table 9. Sample size of cabbage farmers participating in the economic impact assessment study of diamondback moth biocontrol, by sublocation and country

Country	District	Division	October–February	March–July	Release status
Kenya	Nyandarua	South Kinangop	130	130	W
Kenya	Nyeri	Kieni East	64	64	W/o
Kenya	Nyeri	Kieni West	70	70	W
Kenya	Kiambu	Kikuyu	30	17	W
Kenya	Kiambu	Limuru	49	33	W
Tanzania	Lushoto		150	143	W/o
Tanzania	Arusha		180	180	W
Total			**673**	**637**	

W, with; W/o, without.

Data analysis will be carried out in two steps. First, propensity score matching will be used to select a sub sample from the 'with biological control' group that matches the 'without biological control' group. In a second step stochastic efficiency frontiers estimation will be carried out.

4. *Biocontrol-compatible management methods for other important pests*

The studies on occurrence and host suitability of wild crucifers (PhD project of Mrs Ruth Gathu) are continuing. Six wild species, some from the highlands (*Rorippa* sp., *R. cryptantha, R. nudiuscula, Raphanus raphanistrum* L.), one from the lowlands (*Rorippa micrantha*), and one that occurs in both areas (*Erucastrum arabicum*) were investigated. All were found to attract egg-laying females and were suitable for DBM development. A life-table analysis showed that the intrinsic rate of increase as well as the net reproductive rate of DBM on *E. arabicum* and *R. cryptantha* was higher than on the cultivated cabbage and kale.

The suitability of the same species for both exotic parasitoids (*D. semiclausum* and *C. plutellae*) was also investigated. Both parasitoids can complete development in DBM reared on any of these host plants. There is some effect on developmental time, longevity and reproductive potential of both parasitoid species; however, parasitoid development is in general not much affected by the host plants studied.

5. *Exploration for heat-tolerant pupal parasitoids*

During a visit to Romania in September 2005, the basis was laid for a cooperative research activity with the A. I. Cuza University (AICU) of Iasi. The aim is to evaluate the changes in the parasitoid guild with advancing temperature and thus find heat-tolerant parasitoids for introduction and release in Southeast Asia. It was agreed to develop a joint work plan once a student of AICU had been identified and start work in the 2006 season.

6. *Technology transfer and training programme*

A planning meeting with all project partners was held at *icipe* headquarters in June 2005. All working groups presented their findings (France, Kenya, South Africa, Syria, Tanzania, Uganda) and a way forward was charted. Highest priority was given to releases of *D. semiclausum* in all Project countries, followed by the continuation of studies on and release of *C. plutellae*. The possible introduction to East Africa of a third parasitoid species was discussed and all national programmes expressed interest. The species, *Diadromus collaris*, could be sourced from South Africa.

A proposal was submitted to BEAF for funding of a postdoctoral fellowship in agricultural economics. The request was approved and Dr Dagmar Mithöfer of the University of Hannover was selected and started work in March 2005. The postdoctoral research project 'Economic impact assessment of biological control of the diamondback moth in crucifers in East Africa' directly contributes to output 3. The aim of this activity is to ex post assess the economic impact of the DBM biocontrol and identify factors that are related to the success of the biocontrol project. Surveys were carried out in Central Province, Kenya and Northern Zone, Tanzania. Due to budgetary and other constraints, Uganda and Ethiopia, were dropped from this activity. Detailed information on activities related to this project can be found in a separate progress report (project number: 03.78640.4–001.00, contract number: 81074619). *(See following report.)*

Output

Journal articles

Macharia I., Löhr B. and De Groote H. (2005) Assessing the potential impact of biological control of *Plutella xylostella* (diamondback moth) in cabbage production in Kenya. *Crop Protection* 24, 981–989.

Rossbach A., Löhr B. and Vidal S. (2005) Generalism versus specialism: Responses of *Diadegma mollipla* (Holmgren) and *Diadegma semiclausum* (Hellen) to the host shift of the diamondback moth (*Plutella xylostella* L.) to peas. *Journal of Insect Behaviour* 18, 491–503.

Wagener B., Reineke A., *Löhr B.* and Zebitz C. P. W. (2004) A PCR-based approach to distinguish important *Diadegma* species (Hymenoptera: Ichneumonidae) associated with diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *Bulletin of Entomological Research* 94, 465–471.

Book chapters

Löhr B. and Kfir R. (2004) Diamondback moth, *Plutella xylostella* (L.) in Africa: A review with emphasis on biological control, pp. 71–84. In *Proceedings of an International Symposium on Improving Biocontrol of* Plutella xylostella. 21–24 October 2002, Montpellier, France (Edited by A. Kirk and D. Bordat). CIRAD, Montpellier.

Conferences attended

Proceedings of the XV International Plant Protection Congress, 10–15 May 2004, Beijing, China. Attended by: I. Macharia, B, Löhr and H. deGroote.

International Congress of Entomology, 16–21 August 2004, Brisbane, Australia. Attended by B. Löhr, R. Gathu and C. Momanyi.

International Symposium of Biological Control of Arthropods, 12–16 September 2005, Davos, Switzerland. Attended by B. Nyambo and B. Löhr.

Capacity building

PhD students

B. Wagener (Germany) Molecular systematics of selected *Diadegma* species (Hymenoptera: Ichneumonidae, Campopleginae) important in biological control. University of Hohenheim, Germany (defence scheduled for 29 September 2006).

A. Rossbach (Germany) Influence of the host shift of the diamondback moth, *Plutella xylostella* L., to peas on its associated parasitoids. University of Göttingen, Germany (PhD scheduled for 2006).

R. Gathu (Kenya) Role of wild crucifers in management of diamondback moth, *Plutella xylostella* L. (Lepidoptera: Plutellidae) and its natural enemies in Kenya. University of Hannover, Germany (ongoing).

MSc students

C. Momanyi (Kenya) Biological impact assessment of an introduced exotic parasitoid *Diadegma semiclausum* (Hellen) on *Plutella xylostella* (L.) and its local natural enemies in Kenya. Jomo Kenyatta University of Agriculture and Technology, Kenya (completed).

R. Nofemela (South Africa) Studies on parasitoids of the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), in South Africa. Rhodes University, South Africa (completed).

I. Macharia (Kenya) *Ex-ante* economic impact assessment of classical biological control of diamondback moth in cabbage production by use of exotic parasitoid *Diadegma semiclausum* (Hellen). Jomo Kenyatta University of Agriculture and Technology, Kenya (completed).

K. Olwasi (Kenya) Egg-laying behaviour, life-table statistics and parasitism of diamondback moth [*Plutella xylostella* (L.), Lepidoptera: Plutellidae] on commercial crucifer cultivars in Kenya. Egerton University, Kenya (ongoing).

K. Kastrup (Denmark) Field mortality studies of diamondback moth larvae and pupae in semi-arid conditions of Kenya. Royal Veterinary and Agricultural University, Copenhagen (completed).

Impact

The Project can already now be termed an outstanding success, as indicated in the economic impact assessment conducted by Ibrahim Macharia. The impact of both parasitoids on DBM populations in Kenya, Uganda and Tanzania is much higher than the Project team could have expected at the outset. The impact could be augmented considerably if the parasitoids can also be released in other countries that did not participate in the Project activities like Cameroon, Malawi and Mozambique and if an import permit would be granted by the government of Ethiopia.

Economic Impact Assessment as a Decision-Making Tool for Resource Allocation in Horticultural Research in East Africa

Background, approach and objectives

The horticulture industry is currently the third most important foreign exchange earner after tea and tourism in Kenya. It is the fastest growing agricultural sub-sector and contributes 23% of gross domestic product (GDP) (CBS, 2003). The World Bank estimated that the export horticultural industry provided jobs to 2 million people in Kenya (Dolan, 2001) and a single export crop—French bean—provides half a million people with their main source of income (Swanberg, 1995). A recent study of the relevance of export vegetable production to poverty alleviation in Kenya showed a significant positive impact of the industry on producers and the workforce employed in the sector (McCulloch and Ota, 2002). In addition to income-generation, vegetables are vital for the supply of vitamins and other micronutrients to consumers. The positive role vegetables can play in overcoming micronutrient deficiencies is well-documented (Bellin and Leitzmann, 1995). Women farmers play an important role in vegetable production. In a survey of five major French bean growing areas, 17 to 40% of the growers were women (Anyango and Nabwile, 1995). In another study comprising beans, tomato and cabbage growers, Michalik (1994) found 21.5% of the farmers to be women.

Smallholders produce an estimate of 50% of export production (Jaffee, 2003). However, only 6% of the volume of Kenyan fresh fruit and vegetables (FFV) horticultural production targets the export market; 94% is consumed domestically [Nyoro et al., 2004, based on Ministry of Agriculture (MoA) data]. The export market is served by a few large-scale own company farms, an increasing number of contracted commercial horticultural farms and a declining but still significant number of contracted smallholder farms (Dijkstra and Magori, 1995). Independent smallholders produce the bulk of the vegetables and fruits for domestic markets. Domestically consumed FFV increasingly reach the consumer via supermarket chains (5% of the FFV) while kiosks and open markets hold the major share of purchases, i.e. 35 and 56% respectively. The export sector is facing increasingly more stringent food safety standards and the formal domestic retail sector seems to follow the same trend (Nyoro et al., 2004).

This generally positive development is put in jeopardy by at least two developments. First, the increased intensity both in local market production and even more so in export-oriented systems,' has led to a chemical spiral with rising production costs and decreasing productivity. This is associated with a high risk to human health, especially for farm labourers, many of them women and children, and environmental pollution. Second, the European Union, Kenya's major export market, has enacted legislation on maximum pesticide residue limits that endangers the continuation of small-scale farmer participation in the export production as exporters are inclined to shift production to larger producers to reduce their risk of non-compliance to new regulations. This was exacerbated by the introduction of private, non-legal industry standards like EurepGAP, which require extensive documentation and certification, thereby increasing production costs. The maximum residue limits are enforced since 1st January 2005.

Research at *icipe* has demonstrated that alternative methods of pest management exist, which are more environmentally benign and less harmful to producers and at the same time generating horticultural products that are safer for consumers. However, policies that could facilitate a diffusion of these methods have not been put in place, so far, perhaps because policy makers are uncertain about the economic and social benefits of such changes. Therefore, a comprehensive study on the expected impact of environmentally benign and less hazardous crop and pest management technologies will provide the necessary information basis for identifying further research needs, for the prioritisation of *icipe*'s horticultural research portfolio and for developing policy recommendations that can induce change towards more sustainable horticultural production and marketing systems in eastern Africa. The objectives of the project are to: (1) analyse the status of current production practices, (2) assess the impact of sustainable technologies and farmer training and (3) evaluate the policy regimes and their impact on sustainable horticultural production.

Participating scientist: *D. Mithöfer*

Assisted by: *E. Nang'ole*

Donors: *German Federal Ministry of Economic Cooperation and Development through the German Agency of Technical Cooperation*

Collaborators: *KENYA: Ministry of Agriculture and Rural Development, Horticulture Division; division horticulture officers and frontline extension workers. GERMANY: University of Hannover, Faculty of Economics and Business Administration*

Work in progress

Project activities commenced in March 2005. Informal introductory meetings were held with all stakeholders of the Kenyan horticulture sector. These included public, e.g. Ministry of Agriculture, Horticultural Crops Development Authority (HCDA), FAO, GTZ and private institutions, e.g. Fresh Produce Exporters Association (FPEAK), certification bodies, selected exporters as well as NGOs like the Horticulture Development Centre.

With support of the extension officers of the Ministry of Agriculture and Rural Development, a survey to determine the number of smallholders in export production was conducted in nine districts of Central and Eastern Province (Nyeri, Kirinyaga, Thika, Maragua and Murang'a districts in Central Province and Meru Central, Machakos, Makueni, Meru North districts in Eastern Province). This census provided information on the number of EurepGAP certified and non-certified small export producers linked to an exporter, non-certified small export producers linked to middlemen or producing independently and finally, as the control group, an estimate of the number of producers growing for the domestic market.

Two studies on the economic impact of EurepGAP standards on smallholder and medium- to large-scale producers commenced in September 2005. The smallholder study is based on a random sample of 540 farmers in 5 districts (Nyeri, Kirinyaga, Murang'a, Makueni and Meru Central districts). The study will assess the economic impact of EurepGAP standards on farm performance and factors associated with adoption of standards. Finally, it will assess the impact of production standards on pesticide use and farmers' health. The study of medium- to large-scale producers is based on case studies of 30 producers who are linked to a variety of exporters. It assesses the impact of certification on medium- to large-scale production and also compares it to the certified smallholders. First results of these studies are expected by the end of 2006.

The second objective will be to evaluate the impact of training on performance of smallholders in horticulture as well as the changing needs in horticulture. A PhD student in Agricultural Economics sponsored by *icipe*'s ARPPIS programme will carry out further research (starts in September 2006). Related to objective one and two, another PhD research project will commence at the end of 2006 to analyse the negative external effects of Kenyan horticulture.

References

Anyango J. J. and Nabwile S. M. (1995) A survey on French beans production by smallholders in Kenya—pest status, plant protection practices, economics and role of gender. A report to GTZ IPM Horticulture Project, Nairobi.

Bellin F. and Leitzmann C. (1995) Die Bedeutung der Mikronährstoffe für die menschliche Entwicklung—ein Plädoyer für Gemüse (The role of micronutrients in human development). *Entwicklung und Ländlicher Raum* 4/95, pp. 7–9.

CBS (2003) Economic Survey. Central Bureau of Statistics, Ministry of Planning and National Development, Republic of Kenya.

Dijkstra T. and Magori T. D. (1995) Horticultural production and marketing in Kenya—Part 5. Food and Nutrition Programme Studies Report 53/1995, Leiden African Studies Centre, Leiden.

Dolan C. (2001) The 'good wife' struggles over resources in the Kenyan horticultural sector. *Journal of Development Studies* 37, 39–70.

Jaffee S. (2003) From challenge to opportunity: The transformation of the Kenyan fresh vegetable trade in the context of emerging food safety and other standards. The World Bank, Washington, DC.

McCulloch N. and Ota M. (2002) Export horticulture and poverty in Kenya. Paper presented at Conference on Globalisation and Inequality, Centre for the Study of Globalisation and Regionalisation, University of Warwick.

Michalik S. (1994) Crop protection measures of Kenyan vegetable farmers and their use of pesticides—A knowledge, attitude and practice survey. A report to GTZ IPM Horticulture Project, GTZ, Nairobi.

Nyoro J. K., Ariga J. and Komo I. (2004) Kenyan Case Study on Fresh Products, Vegetables and Dairy Products. Re-governing Markets Phase I. Draft Report. Tegemeo Institute of Agricultural Policy and Development. Nairobi, Kenya.

Swanberg K. (1995) The Kenyan green revolution. *Horticultural Trade Journal* 3, 3–5.

Output

Conferences attended

International Research on Food Security, Natural Resource Management and Rural Development (Tropentag 2005) conference on "The Global Food & Product Chain Dynamics, Innovations, Conflicts, Strategies" held at the University of Hohenheim, Stuttgart-Hohenheim, 11–13 October, 2005. Attended by: D. Mithöfer.

Research proposals

Improving biodiversity conservation in the horticultural farming systems in Eastern Africa. Submitted to GEF (October 2005).

Capacity building

PhD student

S. Asfaw (Ethiopia) Economic impact of food safety standards on smallholder fresh export produce in Kenya: Linking contract farming, farmer health and rural poverty. Development and Agricultural Economics, Faculty of Economics and Business Administration, University of Hannover, Germany (ongoing).

MSc student

K. Mausch (Germany) Impact of EurepGAP standards in Kenya: Comparing smallholders to large-scale producers. Development and Agricultural Economics, Faculty of Economics and Business Administration, University of Hannover, Germany (ongoing).

DEVELOPMENT OF ENVIRONMENTALLY FRIENDLY MANAGEMENT METHODS FOR RED SPIDER MITES IN SMALLHOLDER TOMATO PRODUCTION SYSTEMS IN EAST AND SOUTHERN AFRICA

Background, approach and objectives

Tomato is one of the most important vegetables in East and Southern Africa yet yields in smallholder production systems are far below the crop's potential. The red spider mite (RSM) *Tetranychus evansi* Baker & Pritchard is probably of American origin and was accidentally introduced to Africa in the late 1970s. It was first recorded in Zimbabwe in 1979 and has spread northwards reaching Zambia at around 1985 and Malawi 1990. In 2001 it was found in Kenya and in 2002 it was recorded from Somalia. It is now also present in several countries in central and western Africa (Congo, Senegal, Niger, The Gambia). *Tetranychus evansi* is currently the most serious pest of tomatoes in East and Southern Africa. Since it is an introduced species, most indigenous natural enemies do not feed on it. This leads to rapid population build-up mainly in the dry season, frequently leading to total crop loss. Current control practices involve regular applications of synthetic acaricides with long pre-harvest intervals, which result in pesticide contamination of producers, the produce and the environment. In addition, these pesticide treatments are often not effective since the spraying techniques used by African smallholders are inadequate for the control of spider mites.

The project aims to develop an integrated pest management (IPM) strategy for RSM in East and Southern Africa focusing on classical biological control, host plant resistance, acaricide resistance management, improved crop management and improved pesticide application techniques.

Since *T. evansi* is probably of South American origin, surveys for natural enemies have been conducted in areas of Brazil and Argentina that are climatically similar to the major tomato production areas of Kenya and Zimbabwe. Predators found are tested for their suitability for introduction into Africa and the predatory mite *Phytoseiulus longipes* Evans has been imported into Kenya, where it is currently kept at *icipe*'s quarantine facilities awaiting a release permit from the Kenyan authorities.

Resistance mechanisms in RSM resistant tomato accessions have been investigated and breeding programmes started to introduce the resistance into commercial varieties.

Commonly used acaricides were tested with *T. evansi* strains from major tomato producing areas of Zimbabwe and Kenya to establish the resistance status of the populations. The results are used for recommendations to farmers and in training programmes on pruning and staking of tomatoes and proper pesticide application.

Participating scientists: *M. Knapp, A. Hassanali, N. K. Maniania*

Assisted by: *B. Muia, M. Kungu, C. Kyalo and E. O. Ouna, R. Rotich (Arthropod Pathology Unit)*

Donor: *German Federal Ministry of Economic Co-operation and Development, and icipe core fund donors (APU)*

Collaborators: *KENYA: Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya. ZIMBABWE: Plant Protection Research Institute, Harare, Zimbabwe. SOUTH AFRICA: Plant Protection Research Institute, Pretoria, South Africa. CHINA: World Vegetable Centre, Taiwan. BRAZIL: Escola Superior de Agricultura "Luiz de Queiroz", University of São Paulo, Brazil; Universidade Federal Rural de Pernambuco, Recife, Brazil; Universidade Rural de Cariri, Crato, Brazil; Universidade de Lavras, Lavras, Brazil. FRANCE: Ecole Nationale Superieure Agronomique, Montpellier, France*

Collaborating department: *Behavioural and Chemical Ecology Department*

Collaborating support unit: *Arthropod Pathology Unit*

BIOLOGICAL CONTROL OF *TETRANYCHUS EVANSI*

1. Exploration for biocontrol agents for T. evansi *in South America*

Surveys for predators of *Tetranychus evansi* on solanaceous plants were carried out in Brazil and Argentina to determine prospective species for the control of the pest in Africa. Surveys were carried out in areas identified as climatically similar to regions in Africa where *T. evansi* has been reported as a pest and where prospective natural enemies may be introduced.

Northeast and southeast Brazil. A total of 56,445 mites and insects were found in 330 samples collected from 20 different species of solanaceous plants. *Tetranychus evansi* was found in only three samples, on *Solanum americanum* Mill. and *Lycopersicon esculentum* Mill. A total of 5023 specimens of predatory mites, of at least 44 species, and 494 specimens of acarophagous insects, of at least three species were collected. The predominant predatory mites were (in decreasing order): *Phytoseius guianensis* DeLeon, *Pronematus ubiquitus* (McGregor), *Asca* sp., *Paraphytoseius orientalis* (Narayanan, Kaur & Ghai), *Phytoseius woodburyii* DeLeon, *Amblyseius compositus* Denmark & Muma, *Homeopronematus anconai* (Baker), *Neoparaphytoseius sooretamus* (El-Banhawy), *Cunaxoides* sp., *Typhlodromus paraevectus* Moraes & McMurtry, *Typhlodromalus peregrinus* (Muma) and *Phytoseius cismontanus* DeLeon. However, no predatory mites were found in association with *T. evansi*. Among the insects, although not the most abundant, *Stethorus tridens* Gordon seemed to be most promising, as it was found associated with *T. evansi* in all samples in which the latter was found. *Feltiella* sp. was the most abundant acarophagous insect found, but it was never found associated with the pest.

Central-western Brazil. In central-western Brazil, 4496 mites were collected, 3964 belonging to the family Tetranychidae and 471 belonging to the family Phytoseiidae. More than 70 different plant species were examined, 16 of them from the family Solanaceae. *Euseius citrifolius* Denmark & Muma and *E. concordis* (Chant) were the phytoseiids most frequently collected, both of them were found in association with *T. evansi* on tomatoes and *S. americanum*, the only plants where *T. evansi* was encountered. *Neoseiulus ideaus* Denmark & Muma, *Proprioseiopsis mexicanus* (Garman), *P. ovatus* (Garman) and *Typhlodromalus aripo* DeLeon were also found together with *T. evansi*.'

Southern and southeast Brazil. In southern and southeast Brazil, 34,357 tetranychids and 1425 phytoseiids were collected from 22 different species of Solanaceae. *Phytoseius guianensis* and *Galendromus annectens* DeLeon were the most common predatory mites but they were not associated with *T. evansi*. *Euseius ho* (DeLeon), *E. inouei* (Ehara & Moreas), *Neoseiulus califórnicus* (McGregor), *N. ideaus*, *Phytoseiulus fragariae* Denmark & Schicha and *P. longipes* were found in association with *T. evansi*.

Northern Argentina. *Tetranychus evansi* was found much more frequently and in higher numbers in Argentina than in Brazil. *Euseius caseariae* DeLeon was the most frequently collected phytoseiid mite; however, *N. californicus* was the most abundant one. This species as well as *E. citrifolius*, *E. concordis*, *Neoseiulus tunus* (DeLeon), *N. ideaus*, *P. fragariae* and *Proprioseiopsis cannaensis* (Muma) were collected together with *T. evansi*.

Phytoseiulus longipes, *P. fragariae* and *S. tridens* were selected for further investigations to determine their suitability as classical biological agents.

Life tables of **Phytosieulus longipes** *feeding on* **Tetranychus evansi** *at four different temperatures*

The development and reproduction of the *P. longipes* population collected at Uruguaiana, Rio Grande do Sul, was investigated at 15, 20, 25 and 30 °C with *T. evansi* as prey. The duration of the immature phase ranged from 3.1 to 15.4 days, at 30 and 15 °C, respectively. The lower thermal threshold for immature development was calculated as 12.0 °C. Immature survival was high at all tested temperatures (minimum of 88% at 30 °C). The intrinsic rate of increase (r_m) of *P. longipes* ranged from 0.091 to 0.416 females/female/day, at 15 and 30 °C, respectively (Table 1). These values suggest that *P. longipes* is able to develop at a wide range of temperatures feeding on *T. evansi* and has the potential to control *T. evansi* populations.

Table 1. Demographic parameters of *Phytoseiulus longipes* population feeding on *Tetranychus evansi* at four temperatures

	Demographic parameters				
Temperature (°C)	R_o	T	λ	Dt	r_m
15	9.74	26.44	1.09	8.05	0.091
20	10.01	18.65	1.13	5.61	0.123
25	13.88	12.92	1.23	3.40	0.293
30	13.84	8.17	1.38	2.15	0.416

Prey preference of Phytosieulus longipes

The biology of *P. longipes*, was studied in the laboratory at 25 ± 1.0 °C, 83 ± 12% RH and 12/12 h photoperiod with four different food sources, i.e. pollen of *Typha* sp. and *Ricinus communis* and the spider mites *Tetranychus evansi* and *T. urticae* Koch. Immature development was similar on the two spider mite species. When offered pollen none of the mites survived the deutonymphal stage. Oviposition and survival were also similar and very high with both spider mite species while oviposition was almost zero and all mites were dead after 11 days on the pollen diet (Table 2).

Table 2. Mean daily oviposition rate and survivorship of *Phytoseiulus longipes* on different food sources at 25 ± 1.0 °C, 83 ± 12 % RH and 12/12 h photoperiod

		Survivorship (%)*		
Food source	Eggs/female/day	Day 4	Day 8	Day 11
Tetranychus evansi	3.4 ± 0.1 a	100.0 a	95.0 a	80.0 a
T. urticae	3.5 ± 0.1 a	100.0 a	100.0 a	85.0 a
Typha sp.	0.01 ± 0.1 b	15.0 b	10.0 b	0.0 b
Ricinus communis	0.01 ± 0.1 b	5.0 b	0.0 b	0.0 b

Means followed by the same letters in the same column do not differ statistically (Student-Newman-Keuls test, $P < 0.05$).
*Days after the beginning of the observations.

When given the choice between *T. evansi* and *T. urticae* the predators were found in higher proportions on leaflets infested with *T. evansi* than with *T. urticae*. On the former leaflets, they also laid more eggs (Figures 1 and 2).

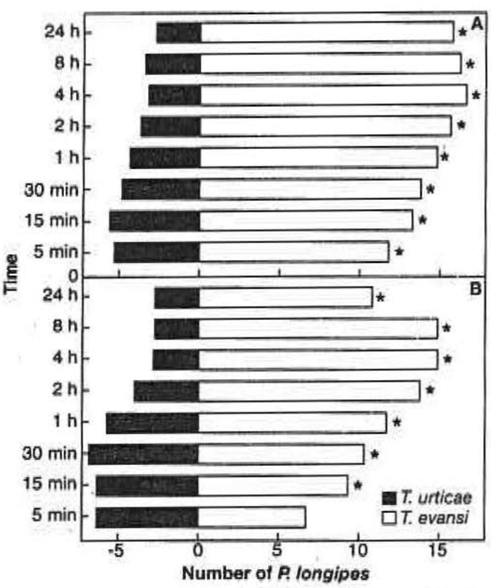


Figure 1. Number of *Phytoseiulus longipes* found on tomato leaflets infested with *Tetranychus evansi* or *T. urticae*. (A) *P. longipes* reared on *T. evansi*, (B) *P. longipes* reared on *T. urticae*. *Indicates significant differences (χ^2, $P < 0.05$).

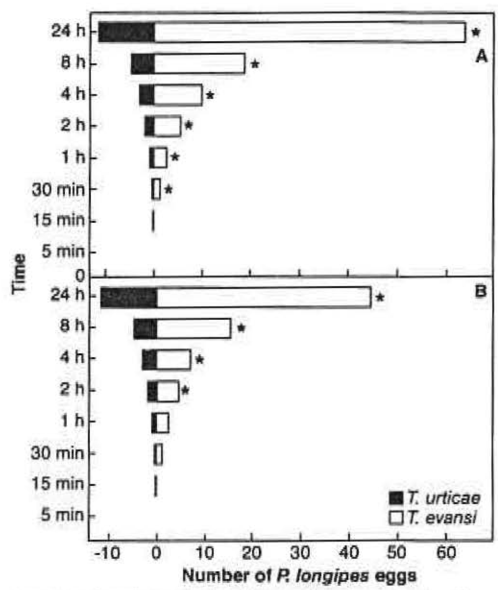


Figure 2. Number of eggs laid by *Phytoseiulus longipes* on tomato leaflets infested with *Tetranychus evansi* or *T. urticae*. (A) *P. longipes* reared on *T. evansi*, (B) *P. longipes* reared on *T. urticae*. *Indicates significant differences (χ^2, $P < 0.05$).

Development and population increase of Phytoseilus fragariae *feeding on* Tetranychus evansi *or* T. urticae *at four different temperatures*

The development and population increase of *P. fragariae* feeding on *Tetranychus evansi* or *T. urticae* was investigated at 15, 20, 25 and 30°C. At all temperatures, development was slightly quicker on *T. urticae* than on *T. evansi*. Survival of the immature phase was 73% or higher when *P. fragariae* was reared on *T. evansi* and 92% or higher when it was reared on *T. urticae*. At all temperatures, the intrinsic rate of increase (r_m) was 2 to 3 times higher on *T. urticae* than on *T. evansi* (Table 3). Compared to r_m reported for other species in the genus *Phytoseiulus*, the intrinsic rate of increase was low when prey was *T. evansi* and comparable to other studies when prey was *T. urticae*. The results suggest that the predator could be effective in the control of *T. urticae*, but probably not effective in the control of *T. evansi*.

Table 3. Life table parameters of *Phytoseiulus fragariae* on *Tetranychus evansi* and *T. urticae* at four different temperatures

	Temperature (°C)							
	15		20		25		30	
Parameters	*T. evansi*	*T. urticae*	*T. evansi*	*T. urticae*	*T. evansi*	*T. urticae*	*T. evansi*	*T. urticae*
R_0	2.30	22.04	2.92	33.73	3.45	16.29	3.59	28.13
T	35.12	39.62	21.06	27.12	15.82	15.80	13.35	12.54
r_m	0.024	0.078	0.051	0.130	0.078	0.177	0.096	0.266
λ	1.024	1.081	1.052	1.139	1.081	1.193	1.100	1.305
TD	29.16	8.88	13.62	5.34	8.86	3.92	7.24	2.61

Biology of the acarophagous ladybird beetle Stethorus tridens *feeding on* T. evansi

The biology of *S. tridens* feeding on *T. evansi* was studied in the laboratory. The number of prey consumed by *S. tridens* increased with the larval instars and the total number consumed during the developmental time was 184.1 *T. evansi* nymphs. The daily consumption was 41.3 and 67.8 for adult males and females, respectively. *Stethorus tridens* successfully developed to adulthood from 20 to 30°C but failed at 15 and 35°C. The mean developmental time from egg to adult was between 23.8 days at 20°C and 12.1 days at 30°C (Table 4). At 27°C, the sex ratio was 1.17 females for 1 male and the mean preoviposition, oviposition and postoviposition periods were 10.3, 31.2 and 30.2 days, respectively. The oviposition rate was 4.0 eggs/female/day with a female longevity of 71.6 days and an intrinsic rate of natural increase (r_m) of 0.104 females/female/day.

Table 4. Mean developmental time (days ± SE) of *Stethorus tridens* at six constant temperatures

	Temperature (°C)					
Stage	15	20	24	27	30	35
Egg	16.3 ± 2.03 a	5.9 ± 0.14 b	4.0 ± 0.04 c	3.9 ± 0.08 c	3.0 ± 0.03 d	3.0 ± 0.00 d
Instar 1	-	3.9 ± 0.11 a	2.2 ± 0.12 b	2.2 ± 0.13 b	1.9 ± 0.07 bc	1.0 ± 0.01 c
Instar 2	-	2.2 ± 0.10 a	2.0 ± 0.15 ab	1.8 ± 0.11 b	1.1 ± 0.03 c	-
Instar 3	-	2.6 ± 0.11 a	2.4 ± 0.14 a	2.0 ± 0.14 b	1.1 ± 0.05 c	-
Instar 4	-	4.3 ± 0.09 a	3.1 ± 0.13 b	3.1 ± 0.15 b	2.3 ± 0.07 c	-
Pupa	-	5.0 ± 0.03 a	4.0 ± 0.06 b	3.5 ± 0.16 c	2.8 ± 0.07 d	-
Total	-	23.8 ± 0.24 a	17.4 ± 0.22 b	16.2 ± 0.22 c	12.1 ± 0.16 d	-

Means followed by the same letter in the same row are not significantly different (Student-Newman-Keuls test, 5%).
-, no beetles alive.

The functional and numerical response of *S. tridens* on *T. evansi* was studied at 25°C, 70 ± 10% RH and 12/12 h photoperiod. Newly emerged adult female *S. tridens* were obtained from a stock colony for the tests, conducted at the following prey densities: 5, 20, 40, 60, 80 and 100 *T. evansi* nymphs per arena (5 cm^2). The number of prey consumed was evaluated every 24 hours, when dead mites were replaced. Adult ovipositing *S. tridens* females showed functional response type II. The maximum prey consumption was 32

T. evansi nymphs at the density of 100 prey per beetle. At the density of five *T. evansi*, predation was 100%, suggesting that the density available was lower than the consumption potential of the predator. At the density of 20 prey, predation ranged from 68 to 87% and decreased to 30% at prey density of 100 prey. *Stethorus tridens* did not lay eggs at the density of five *T. evansi* per predator; some oviposition was observed at the density of 20 prey specimens per arena. The mean fecundity was 11.5, 20.8, 30.4, 25.2 and 30.7 eggs per female at prey densities of 20, 40, 60, 80 and 100, respectively.

2. *Suitability of* Tetranychus evansi *as prey for the predatory mites* Asca *sp.,* Paraphytoseius orientalis, Phytoseius guianensis, Phytoseius cismontanus *and* Pronematus ubiquitus

The survival and fecundity of five of the most common predatory mites found on Solanaceae in northeast Brazil: *Asca* sp., *Paraphytoseius orientalis*, *Phytoseius guianensis*, *P. cismontanus* De Leon and *Pronematus ubiquitus* on four different food sources [*T. evansi*; pollen of *Ricinus communis* L., *Aculops lycopersici* (Massee) and combination of *A. lycopersici* + pollen] were studied in the laboratory. The oviposition of all predatory mites was very low to zero on *T. evansi* and significantly lower than on the other diets (Table 5). With the exception of *P. guianensis* and *P. cismontanus* that showed the same survival rates on all diets, the survival of the predatory mites was significantly lower on *T. evansi*. It was concluded that these predatory mites are not suitable as biocontrol agents for *T. evansi*.

Table 5. Oviposition rates of five different predatory mites fed *Tetranychus evansi*, *Aculops lycopersici* and/or pollen

	Oviposition (eggs/♀/day) ± SE			
Predator species	*T. evansi*	*A. lycopersici*	*A. lycopersici* + pollen	Pollen
Asca sp.	0.0 ± 0.00 bC	0.1 ± 0.03 aC	0.1 ± 0.04 aC	0.0 ± 0.00 bC
Pronematus ubiquitus	0.0 ± 0.00 cC	0.8 ± 0.09 aB	0.7 ± 0.15 aB	0.3 ± 0.04 bB
Phytoseius guianensis	0.1 ± 0.03 bAB	0.7 ± 0.07 aB	0.5 ± 0.08 aB	0.6 ± 0.06 aA
P. cismontanus	0.2 ± 0.04 bA	0.7 ± 0.05 aB	0.7 ± 0.08 aB	0.6 ± 0.06 aA
Paraphytoseius orientalis	0.1 ± 0.04 cB	1.8 ± 0.07 aA	2.0 ± 0.12 aA	0.7 ± 0.09 bA

Means followed by the same upper case letter in the same column or lower case letter in the same row are not significantly different (Student-Newman-Keuls test at 5%).

3. *Population dynamics of* Tetranychus evansi *and associated arthropods at Recife-Brazil*

The population dynamics of *Tetranychus evansi*, other phytophagous mites and their antagonists was studied in an experimental field at Recife on *S. americanum* and *L. esculentum* (tomato). *Tetranychus evansi* and *A. lycopersici* were the most common phytophagous mites recorded on both plant species. The population of *T. evansi* was significantly higher on *S. americanum* while *A. lycopersici* was significantly more common on tomato. Both phytophagous mite populations were decimated by fungal epizootics during the rainy season. *Tetranychus evansi* was attacked by *Neozygites floridana* Weiser & Muma while *A. lycopersici* was attacked by *Hirsutella thompsonii* Fisher. The infection rate and population drop in *T. evansi* was higher on *S. americanum* than tomato. The fungus quickly decimated the red spider mite population and kept it at low levels for 1.5 and 2 months on *S. americanum* and tomato, respectively. *Stethorus tridens* and *H. anconai* were the most common predators encountered. *Stethorus tridens* was found associated to *T. evansi* throughout the experiment and was significantly more numerous on *S. americanum*. In most cases, the predator population increased as pest population increased without controlling the pest. However, on *S. americanum*, in some cases, the increases and decreases in *S. tridens* populations coincided with inverse trend in pest populations (Figure 3). *Homeopronematus anconai* was more related to *A. lycopersici*. Other predators were recorded but rather rare: the predatory mites *Amblyseius aerialis* (Muma), *A. tamatavensis* Blommers, *E. concordis*, *Iphyseioides zuluagai* Denmark & Muma, *P. cannaensis* and *Asca* sp. and the acarophagous insects *Scolothrips sexmaculatus* (Pergande), *Feltiella* sp. and *Oligota* sp.

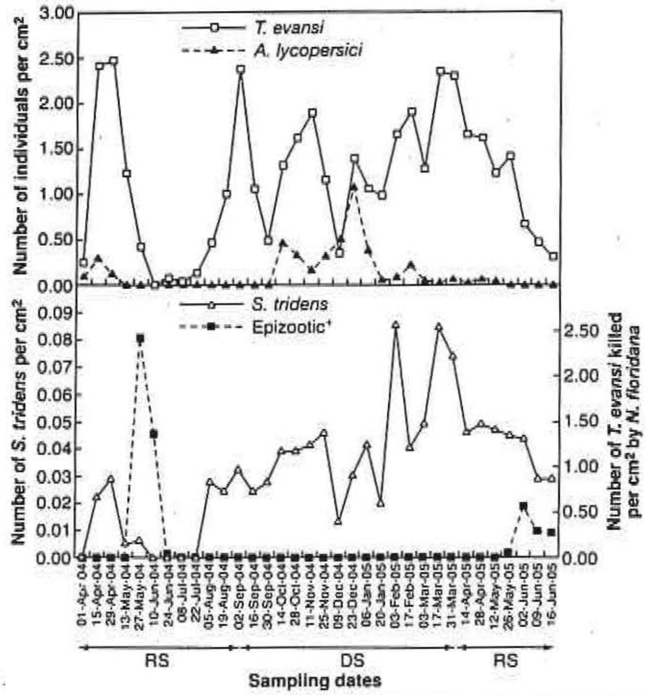


Figure 3. Fluctuation of the most common arthropod species collected on *Solanum americanum* from May 2004 to June 2005 at Recife. *Number of *Tetranychus evansi* killed by *Neozygites floridana*. RS, rainy season; DS, dry season

4. *Preliminary investigations on the mite pathogen* Neozygites floridana

Neozygites floridana was reported as a pathogen of *T. evansi* over 20 years ago in a semi-arid region of northeast Brazil. In 2004, isolates of this pathogen were collected in northeast (Recife-Pernambuco) and southern (Piracicaba-São Paulo) Brazil, indicating that epizootics occur over a broad range of climates. Epizootics of this pathogen wiped out populations of *T. evansi* in Recife (see above) and in Piracicaba the prevalence of the pathogen varied throughout the year but infection was detected in almost all samples taken from April to December 2004. Pathogenecity assays against *T. evansi* and *T. urticae* were conducted by transferring adult females of each mite species to leaf discs containing sporulated cadavers with a halo of conidia of each fungal isolate. All isolates caused some degree of infectivity to both species. However, there was a great variation in mortality and mummification caused by these isolates indicating some degree of host specificity. One isolate collected from *T. evansi* was highly virulent and only caused mummification of *T. evansi*. After 10 days, this isolate caused 61% infection and 41% mummification of *T. evansi*. Most mites died and mummified 4 to 6 days post-infection. Isolates causing high mummification in a short period of time would be more likely to cause epizootics and to establish in a new environment. Therefore, an isolate with these attributes would be the best candidate for introduction to Africa.

5. *Introduction of biological control agents*

Phytoseiulus longipes from Brazil was introduced into Kenya in September 2005 and is currently kept at *icipe*'s quarantine facilities awaiting a release permit from the Government of Kenya.

6. *Effects of host plants on the life history of the predator* Neoseiulus californicus *with the prey* Tetranychus evansi

The predatory mite *N. californicus* was found on bean plants infested with *T. evansi* in Naivasha, Kenya in 2004 whereas on tomato no predatory mites were ever found associated with the spider mite in extensive surveys in East and Southern Africa. The influence of the host plant of *T. evansi* on the performance of *N. californicus* was investigated in the laboratory. Spider mites reared on beans or tomatoes were offered to *N. californicus* on either bean or tomato leaves or in a small cage. In all cases *N. californicus* laid more eggs when fed *T. evansi* reared on beans than on *T. evansi* reared on tomatoes (Table 6).

Table 6. Oviposition rate (mean ± SE), sample size and sex ratio per combination of *Neoseiulus californicus*

Prey and substrate	Eggs/female/day	Sex ratio
TomEvansi[1] on tomato	0.66 ± 0.29	62.90
TomEvansi on bean	1.21 ± 0.47	60.98
TomEvansi in cage	1.10 ± 0.64	73.50
BeanEvansi[2] on tomato	1.33 ± 0.50	65.87
BeanEvansi on bean	1.83 ± 0.48	74.51
BeanEvansi in cage	1.52 ± 0.63	69.84

[1]*Tetranychus evansi* reared on tomato.
[2]*T. evansi* reared on beans.

The predatory mite successfully completed its development feeding on both preys. However, the development from egg to adult was longer when spider mites from tomatoes were offered as prey. These results show that the host plant has a significant influence on the performance of the predator.

7. *Diversity of Phytoseiidae in Kenya and Zimbabwe*

Surveys to collect Phytoseiidae have been conducted in all major agroecological zones of Kenya to evaluate the diversity and distribution of predatory mites in the country. The identification is currently ongoing. In Zimbabwe, the major objective was to find *Phytoseiulus longipes* since this species was originally described from Harare. It was, however, never found during previous surveys in tomato fields and also not recovered during the surveys conducted in 2005. A strain from southern Africa had been evaluated as biocontrol agent for *T. evansi* in California in the 1980s but proved to be ineffective. Therefore, a comparison of the morphology, biology and genetic diversity of the southern African and Brazilian strains of this species could provide insight in the reasons of their differing prey preference.

HOST PLANT RESISTANCE IN TOMATO

Resistant varieties are an environmentally friendly and in general a cost-effective way of reducing pest damage, rendering them a most desirable tool for resource-poor smallholder agriculture. Resistance comes with the seed and needs little or no extra cost to make it work.

8. *Selection of tomato genotypes with high acyl sugar content based on colorimetric analysis*

An assay was conducted for the determination of acyl-sugars on tomato plants of a segregating population at University of Lavras, Brazil. Plants with high acyl sugar content were selected for later use in assays to determine resistance to *T. evansi*. Acyl-sugars are present in exudates of type IV glandular trichomes of *Lycopersicon pennellii*, conferring a high degree of resistance to many arthropod pests, including whiteflies, tomato pinworm and mites. With the colorimetric method developed at University of Lavras the selection of tomato plants can be done based on acyl-sugar levels, facilitating breeding programmes for resistance to pests. The assay was set up using a total of 500 potted plants: 400 plants of the F_2RC_3 population of the crossing between *L. esculentum* 'TOM-584' and *L. pennellii* 'LA-716', 50 control plants with high acyl-sugar content (*L. pennellii* 'LA-716') and 50 control plants with low acyl-sugar content (*L. esculentum* 'TOM-584'). Based on the evaluation, 32 plants with high and 29 plants with low acyl-sugar contents of the segregating population, 5 'LA-716' plants and 6 'TOM-584' plants were selected for resistance bioassays along with the high acyl-sugar (HiAS) accession 'LA-716' and the standard low-acyl-sugar (LoAS) 'TOM-584', for their level of resistance to *T. evansi*, by thumbtack assay. Distances travelled by the mites on the leaf surface were significantly larger in 'TOM-584' than in 'LA-716', indicating the high level of mite repellence of the latter genotype. Clones from high acyl-sugar (HiAS) plants behaved similarly to 'LA-716', whereas clones from low acyl-sugar (LoAS) plants behaved similarly to 'TOM-584' (Table 7). Distances travelled by the mites were significantly longer in LoAS than in HiAS clones.

Table 7. Average distance travelled by female *Tetranychus evansi* on the surface of tomato genotypes after 20, 40 and 60 min

Contrast	Contrast estimate		
	Distance after 20 min	Distance after 40 min	Distance after 60 min
'LA-716' vs 'TOM-584'	-5.36667 **	-5.80000 **	-5.77083 **
'LA-716' vs HiAS clones	-1.08695 ns	-1.01301 ns	-0.98887 ns
'TOM-584' vs LoAS clones	0.62542 ns	0.42470 ns	0.01399 ns
HiAS vs LoAS	-3.65415 **	-4.36212 **	-4.7679 **

**Significant ($P < 0.01$, Student's *t*-test).

9. *Chemical composition and activity of volatile compounds and essential oils in tomato accessions against* Tetranychus evansi

The chemical composition of volatile compounds and essential oils of seven tomato accessions was analysed and their activity against *T. evansi* tested in olfactometer tests. The accessions tested comprised of five accessions of cultivated tomato, *L. esculentum*; the susceptible variety Money Maker (MM) and Marglobe (MG), JKUAT 22/202183 (J22), JKUAT 19 (J19) and LO 3279 (LO), which had shown resistance to *T. evansi*. The resistant accessions *L. hirsutum* PI 134417 (Lh) and *L. peruvianum* LA 2185 (Lp) were also investigated. 2-Tridecanone was found in very high quantities in *L. hirsutum* and is known to be toxic to spider mites. Other major volatile compounds detected include 2-undecanone and 3-methyl-2-butanone. 2-Tridecananone, β-caryophyllene, α-humulene and 2-undecanone were the major compounds detected in the essential oils (Table 8).

Table 8. Relative abundance (%) of compounds in the essential oils of different tomato accessions

Compound	MM	MG	Lh	J22	J19	Lp	LO
2-Undecanone	-	-	12.3	-	7.1	2.4	0.3
2-Dodecanone	-	-	0.6	-	0.4	0.3	-
2-Tridecanone	-	-	48.5	1.1	27.1	39.6	12.6
2-Pentadecanone	3.3	1.6	2.4	2.5	-	1.9	1.4
2-Decanone	-	-	0.04	-	-	0.06	-
3-Methyl-2-butanone	0.6	0.04	0.01	0.03	0.02	0.04	0.03
β-Phellandrene	0.3	2.0	-	2.4	-	2.1	3.1
β-Caryophyllene	2.1	0.8	2.9	19.8	5.4	2.7	7.8
δ-Elemene	0.4	6.9	-	5.4	0.1	2.8	0.7
β-Elemene	-	2.2	0.1	1.2	0.2	1.0	-
α-Humulene	0.6	15.4	0.8	4.9	1.4	3.0	0.1
δ-Cadinene	0.1	1.3	0.1	-	0.1	0.7	0.03
Terpinolene	0.1	-	-	0.6	-	-	0.4
α-Pinene	-	-	-	0.02	-	4.9	-
β-Pinene	0.06	-	-	-	-	7.4	-

The identification of compounds was based on integration of peaks in the GC-MS total ion chromatogram.

In olfactometer tests *T. evansi* significantly preferred the susceptible accession Money Maker to Marglobe, PI 134417, LA 2185 and LO 3279 (Figure 4).

Spider mite response to essential oil treated cotton balls was significantly lower than to untreated cotton balls in accessions PI 134417, LA 2185, LO 3279 and JKUAT 22/202183.

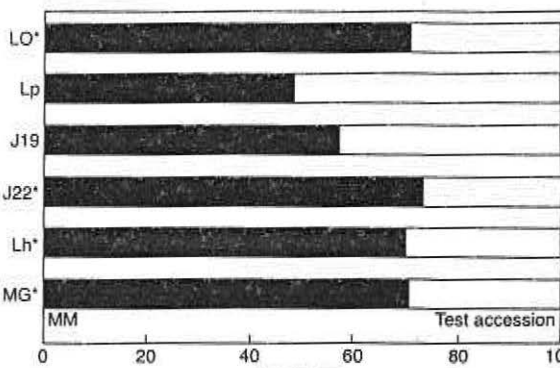


Figure 4. Percentage response of adult female *Tetranychus evansi* to the susceptible accession Money Maker and the test accessions. *Indicates significant differences (χ^2, $P < 0.05$)

10. *Role of trichomes in the resistance of tomato to* Tetranychus evansi

The accessions mentioned above plus the commercial tomato variety Rio Grande (RG) were investigated for differences in trichome types and numbers and their relationship to mite resistance.

The density of trichome types I, IV, V and VI on the abaxial leaf surface was significantly different between the accessions tested (Table 9). Type VII trichomes were not present in all accessions. Both wild tomato accessions had very high densities of type IV trichomes, which have been reported to play a major role in the resistance of *L. hirsutum* to arthropods.

Table 9. Density of different trichome types on the abaxial surface of leaves of different tomato accessions

	Trichome type					
Accession	I	II	III	IV	V	VI
MM	0.2 ± 0.24 b	0.0 ± 0.00 a	0.0 ± 0.00 a	0.0 ± 0.00 b	15.1 ± 1.39 a	4.0 ± 0.65 ba
MG	1.0 ± 0.45 b	0.0 ± 0.00 a	0.0 ± 0.00 a	0.7 ± 0.52 c	5.6 ± 1.13 ba	3.3 ± 0.74 ba
Lh	1.7 ± 0.56 b	0.2 ± 0.24 a	0.0 ± 0.00 a	12.3 ± 1.92 b	1.2 ±0.49 c	5.2 ± 1.22 ba
J22	0.2 ± 0.24 b	0.0 ± 0.00 a	0.0 ± 0.00 a	0.0 ± 0.00 c	16.6 ± 1.33 a	0.0 ± 0.00 c
J19	0.5 ± 0.33 b	0.0 ± 0.00 a	0.2 ± 0.24 a	0.0 ± 0.00 c	9.2 ± 1.28 ba	3.8 ± 0.82 a
Lp	2.6 ± 0.64 a	0.0 ± 0.00 a	0.0 ± 0.00 a	11.3 ± 1.39 a	0.0 ±0.00 c	1.4 ± 0.53 bc
LO	0.2 ± 0.24 b	0.7 ± 0.40 a	0.0 ± 0.00 a	1.2 ± 0.49 c	3.6 ±0.74 b	2.1 ± 0.6 ba
RG	0.0 ± 0.00 b	0.2 ± 0.24 a	0.0 ± 0.00 a	0.0 ± 0.00 c	22.3 ± 1.51 a	4.0 ± 0.88 ba

Means followed by the same letter in the same row do not differ statistically (Student-Newman-Keuls test, $P < 0.05$).

There were significant differences in oviposition and survival of *T. evansi* between the accessions, and a significant negative correlation between type IV trichome density and oviposition. Survival was negatively correlated to type I trichome density and positively correlated to type V trichome density.

11. Resistance tests in the field

Accessions of cultivated tomato that had shown resistance in preliminary laboratory experiments were planted in the field together with the susceptible check Money Maker and the resistant check *Lycopersicon hirsutum*. The plants were left for natural infestation with *T. evansi* and scored for mite damage six times at weekly intervals after the first infestation had been detected. Mite damage was significantly lower than in the susceptible check and significantly higher than in the resistant accessions in most varieties tested; however, differences within the test accession were small and none of the *L. esculentum* accessions can be regarded as resistant under field conditions.

IMPROVED CROP MANAGEMENT STUDIES

12. Development of tomato hybrids (Lycopersicon esculentum x Lycopersicon hirsutum *f.* glabratum) *resistant to* Tetranychus evansi

Interspecific crosses between *Lycopersicon hirsutum* f. *glabratum* accession LA 2204 and the tomato variety 'Money Maker' were initiated and their resistance to *Tetranychus evansi* evaluated. The F_1, F_2, BC_1 and BC_2 generations were developed with 'Money Maker' as the recurrent female parent, while LA 2204 was the initial pollen donor. Trichome types that were identified on the abaxial and adaxial surfaces of both parent tomato plants and F_1, F_2, BC_1 and BC_2 generations included types I, III, IV, V, VI and VII. Type II trichomes were absent on parents and the F_1, F_2, BC_1 and BC_2 generations. Type IV trichomes were absent on 'Money Maker', while type V were absent on accession LA 2204. The F_1, F_2, BC_1 and BC_2 generations possessed both type IV and V trichomes. Type IV glandular trichomes were predominant on accession LA 2204, while non-glandular type V trichomes were predominant on variety 'Money Maker' and the F_1, F_2, BC_1 and BC_2 generations.

Egg hatchability and immature survival were lowest in accession LA 2204, highest in 'Money Maker' and intermediate on F_1, F_2, BC_1 and BC_2 generations. The same trends were observed in fecundity and adult survival (Table 10).

Table 10. Fecundity and longevity of *Tetranychus evansi* females on six tomato lines

Tomato line	Eggs/female	Longevity (days)
'Money Maker'	57.9 ± 4.46 a	13.1 ± 1.06 a
LA 2204	0.04 ± 0.02 d	4.5 ± 0.23 d
F_1	10.5 ± 1.94 c	8.7 ± 0.43 bc
F_2	5.4 ± 0.94 c	6.9 ± 0.38 cd
BC_1	26.5 ± 2.25 b	9.2 ± 0.49 bc
BC_2	26.4 ± 2.32 b	9.4 ± 0.49 bc

Means with the same letter notation within columns are not significantly different (Tukey test, $P < 0.05$).

Repellence studies using thumbtack bioassay demonstrated that leaves of accession LA 2204 and F_1, F_2, BC_1 and BC_2 generations were more repellent to *T. evansi* than those of 'Money Maker'. Greenhouse bioassays showed that population densities were significantly higher on 'Money Maker' than on F_1, F_2, BC_1 and BC_2 generations and accession LA 2204 18 days after infestation. Multiple regression and correlation analyses demonstrated that there is a significant relationship between the behaviour of mites and trichomes. Glandular trichomes type IV may be responsible for the high level of resistance in accession LA 2204 to *T. evansi*.

INTEGRATED MANAGEMENT OF *TETRANYCHUS EVANSI*

13. Susceptibility of T. evansi *to frequently used acaricides*

Farmers frequently complain that acaricide treatments to control *Tetranychus evansi* are not efficient. To investigate if this is caused by resistance of the pest to the products used or due to other factors, e.g. poor application techniques, the most commonly used acaricides in Kenya and Zimbabwe were tested in the laboratory on *T. evansi* strains from the most important tomato growing areas in both countries to establish their efficiency in controlling the mites. Most acaricides caused high mortality in most populations tested. However, the most frequently used product, Dimethoate, performed poorly with adult female mortality ranging from 7.5 to 45.8% in Kenya and 7.9 to 38.1% in Zimbabwe. Dimethoate should therefore not be used for the control of *T. evansi*. These results confirm observations that control failure in many cases is caused by inadequate application techniques. The project has shown earlier that pruning and staking of tomatoes in connection with careful application of effective acaricides can greatly improve spider mite control.

14. Training of trainers and farmers in tomato IPM in Zimbabwe

A training of trainers (ToT) course for 20 extension service staff in Zimbabwe was conducted in October 2004. The extensionists were trained in tomato IPM and methods to train farmers. One of the trainees conducted a pilot season-long farmers' field school (FFS) in tomato IPM at Chinamhora, near Harare with backstopping by the coordinator of the project activities in Zimbabwe. Further training activities have been postponed until after the release of *Phytoseiulus longipes* as a biocontrol agent to include the biocontrol in the training programme.

SUSCEPTIBILITY OF DIFFERENT LIFE STAGES OF *TETRANYCHUS EVANSI* TO THE ENTOMOPATHOGENIC FUNGI *BEAUVERIA BASSIANA* AND *METARHIZIUM ANISOPLIAE* AND THE EFFECTS OF INFECTION ON FECUNDITY AND EGG FERTILITY

The susceptibility of various developmental stages of *Tetranychus evansi* Baker & Pritchard (eggs, larvae, protonymphs, deutonymphs and adults) to the entomopathogenic fungi *Metarhizium anisopliae* (Metschnikoff) Sorokin and *Beauveria bassiana* (Balsamo) Vuillemin was evaluated by the Arthropod Pathology Unit (APU) under laboratory conditions. Three concentrations (3.0×10^6, 1.0×10^7 and 1.0×10^8 conidia/ml) of both fungi were used for each stage. The effect of fungal infection on fecundity and egg fertility was also investigated using both fungal species.

15. Effect of fungal infection of deutonymphs on fecundity and egg fertility

Female mites in the controls laid more eggs than those derived from fungus-treated deutonymphs ($F = 84.3$; df = 2,12; $P = 0.0001$); but there was no significant difference between the number of eggs laid by mites in *B. bassiana*-treated and *M. anisopliae*-treated lots (Figure 5). More eggs

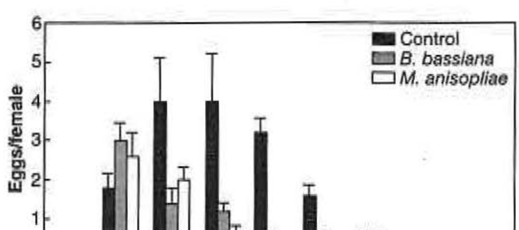


Figure 5. Effect of fungal infection by *Beauveria bassiana* and *Metarhizium anisopliae* on the fecundity of female *Tetranychus evansi* at 26 ± 2°C

were laid the first day by fungus-treated female mites while the peak was reached the second and the third days in the control treatments. Females treated with *M. anisopliae* stopped laying eggs after three days (Figure 5). The percentage egg fertility was 93.0 ± 3.6, 91.0 ± 3.7 and 90.0 ± 4.3, in control, *B. bassiana* and *M. anisopliae* treatments, respectively, and was not significantly different ($F = 0.13$; df = 2,12; $P = 0.8805$).

16. *Effect of fungal infection on egg hatchability*

There was a significant difference in egg hatchability between controls and fungus-treated eggs at all the concentrations used ($F = 146.4$; df = 6,28; $P = 0.001$) (Figure 6). All the eggs in the controls hatched. Eggs that did not hatch were mycosed. The level of reduction in egg hatchability was similar with both fungal isolates at the same concentrations. However, the reduction was significantly higher at 1.0×10^7 and 1.0×10^8 conidia/ml than at the lowest concentration of 3.0×10^6 conidia/ml (Figure 6).

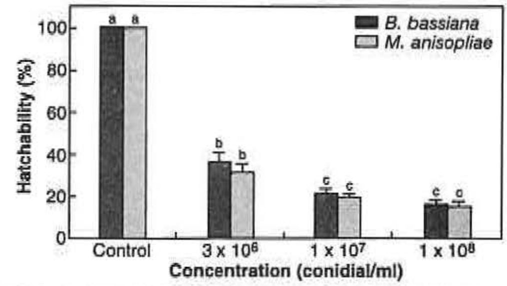


Figure 6. Egg hatchability of *Tetranychus evansi* 6 days post-treatment at 26 ± 2°C with different concentrations of *Beauveria bassiana* and *Metarhizium anisopliae*. Columns bearing the same letter are not significantly different (Student-Newman-Keuls test, $P = 0.05$)

17. *Effect of fungal infection on the motile stages of* Tetranychus evansi

Control mortality for larvae, protonymphs, deutonymphs and adults was 5, 3, 4 and 2%, respectively, 7 days post-inoculation. There was a significant difference in mortality among the different developmental stages at all the concentrations with both fungal isolates; *B. bassiana*: 3.0×10^6 ($F = 12.5$; df = 3,16; $P = 0.0002$); 1.0×10^7 ($F = 16.1$; df = 3,16; $P = 0.0001$); 1.0×10^8 ($F = 120.3$; df = 3,16; $P = 0.0001$); *M. anisopliae*: 3.0×10^6 ($F = 15.9$; df = 3,16; $P = 0.0001$); 1.0×10^7 ($F = 23.4$; df = 3,16; $P = 0.0001$); 1.0×10^8 ($F = 33.9$; df = 3,16; $P = 0.0001$) (Table 11). Generally, mortality increased with the age of mites with adults being the most susceptible to fungal infection (Table 11). However, the differences between deutonymphs and adults were not significant in some cases. At all the concentrations, both fungal isolates caused significant mortality as compared to the controls: larvae ($F = 30.7$; df = 6,28; $P = 0.0001$); protonymphs ($F = 77.3$; df = 6,28; $P = 0.0001$); deutonymphs ($F = 81.4$; df = 6,28; $P = 0.0001$); adults ($F = 103.5$; df = 6,28; $P = 0.0001$) (Table 11). Within each developmental stage of *T. evansi*, mortality caused by *B. bassiana* and *M. anisopliae* was dose-dependant with the highest mortality recorded with the highest concentration (Table 11). There was significant difference between the concentrations of both fungal isolates (Table 11).

Table 11. Susceptibility of different developmental stages of *Tetranychus evansi* to *Beauveria bassiana* and *Metarhizium anisopliae*. Mortality at 7 days post-infection at 26 ± 2°C

Isolate	Concentration (Conidia/ml)	Developmental stages (% mortality ± SE) Larvae	Protonymph	Deutonymph	Adult
B. bassiana	3.0×10^6	20.0 ± 2.7 cA	22.0 ± 2.0 dA	41.0 ± 3.7 cB	33.0 ± 2.0 cB
	1.0×10^7	33.0 ± 2.0 bA	35.0 ± 1.6 cA	58.0 ± 3.4 bB	57.0 ± 5.1 bB
	1.0×10^8	48.0 ± 2.5 aA	51.0 ± 1.9 bA	78.0 ± 2.0 aB	93.0 ± 1.2 aC
M. anisopliae	3.0×10^6	22.0 ± 2.5 cA	30.0 ± 2.7 cdB	35.0 ± 1.6 cB	44.0 ± 1.9 cC
	1.0×10^7	33.0 ± 2.5 bA	56.0 ± 3.7 bB	56.0 ± 1.9 bB	64.0 ± 2.4 bB
	1.0×10^8	43.0 ± 3.4 abA	75.0 ± 2.7 aB	82.0 ± 2.5 aB	93.0 ± 2.5 aC
Control	0	5.0 ± 1.6 dA	3.0 ± 1.2 cA	4.0 ± 1.9 dA	2.0 ± 1.2 dA

Means within columns bearing the same lower case letter and within rows bearing the same upper case letter are not significantly different (Student-Newman-Keuls test, $P = 0.05$).

The results of this study show that *B. bassiana* isolate GPK and *M. anisopliae* isolate *icipe* 78 are able to cause significant mortality in eggs and motile stages of *T. evansi* with eggs and adults being the most susceptible stages. In addition, fungal infection reduced oviposition of females. These characteristics make *B. bassiana* and *M. anisopliae* very promising control agents for *T. evansi*. However, before they are used as part of an IPM approach, their compatibility with other biocontrol agents such as beneficial insects and pesticides used in the system has to be tested.

Output

Journal articles

Fiaboé K. K. M., de Moraes G. J. and Gondim M. G. C. Jr (2004) A new genus and a new species of phytoseiid mite (Acari: Phytoseiidae) from northeastern Brazil. *Zootaxa* 599, 1–4.

Furtado I. P., Kreiter S., de Moraes G. J., Tixier M.-S., Flechtmann C. H. W. and *Knapp M.* (2004) [2005] Plant mites (Acari) from northeastern Brazil, with descriptions of two new species of the family Phytoseiidae (Mesostigmata). *Acarologia* XLV, 131–143.

Kithusi G. G., *Knapp M.*, Shibairo S. I., Nderitu J. H. and Njoroge K. (2004) Effects of four biopesticides on the spider mite *Tetranychus evansi* Baker and Pritchard in the laboratory. *Phytophaga* XIV, 549–556.

Rosa A. A., Gondim M. G. C. Jr., *Fiaboé K. K. M.*, de Moraes G. J. and *Knapp M.* (2005) (Scientific Note) Predatory mites associated with *Tetranychus evansi* Baker & Pritchard (Acari: Tetranychidae) on native solanaceous plants of coastal Pernambuco State, Brazil. *Neotropical Entomology* 34, 689–692.

Wekesa V. W., Maniania N. K., Knapp M. and Boga H. I. (2005) Pathogenicity of *Beauveria bassiana* and *Metarhizium anisopliae* to the tobacco spider mite *Tetranychus evansi*. *Experimental and Applied Acarology* 36, 41–50.

Book chapter

Herren H. R., Schulthess F. and *Knapp M.* (2005) Towards zero pesticide use in tropical agroecosystems, pp. 135–146. In *The Pesticide Detox* (Edited by J. Pretty). Earthscan Publications Ltd, London.

Abstracts published

Britto E. P. J., da Silva F. R., *Fiaboé K. K. M.* Gondim M. G. C. Jr., de Moraes G. J., Delalibera I. and *Knapp M.* (2005) Population dynamics of predators associated with *Tetranychus evansi* Baker & Pritchard (Acari: Tetranychidae) in solanaceous plants in Recife. 9º Simpósio de Controle Biológico (SICONBIOL), Recife 15 a 19 maio 2005, p. 169.

Knapp M., Sarr I., Baumgärtner J. and Ogol C. K. P. O. (2004) Spatial and temporal dynamics of *Tetranychus urticae* in small scale tomato fields in Kenya. Third African Acarology Symposium, Cairo, Egypt, 11–25 January 2004, p. 44.

Kithusi G. G. and *Knapp M.* (2004) Effects of four biopesticides on the spider mite *Tetranychus evansi* Baker and Pritchard in the laboratory. 5th Symposium of the European Association of Acarologists Berlin, 26–30 July, 2004, p. 43.

Murungi L. K., Knapp M., Hassanali A., Agong S. G. and Masinde P. W. (2004) The activity of leaf-emitted volatile compounds and essential oils in tomato accessions against the tobacco spider mite *Tetranychus evansi* Baker and Pritchard. Fourth Workshop on Sustainable Horticulture in the Tropics. Moi University, Eldoret, Kenya, 24–27 November 2004, pp. 20–21.

Navajas M., *Wagener B.* and *Knapp M.* (2004) Molecular diagnosis of species as a significant tool for biodiversity studies: Examples of the discrimination of *Tetranychus evansi* and the closely related species *T. urticae*. Third African Acarology Symposium, Cairo, Egypt, 11–25 January 2004, p. 34.

Saunyama I. G. M., Kwaramba J. R. and *Knapp M.* (2005) Toxicity of Amitraz, Dimethoate and Malathion to the spider mite *Tetranychus evansi* Baker & Pritchard and the beneficial arthropods *Phytoseiulus persimilis* Athias-Henriot, *Hippodamia variegata* (Goeze) and *Diaeretiella rapae* (McIntosh). 9º Simpósio de Controle Biológico (SICONBIOL), Recife 15 a 19 maio 2005, p. 175.

Wosula E. N., Agong S. G. and *Knapp M.* (2005) Development of tomato hybrids (*Lycopersicon esculentum* x *Lycopersicon hirsutum*) resistant to tobacco spider mite *(Tetranychus evansi)*. Fifth Workshop on Sustainable Horticultural Production in the Tropics, 23 to 26 November 2005. Agricultural Resources Centre, Egerton University, Njoro, Kenya, p. 5.

Reports

Knapp M.: Development of environmentally friendly management methods for red spider mites in small-holder tomato production systems in East and Southern Africa. Annual Report. Submitted to Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). March 2004.

Knapp M.: Development of environmentally friendly management methods for red spider mites in small-holder tomato production systems in East and Southern Africa. Annual Report. Submitted to Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). March 2005.

Conferences attended

9º Simpósio de Controle Biológico (SICONBIOL), 15 a 19 May 2005, Recife. Attended by: I. G. M. Saunyama, M. Knapp, E. P. J. Britto, F. R. da Silva, K. K. M. Fiaboé, M. G. C. Gondim Jr. and G. J. de Moraes.

XX Congresso Brasileiro de Entomologia, 5–10 September 2004, Gramado. Attended by: K. K. M. Fiaboé, M. G. C. Gondim Jr, I. P. Furtado and G. J. de Moraes.

Fifth Symposium of the European Association of Acarologists, 26–30 July 2004, Berlin. Attended by: G. G. Kithusi and M. Knapp.

Third African Acarology Symposium, 11–25 January 2004, Cairo, Egypt. Attended by: M. Navajas and M. Knapp.

Workshops attended

Fourth Workshop on Sustainable Horticulture in the Tropics. 24–27 November 2004, Moi University, Eldoret, Kenya. Attended by: L. K. Murungi, S. G. Agong and P. W. Masinde.

Fifth Workshop on Sustainable Horticultural Production in the Tropics, 23 to 26 November 2005, Agricultural Resources Centre, Egerton University, Njoro, Kenya. Attended by: E. N. Wosula, S. G. Agong.

Research proposals

Classical biological control of the red spider mite (RSM), *Tetranychus evansi*, in tomato and other important vegetables in East and Southern Africa (IFAD).

IPM of vegetable crops in East and Southern Africa, with emphasis on biological control of the invasive red spider mite, *Tetranychus evansi*, and other pest mites in tomatoes. (Submitted to IPM-CRSP by Dr A. E. Hajek, Cornell University).

Assessment of the biodiversity of tetranychid mites in East Africa using conventional and molecular taxonomic methods (ARPPIS).

Integration of classical biological control of the tomato red spider mite, *Tetranychus evansi*, into tomato IPM in East and Southern Africa. Proposal for a Planning and Partnering Grant (PPG) developed in collaboration between Cornell University, University of Sao Paulo (ESALQ) and *icipe*. (Submitted to IPM-CRSP by Dr A. E. Hajek, Cornell University).

The potential of pathogenic fungi in the control of economically important spider mite species. (ARPPIS, together with Dr N. K. Maniania).

Consultancies undertaken

Training course on Plant Parasitic Mites for Dudutech Kenya, December 2004.

Capacity building

PhD students

D. B. Mugisho (Democratic Republic of Congo) The potential of pathogenic fungi in the control of economically important spider mite species *Tetranychus urticae* Koch and *Tetranychus evansi* Baker & Pritchard. (ARPPIS, JKUAT, Kenya) (ongoing). (Based at the Arthropod Pathology Unit.)

F. J. Toroitich (Kenya) Assessment of the biodiversity of tetranychid mites in East Africa using conventional and molecular taxonomic methods. (ARPPIS, Northwest University, Potchefstrom Campus, South Africa) (ongoing).

I. G. M. Saunyama (Zimbabwe) The bio-ecology and control of red spider mites, *Tetranychus evansi*, Pritchard & Baker (Acari: Tetranychidae) on tomatoes in Zimbabwe (ARPPIS, University of Zimbabwe) (ongoing).

K. K. M. Fiaboé (Togo) Studies of potential predators of tomato red spider mite *Tetranychus evansi* (Baker & Pritchard) in Brazil for possible introduction as biocontrol agents in Africa (ARPPIS, Kenyatta University, Kenya) (thesis submitted).

I. P. Furtado (Brazil) Selection of natural enemies for the biological control of *Tetranychus evansi* Baker & Pritchard (Acari: Tetranychidae) in Africa (DRIP, ENSA Montpellier) (completed).

MSc students

J. M. Machini (Kenya) Evaluation of a new acaricide ("Oberon") in the control of red spider mites *(Tetranychus evansi)* on tomatoes *(Lycopersicon esculentum)* and its effect on the predator *Phytoseiulus persimilis* (University of Nairobi) (MSc awarded in 2005).

G. G. Kithusi (Kenya) Evaluation of biopeticides in control of red spider mites *(Tetranychus evansi)* on tomatoes *(Lycopersicon esculentum)* (University of Nairobi) (MSc awarded in 2005).

L. K. Murungi (Kenya) Evaluating the activity of leaf-emitted volatile compounds in tomato accessions against the tobacco spider mite *Tetranychus evansi* Baker and Pritchard. (JKUAT, Kenya) (MSc awarded in 2005).

G. K. Onyambu (Kenya) Studies of the role of non-volatile phytochemicals in the resistance of tomatoes (*Lycopersicon esculentum* Mill.) to tobacco spider mite *Tetranychus evansi* Baker and Pritchard. (JKUAT, Kenya) (MSc awarded in 2005).

M. Koller (Austria) Morphological and physiological effects of the host plant on the life history of the predator *Neoseiulus californicus* (Acari: Phytoseiidae) with the prey *Tetranychus evansi* (Acari: Tetranychidae). BOKU, Vienna (writing her thesis).

F. J. Toroitich (Kenya) Resistance status of tobacco spider mite *(Tetranychus evansi)* to currently recommended acaricides on tomatoes. (University of Nairobi).

M. Ferrero (France) Life tables of the predatory mite *Phytoseiulus longipes* feeding on *Tetranychus evansi* at four temperatures (ENSA-Montpellier) (MSc awarded in 2005).

V. W. Wekesa (Kenya) Evaluation of pathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* for the control of tobacco spider mite, *Tetranychus evansi* Baker & Pritchard (Acarina: Tetranychidae). Jomo Kenyatta University of Agriculture and Technology, Kenya (completed). (Based at the Arthropod Pathology Unit.)

Impact

- *Phytoseiulus longipes*, the most promising candidate for classical biological control of *T. evansi* discovered in Brazil, has been imported into Kenya but is still under quârantine awaiting a release permit.
- High acyl-sugar content hybrids between *L. esculentum* and *L. pennellii* resistant to *T. evansi* have been developed. Agronomic properties of these hybrids are very similar to cultivated tomatoes and offer the possibility to develop a resistant commercial tomato variety.

AFRICAN FRUIT FLY INITIATIVE (AFFI)

Background, approach and objectives

World trade in tropical fruits is expanding rapidly and there is a tremendous potential for many African countries to become major producers and exporters of fruits and vegetables. Generally, production of tropical fruits plays an important role in achieving food security both at household and national levels, and offers increased opportunity for trade and employment, as well as serving as a major source of income and foreign exchange. Locally grown fruits such as mango is particularly gaining recognition as a major source of vitamins and other important nutrients. Smallholder farmers commonly grow this fruit across Africa both for home use to improve nutrition, and for the much needed cash income in domestic and export markets. Promotion of consumption of fruits has been included in national nutrition programmes of many African countries. This is leading to increased changes in dietary patterns, resulting in increased domestic demands and consumption of fruits. Additionally, the demand for quality tropical fruits in the EU, the Middle East, North America and Japan is growing rapidly. The above factors, combined with increasing globalisation of trade, have created new and lucrative production and trade opportunities in Africa. However, a complex of indigenous and exotic fruit flies threatens production and export of fruits from Africa. Aside from causing extensive direct damage to fruits in the field, infestation by fruit flies also restricts the free trade and export of fruits to lucrative markets abroad. The fragmented nature of fruit cultivation, vast reservoirs of host plants and poor quarantine settings make the African climate a suitable environment for development and survival of several damaging fruit flies. The success of the horticultural industry in Africa whether it is for the rapidly expanding domestic market or for export of fruits, is heavily dependent on sound fruit fly management. The African Fruit Fly Initiative (AFFI) using mango as a model crop is addressing these problems through the development of an IPM package for management of the complex of fruit flies. The package includes application of food bait, combined with soil inoculation of the entomopathogenic fungus, *Metarhizium anisopliae,* targeting the immature stages in the soil (pupariating larvae and puparia) as the primary IPM components supplemented with orchard sanitation and conservation of natural enemies.

The programme is also building capacity of young Africans by training at both the PhD and MSc levels in areas related to fruit fly management and training of extension and quarantine personnel as members of national fruit fly teams and mobile fruit fly schools in all the participating countries.

Work in progress

1. *Large-scale survey to delimit the area covered by* Bactrocera invadens *in East Africa*

Participating scientists: *S. Ekesi, M. K. Billah, S. A. Lux*

Assisted by: *P. W. Nderitu*

Donors: *FAO*

Collaborators: *KENYA: Kenya Plant Health Inspectorate Service. TANZANIA: Agricultural Research Institute, Mikocheni, Dar es Salaam, Tanzania; Plant Protection Division, Ministry of Agriculture and Food Security, Zanzibar, Tanzania. UGANDA: Kawanda Agricultural Research Institute, Kampala, Uganda; Ministry of Agriculture, Animal Industry and Fisheries, Entebbe, Uganda*

Collaborating support unit: *Biosystematics support unit*

Under the FAO-TCP project on Surveillance and Management of *Bactrocera invadens,* a large-scale survey was initiated in Kenya, Tanzania (Mainland and Zanzibar) and Uganda with the aim of determining the extent of spread of the pest. All material collected in these surveys were sent to the BSU for identification. Surveys were conducted along pre-determined nationwide transects that were drawn, discussed and agreed upon by members of the project from the participating countries. In Kenya, 3 transects were chosen covering 1152 km and 74 Lynfield traps baited with methyl eugenol (ME) deployed. In Tanzania Mainland, 2 transects were used covering 2514 km with 108 traps. In Uganda, 2 transects were chosen covering 1802 km with 108 traps deployed while in Zanzibar 2 transects were used with 59 Lynfield traps. The results of delimiting surveys conducted in all the countries revealed the presence of the pest in most of the places where trapping was made. It suggests that the known distribution of *B. invadens* broadly extends beyond the three countries, and can be described as trans-African within the equatorial belt. In a few localities, the pest was not detected or occurred in low numbers and additional studies are underway to confirm if such areas could be considered pest free or areas of low prevalence. Traps also captured non-target insects mainly lacewings which are important predators, and highlights the need for careful deployment of ME traps over a large scale especially, in ecologically sensitive areas. AFFI was appointed in this project by the FAO to provide technical co-ordination, specimen identification and general technical backstopping.

2. Fruit fly survey in Ghana

Background

As above, this survey looked for *B. invadens* in Ghana.

Participating scientist: *M. K. Billah*

Donor: *IFAD, FAO*

Collaborators: *Crop Science Department, University of Ghana; Plant Protection and Regulatory Services Directorate, Ghana*

Work in progress

A survey was conducted across 3 of the 10 regions (Eastern, Greater-Accra and Volta) using Lynfield traps baited with a mixture of 4 parts methyl eugenol (ME) as an attractant and 1 part technical grade malathion (EC 50% a.i.) as a killing agent. The invasive fruit fly species, *Bactrocera invadens* was detected in all 3 regions. Given the fact that the pest is of prime quarantine concern, the local District Office of the Ministry of Agriculture, Akropong (where the pest was first detected) and the Zoology Department of the University of Ghana were subsequently informed. A follow-up meeting was arranged with the National Headquarters of the Plant Protection and Regulatory Services Directorate (PPRSD) in Pokuase, Accra where the Director and the resident entomologist were officially informed of the survey findings. Voucher specimens of the pest are deposited in all three institutions and the Crop Science Department of the University of Ghana. Copies of the only publication available at the time (Lux et al., 2003; *Insect Science and Its Application*, pp. 355–361) and a simplified fruit fly identification key prepared by Dr Billah were also donated to the PPRSD Head Office. A journal article on *B. invadens* in Ghana is in preparation.

3. Host range, life history and demographic parameters of Bactrocera invadens

Participating scientists: *S. Ekesi, I. Rwomushana*

Assisted by: *P. W. Nderitu*

Donors: *IFAD, DAAD*

Collaborators: *Agricultural Research Institute, Mikocheni, Dar es Salaam, Tanzania; Plant Protection Division, Ministry of Agriculture and Food Security, Zanzibar, Tanzania*

Bactrocera invadens belongs to the *Bactrocera dorsalis* complex, which is known to be highly polyphagous infesting a wide range of fruits, vegetables and wild plant species. However, because of the novelty status of *B. invadens*, very little is known with regard to its host range. Many African countries are major producers of several fruits and vegetables with export targeting large markets in the EU and the Middle East. A major requirement by countries importing fruits and vegetables is a declaration by exporting countries of the host plants of insect pests considered as quarantine pests to allow for postharvest management recommendations. Having been described as a devastating quarantine pest by the InterAfrican Phytosanitary Council, the need to document the host plants of this important quarantine pest becomes crucial. Also given the growing importance of *B. invadens*, farmers need to make informed decisions about mixed plantation practices to avoid growing crops that harbour large numbers of fruit flies. Currently, over 6907 fruits have been collected from 105 plant species and 43 families, including cultivated and wild host plants in Kenya, Tanzania and Uganda. *Bactrocera invadens* has been reared from mango *Mangifera indica* L. (Anarcadiaceae), lemon orange *Citrus limon* (Burman f.) (Rutaceae), tomato *Lycopersicon esculentum* Miller (Solanaceae), banana *Musa* sp., (Musaceae), guava *Psidium guajava* L. (Myrtaceae), marula *Sclerocarya birrea* H. (Anarcadiaceae), custard apple *Annona muricata* L. (Annonaceae), avocado *Persea americana* M. (Lauraceae), tropical almond *Terminalia catappa* L. (Combretaceae), *Landolphia* sp. and *Ficus* sp. Survey activities are continuing. Among the infested plant species, the highest level of puparia from cultivated plants was recorded from mango followed by banana, while on wild hosts, *Terminalia catappa* (tropical almond) and *Sclerocarya birrea* (marula) are the major plant species.

Since mango is the primary cultivated host plant of the insect, we carried out a field infestation study for mango across various localities in Kenya to ascertain the level of damage on the crop from January 2004 to December 2005. Ripe and, occasionally, unripe fruits were sampled from the tree and the ground (as 'windfalls'). A mixture of mango varieties were sampled but the most common varieties encountered were Apple, Kent, Ngowe and Boribo. At most of the locations, and especially at low elevations, *B. invadens* frequently shared the same fruit with the indigenous fruit fly species *Ceratitis cosyra* but often occurred in higher numbers than *C. cosyra* indicating that competitive displacement of the indigenous species may be in progress. The level of infestation by both fruit flies varied with the location; ranging from 3 to 97.2% flies per kg of fruits, with *B. invadens* dominating in most localities (Table 1). There was a significant inverse relationship between number of flies per kg of fruits and elevation at which fruits were collected, suggesting that *B. invadens* may be a predominantly lowland resident pest. Data obtained from Tanzania and Uganda are being processed.

Table 1. Assessment of level of mango infestation by *Bactrocera invadens* and *Ceratitis cosyra* at different locations in Kenya

Province	Location	No. of fruits	% of fruits infested	No. of fly emergence: *Bactrocera invadens*	No. of fly emergence: *Ceratitis cosyra*	No. of flies/kg
Central	Kiambu	65	3.1	2	3	4.5
Central	Kamiti	113	7.1	1	5	3.0
Central	Muranga	56	19.2	2	11	3.5
Coast	Malindi	92	56.5	803	10	46.9
Coast	Taveta	55	61.8	303	31	28.6
Coast	Muhaka	51	74.5	1056	175	97.2
Eastern	Kitui	32	25.3	15	41	21.0
Eastern	Embu	104	23.8	14	5	3.8
Eastern	Meru	133	11.5	16	2	3.0
Rift Valley	Nguruman	121	76.3	624	30	21.3
Western	Kisumu	36	13.9	10	9	4.8

On artificial diet, development of *B. invadens* immatures lasted 25 days; egg incubation required 1.2 days, larvae 11.1 days and puparia–adult development time was 12.4 days. About 55% of eggs developed to the adult stage. Life expectancy at pupal eclosion was 75.1 days in females and 86.4 days in males. Average net fecundity and net fertility was 794.6 eggs and 608.1 eggs, respectively, while average daily oviposition was 18.2 eggs. Daily population increase was 11% and mean generation time was 31 days. This information is useful in developing mass rearing techniques, predicting population increases and development of management approaches.

4. *Mass rearing of* Bactrocera invadens *and several* Ceratitis *species*

Participating scientist: *S. Ekesi*

Assisted by: *P. W. Nderitu, J. M. Kiilu, M. Wanyonyi, C. Muholo*

Donors: *IAEA, IFAD*

Collaborators: *International Atomic Energy Agency, Vienna, Austria*

For studies on the biology, use of attractants and pathogens for management of the complex of fruit flies, a regular supply of good quality specimens of pre-determined reproductive stages and age is necessary. Apart from *Ceratitis capitata*, which has been reared for decades in different parts of the world with great success only *C. rosa* has been successfully reared on a much smaller scale in South Africa. Reliable methods for rearing large numbers of *Bactrocera invadens* and the several *Ceratitis* are needed. Under an IAEA funded project, methods for laboratory rearing of *B. invadens* and 5 *Ceratitis* species were evaluated.

Stock cultures of *B. invadens* and *C. cosyra* were obtained from mango fruits and evaluation of two adult diets (waste brewer's yeast and enzymatic yeast hydrolysate) showed that pupal harvests in flies maintained on enzymatic yeast hydrolysate were significantly higher in *B. invadens, C. cosyra, C. fasciventris* and *C. rosa* compared with brewer's yeast. However, on *C. anonae*, no significant difference was detected in pupal harvest between the two diets, indicating the need to exploit cheap locally available raw materials for rearing these flies.

Evaluation of different devices for oviposition revealed that *B. invadens* readily accepted artificial diet for oviposition and the number of puparia harvested from artificial diet balls did not differ significantly from whole mango fruits (Table 2). *Ceratitis cosyra,* however, never accepted artificial diet as source of oviposition (Table 2) and flies are still being reared on whole mango fruits. Life history traits and demographic parameters of *C. cosyra* are being generated on whole mango fruits. Development of immatures on mango lasted almost 30 days and approximately 42% of eggs reached adult stage. Current average daily oviposition stands at 10.2 eggs with percentage hatch rate of 68%. Other biological and population parameters will be calculated as soon as the experiment is completed.

Table 2. Mean pupal harvest from different oviposition devices used for *Bactrocera invadens* and *Ceratitis cosyra*

Oviposition device	*C. cosyra*	*B. invadens*
Mango	33.6 ± 1.7 a	167.0 ± 11.5 a
Banana	6.2 ± 1.6 b	41.4 ± 1.3 b
Parafilm ball with artificial diet	0.0 ± 0.0 c	176.4 ± 4.1 a

Means within a column followed by the same letter do not differ significantly by Tukey (HSD) test ($P = 0.05$).

The standard diet used for mass rearing of fruit flies that has been used worldwide since well over 30 years is a wheatbran-based artificial diet developed at the USDA-ARS Pacific Basin Agricultural Research Centre in Honolulu. The possibility of replacing Torula yeast (contained in the standard) with waste brewer's yeast was assessed. Quality parameters measured did not differ significantly from the standard diet when Torula yeast was replaced with 8% brewer's yeast (Table 3), indicating that a cheap alternative to the expensive imported yeast could be found in brewer's yeast in mass rearing of *B. invadens*. Additional studies aimed at substituting wheat in the diet with carrot powder are also underway.

Table 3. Effect of different diets on pupal recovery, pupal weight, adult emergence, flier and egg hatch of *Bactrocera invadens*

	% Brewers yeast/diet			
Parameters	0	4	8	Standard PBARC diet
Pupal recovery (%)	45.7 ± 2.3 b	74.3 ± 1.3 a	85.2 ± 6.2 a	76.3 ± 2.2 a
Pupal wt/100 (g)	0.75 ± 0.02 c	1.01 ± 0.42 b	1.12 ± 0.03 a	1.14 ± 0.05 a
Adult emergence (%)	33.5 ± 8.1 c	56.8 ± 2.2 b	78.4 ± 1.3 a	72.2 ± 5.3 a
Flier (%)	24.4 ± 2.4 c	45.6 ± 3.2 b	82.4 ± 7.5 a	80.4 ± 2.6 a
Egg hatch (%)	20.4 ± 3.3 c	54.5 ± 1.5 b	87.3 ± 3.5 b	88.1 ± 2.2 b

Means within a row followed by the same letter do not differ significantly by Tukey (HSD) test ($P = 0.05$).

5. Development of food baits

Participating scientist: *S. Ekesi*

Assisted by: *P. W. Nderitu, P. A. Oreng*

Donors: *IFAD*

Experiments are continuing with refinement and formulation of the locally-developed bait from waste brewer's yeast. Attraction and feeding propensity of protein-fed and protein-starved *Bactrocera invadens* to the refined bait have been tested in laboratory and field cage conditions. The locally-developed bait was compared with NuLure, Corn steep liquor, Torula yeast and water.

Generally, all protein baits were attractive to *B. invadens,* and protein-starved flies responded more to bait than protein-fed flies (Table 4). The local bait and Torula yeast were more attractive to *B. invadens* compared to the other baits in protein-starved flies (Table 4). However, in protein-fed flies, Torula yeast out-performed the other treatments in terms of attraction to the bait (Table 4). In terms of feeding, both physiological states of flies were observed to feed more on the local bait than on the Torula yeast (Table 4). This cage experiment is now being evaluated under field conditions to assess the possibility of utilising the baits for field suppression.

Table 4. Attraction and feeding response of different food baits to *Bactrocera invadens* in field cages

Fly physiological state/ bait treatments	Parameters		
	No. attraction	Feeding time (s)	Residence time (s)
Protein-starved			
Local bait	8.93 ± 1.81 a	99.7 ± 20.8 a	225.3 ± 56.1 ab
Corn steep liquor	4.33 ± 0.91 b	79.3 ± 15.7 a	338.5 ± 49.4 a
Nulure	2.87 ± 0.48 b	51.0 ± 5.5 a	160.1 ± 60.5 ab
Torula yeast	6.67 ± 0.74 a	12.2 ± 1.9 b	164.3 ± 70.1 b
Water	1.53 ± 0.39 c	7.5 ± 1.6 c	168.8 ± 72.5 b
Protein-fed			
Local bait	1.27 ± 0.32 b	47.7 ± 11.9 a	361.9 ± 69.6 a
Corn steep liquor	0.40 ± 0.16 c	10.6 ± 3.0 b	477.9 ± 49.5 a
Nulure	0.40 ± 0.19 c	27.6 ± 7.5 ab	454.9 ± 58.1 a
Torula yeast	10.47 ± 2.25 a	12.3 ± 2.8 b	286.6 ± 73.8 a
Water	0.13 ± 0.09 c	16.9 ± 4.3 ab	469.5 ± 67.5 a

Means within a column followed by the same letter do not differ significantly by Tukey (HSD) test ($P = 0.05$).

6. Development of fungal pathogen

Participating scientist and students: *E. A. Ouna, J. C. Awino, S. Ekesi*

Assisted by: *E. F. Mlato*

Donors: *IFAD*

Screening activities for more virulent isolates of entomopathogenic fungi to *Bactrocera invadens* have continued with identification of two new isolates namely *Metarhizium anisopliae* isolates *icipe* 41 and 95, which have proven to be highly pathogenic to pupariating larvae. In laboratory studies, these isolates were found to reduce emergence of *B. invadens* to 11 and 8%, respectively from the soil (Table 5) compared with 10 and 30% reduction achieved with previously identified isolates, *M. anisopliae icipe* 18 and 20. Adult flies have also been observed to be very susceptible to fungal pathogen. Out of 11 isolates tested, 8 isolates were highly pathogenic to the insects (Table 5). However, among all the isolates, only *icipe* 20 and 62 exert significant level of virulence on both stages of the insect. The ideal isolate would be the one that attacks all stages of fruit flies rather than strict specificity to one developmental stage. There is, however, the need to test for the effect of biotic and abiotic factors on the pathogenicity of the isolates to *B. invadens* and persistence both in the soil and on baiting stations.

Table 5. Pathogenicity of different isolates of entomopathogenic fungi to pupariating larvae and adults of *Bactrocera invadens*

Fungal species	*icipe* Isolate	Larval bioassay % emerge ± SE	Adult bioassay % mortality ± SE
Metarhizium anisopliae	18	9.5 ± 5.0 d	45.5 ± 7.0 b
Metarhizium anisopliae	20	30.1 ± 5.4 c	100a
Metarhizium anisopliae	41	11.1 ± 1.4 d	44.0 ± 5.1 b
Metarhizium anisopliae	43	36.6 ± 8.7 cb	98.4 ± 1.1 a
Metarhizium anisopliae	53	59.0 ± 9.3 a	90.7 ± 5.9 a
Metarhizium anisopliae	58	79.3 ± 4.7 b	94.0 ± 4.0 a
Metarhizium anisopliae	62	26.9 ± 8.5 c	98.0 ± 2.0 a
Metarhizium anisopliae	95	8.1 ± 1.8 d	47.9 ±12.8 b
Metarhizium anisopliae	285	46.8 ± 5.0 b	100a
Beauveria bassiana	284	44.4 ±10.7 b	100a
Beauveria brongniartii	288	42.9 ±10.6 b	100a
Control	-	82.2 ± 6.4 a	2.4 ± 0.6 c

Means within a column followed by the same letter do not differ significantly by Tukey (HSD) test ($P = 0.05$).

Unlike other fruit fly species from the *Ceratitis* group which are poorly adapted to surviving on local varieties of mango such as Boribo and Ngowe, *B. invadens* seems to be able to survive very well on different varieties of mangoes. Host plant varieties can, however, alter the susceptibility of insects to entomopathogens by either increasing or decreasing their mortality when the insects feed on the host plants. We evaluated the effect of 3 mango varieties (Apple, Boribo and Ngowe) on the pathogenicity of isolate *icipe* 20 when the insect fed on the 3 varieties. On varieties Boribo and Ngowe, preliminary results indicated that emergence of *B. invadens* was reduced to 40 and 50%, respectively compared with 32% on Apple. Although experiments are ongoing with other virulent isolates, the current results suggest that mango variety may influence efficacy of fungus.

7. *Evaluation of indigenous natural enemies against* Bactrocera invadens *and survey for natural enemies in its aboriginal home of Sri Lanka*

Participating scientists: *S. Mohamed, S. Ekesi, S. A. Lux*
Assisted by: *M. Wanyonyi, P. W. Nderitu*
Donors: *IFAD*

Shortly after *Bactrocera invadens* was detected in Kenya, attempts were made to identify native parasitoid species that can attack the pest to establish the existence of new association with the invader. Two *Psyttalia* species and one *Tetrastichus* species were tested (all of which were larval-pupal parasitoids). The acceptance of this pest by the two *Psyttalia* species was low and their eggs were encapsulated in the larvae of *B. invadens*, indicating that these indigenous natural enemies cannot be used for classical biological control of the pest. In the case of *Tetrastichus giffardii*, *B. invadens* readily accepted the parasitoid but majority of the parasitoid eggs were also encapsulated and none of the few individuals of *T. giffardii* progeny that escaped encapsulation was able to complete development to adult stage. This suggests that, in addition to the very destructive nature of *B. invadens*, it also has a potential to act as an ecological sink for some of the indigenous parasitoid fauna such as *T. giffardii* and may cause their extinction. With consultancy funds obtained from FAO, in July 2005, an exploratory activity for natural enemies of *B. invadens* in its presumed aboriginal home of Sri Lanka was initiated jointly with IITA. Contacts were established with the Director General of the Department of Agriculture, Horticultural Crop Research and Development Institute (HORDI), Peradeniya, Sri Lanka and an *icipe* scientist was posted to the institute.

Different species of fruits were collected at low elevation areas of the country where *Bactrocera* species is predominant. Three braconid parasitoids were detected from *Bactrocera* species attacking mango, guava, avocado and tropical almond. Parasitism rates were quite low in all fruits, but efforts were made to rear 2 species of *Psyttalia* (originating from mango) and one *Diachasmimorpha* sp. (originating from snake gourd). The former parasitoids unfortunately yielded only males while larvae exposed to the latter species produced only flies as eggs of the parasitoid were encapsulated by the fruit fly.

Efforts to obtain both live and dead fruit flies and parasitoids from Sri Lanka suffered a setback as it was discovered that the government of Sri Lanka does not permit export of dead and live insects from that country. However, following intense negotiations a few dead insects that have to be returned to Sri Lanka after completion of the studies were approved for taxonomic studies. *icipe* is currently negotiating with the government of Sri Lanka to allow for shipment of live insects from the country. Plans are also underway to import an egg parasitoid (*Fopius arisanus*) and a larval parasitoid (*Diachasmimorpha longicaudata*) (Braconidae: Opiinae) from Hawaii for testing and possible release against *B. invadens*.

8. *Studies on the morphological and genetic diversity of the new invasive fruit fly species* Bactrocera invadens *in Africa*

Participating scientists and student: *M. K. Billah, D. Masiga, S. Ekesi, F. M. Khamis*
Assisted by: *J. Gitau*
Donor: *IFAD*

Collaborator: *M. De Meyer, Royal Museum of Central Africa, Tervuren, Belgium*

Collaborating department: *Molecular Biology and Biotechnology Department*

Collaborating support unit: *Biosystematics Support Unit*

A new invasive fruit fly was first detected in Kenya in March 2003. It was found simultaneously in wild fruit collected near Mombasa and in mangoes purchased in Nairobi. It was clearly a member of the *Bactrocera* genus and turned out to be a new species, *Bactrocera invadens*. It has since turned up in many locations in Africa and is potentially a serious pest. Understanding its taxonomy is a priority and this study is a contribution to this end.

Bactrocera invadens has been observed to exhibit different thoracic colourations. These colour forms have been found in all localities and countries where it has been collected. It is not known whether or not the colour forms from different localities and countries are the same. Morphometric measurements on a total of 973 permanent slides of body parts of *Bactrocera invadens* (prepared in the BSU lab) are already underway in Tervuren, Belgium, using the lab facilities of our collaborator (Dr Marc De Meyer). They include 388 slides from 4 localities in Kenya, 167 slides from 2 localities in Uganda, 183 slides from 2 localities in Tanzania Mainland, 137 slides from 2 localities in Zanzibar, 38 slides from 1 locality in Ghana and 60 slides from 2 localities in Sri Lanka (the aboriginal home of the invasive pest). Additionally, alcohol-preserved specimens of some closely related *Bactrocera* species including *B. zonata, B. kandiensis, B. cucurbitae* and *B. oleae* have been taken along to be used for interspecific comparison. Data has also been generated from 8559 specimens of *B. invadens* sorted into the four main morphotypes from different localities in 8 countries. DNA samples of the four main morphotypes of *B. invadens* have been extracted and purified for preliminary sequencing.

9. On-farm technology evaluation and demonstration of AFFI IPM package

Participating scientists: *S. Ekesi, M. K. Billah*

Assisted by: *P. W. Nderitu, E. F. Mlato, P. A. Oreng*

Donors: *IFAD*

Collaborators: *Ministry of Agriculture and Rural Development, Malindi, Kenya; Kenya Prison Services; Embu mango growers*

Field experiments were initiated during the 2004 to 2005 mango season to demonstrate the efficacy of the IPM package composed of baiting stations and pathogens in Kenya. The trials were conducted at two large mango orchards in Malindi (Coast Province), each measuring 20 ha, and in a mango orchard (of the same size) in Kamiti Prison, Nairobi. In all locations, the experimental set up consisted of a combination of bait application on the trunk and fungal inoculation of the soil as one treatment plus untreated control plots. Treatments efficacy was monitored by counting the number of fruit flies caught on each plot during the season using Nulure and by the actual fruit infestation at the harvest time. Results from these field experiments conducted at two farms indicated potential of using the IPM package for suppression of the *Ceratitis* group (*C. cosyra, C. fasciventris, C. rosa, C. capitata*) of fruit flies occurring in Kamiti. In this locality, application of the package reduced fruit fly population by 69% and fruit infestation occurred at the rate of 8 puparia per kg mango as against 53 puparia per kg mango in untreated control. However, at Malindi where the studies targeted *B. invadens*, application of the bait and fungus only achieved 51% reduction due to farmer interference with the experiment through pesticide application. Also the locally developed bait, when applied to certain tree barks such as pawpaw which farmers intercrop with mango and which is a major host plant of fruit flies, was found to be phytotoxic to the plant and this requires further studies on refinement and formulation.

During the November/December 2005 mango season, the locally developed bait was replaced with commercial food bait consisting of either GF-120 (Success) or NuLure/insecticide in field evaluation and demonstration trials. Trials were initiated on a 12 ha mango orchard in Malindi (Coast Province) targeting mainly *B. invadens*, and on similar size orchards in Embu (Eastern Province) targeting a complex of fruit flies (*Bactrocera invadens, C. cosyra, C. fasciventris, C. rosa* and *C. capitata*). At Malindi, experimental set-up consisted of: (1) weekly application of bait spray (Nulure/Spinosad) on 1 m^2 on the canopy of each tree alone, (2) fungal inoculation of the soil alone at fruit set as one treatment, (3) a combination of weekly bait spray on 1 m^2 of the canopy and fungal inoculation of the soil as one treatment and (4) untreated control plots. At Embu, treatments consisted of: (1) a combination of weekly bait spray (GF-120) on 1 m^2 of the canopy and fungal inoculation of the soil as one treatment and (2) untreated control plots. Efficiency of treatments was monitored by number of fruit flies caught on each plot using NuLure during the season and by the actual fruit infestation at harvest time. At Malindi, application of the bait alone, fungus alone and a combination of the bait and fungus reduced fruit fly population by 58, 64 and 79%, respectively, relative to the control (Figure 1). Mean fruit infestation was 34% in the bait alone, 46% in the fungus alone, 10% in the combination of the bait and fungus and 73% in untreated control plots. Data from the second location at Embu are still being processed.

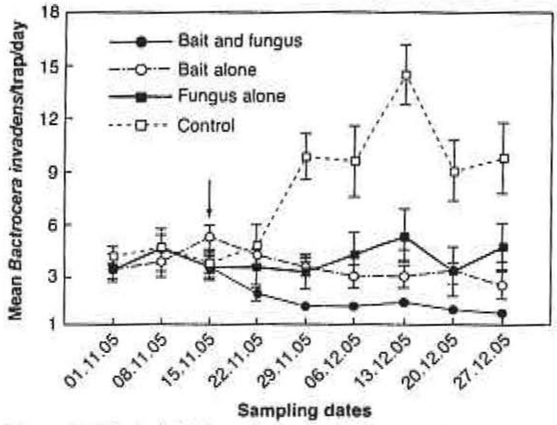


Figure 1. Effect of field application of bait (Nulure/Spinosad) and *Metarhizium anisopliae* on the density of *Bactrocera invadens* on mango at Malindi. Arrow indicates date of first bait spray. Fungus was applied at the onset of fruit set

Although the fungal pathogens have demonstrated potential to reduce fruit fly populations in mango agroecosystems, a comprehensive assessment of their impact on non-target arthropods is essential before their widespread use. Following soil inoculation of the orchards at Malindi, post application invertebrates moving across plots were collected daily for 10 days in pitfall-traps and evaluated in the laboratory for the presence of fungal infection. Of the 2145 invertebrates collected in treated plots in the pitfall traps, only 0.42% were infected with *Metarhizium anisopliae*. Although, the experiment will be repeated for another season, the results suggest that application of *M. anisopliae* in mango orchard is unlikely to adversely affect the invertebrate arthropod population. Non-target data for experiments at Embu are being processed.

Output

Journal articles

Billah M. K., Kimani-Njogu S., Overholt W. A., Wharton R. A., Wilson D. D. and Cobblah M. A. (2005) The effect of host larvae on three *Psyttalia* species (Hymenoptera: Braconidae), parasitoids of fruit-infesting flies (Diptera: Tephritidae). *International Journal of Tropical Insect Science* 25, 168–175.

Copeland R. S., Okeka W., Freidberg A., Merz B., White I. M., de Meyer M. and Luke Q. (2005) Fruit flies (Diptera: Tephritidae) of Kakamega forest, Kenya. *Journal of East African Natural History* 94, 247–278.

Dimbi S., Maniania N. K., Lux S. A. and Mueke J. M. (2004) Effect of constant temperatures on germination, radial growth and virulence of *Metarhizium anisopliae* to three species of African tephritid fruit flies. *BioControl* 49, 83–94.

Ekesi S., Maniania N. K., Mohamed S. A. and *Lux S. A.* (2005) Effect of soil application of different formulations of *Metarhizium anisopliae* on African tephritid fruit flies and their associated endoparasitoids. *Biological Control* 35, 83–91.

Field manual

Training materials from the workshop were put together culminating in the production of a field guide on fruit flies. This was mainly sponsored by the FAO.

Workshops attended

Fourth Research Coordination Meeting on "Development of improved attractants and their integration into fruit fly SIT management programmes" and International Conference on

Area-wide Control of Insect Pests: Integrating Sterile Insect and Related Nuclear and Other Techniques, 4–13 May 2005. Vienna, Austria. Attended by: S. Ekesi and S. A. Lux.

Training courses held

FAO Regional Planning Workshop for Country Coordinators of the National Surveys Undertaken to Determine Distribution of the Invasive *Bactrocera* Fruit Fly in East Africa. 25–27 February 2004, *icipe*, Nairobi, Kenya.

FAO Technical Training Workshop for Leaders of the National Survey Teams (Trainers). 15–19 March 2004, *icipe*, Nairobi, Kenya.

FAO Regional Training Course on Pest Risk Analysis of Fruit Flies. 11–15 July 2005, *icipe*, Nairobi, Kenya.

FAO Regional Training Course on Fruit Fly Taxonomy. 18–22 July 2005, *icipe*, Nairobi, Kenya.

FAO Workshop to Review Progress of the Project on Surveillance and Management of *Bactrocera invadens* in East Africa. 10–12 October 2005, *icipe*, Nairobi, Kenya.

AFFI-SII International Group Training Course on Fruit Fly Management and Training Leaders of National Fruit Fly Teams for AFFI's Mobile Fruit Fly School. 17–28 October 2005, *icipe*, Nairobi, Kenya.

AFFI Mobile Fruit Fly School (MFFS). 28–30 December 2005, Kibaha, Tanzania.

Capacity building

Training of national fruit fly teams (NFFT) and mobile fruit fly school (MFFS)

In November 2004, during the 2nd AFFI meeting, national fruit fly teams were established. In some countries like Uganda, NFFT is operating under the leadership of PhD scientists earlier trained by AFFI. The leaders were provided hands-on training on fruit fly survey methods, handling of attractants, basic taxonomy and application of the IPM package for fruit fly suppression. At the 3rd AFFI planning workshop organised jointly with an International Group Training Course on Fruit fly Management, the training was reviewed and teaching and training curricula for mobile fruit fly school (MFFS) activities were drafted and agreed upon.

The first MFFS activity was conducted in Tanzania at Kibaha from 28–30 December 2005 and attracted over 52 participants drawn from 22 districts covering most of the mango producing areas of the country. In Tanzania, over 502 posters on fruit flies and their management options were distributed to growers during the various training activities.

The BSU was actively involved (in serving as the host training lab) in the creation and training of national fruit fly teams (NFFT) in the East African region.

Dr Billah also participated in the review and drafting of a teaching and training curriculum, which was adapted by AFFI participating countries for use in the creation and teaching in their mobile fruit fly school (MFFS).

Taxonomic training

As part of the preparation towards the exploratory trip to Sri Lanka (the aboriginal home of *Bactrocera invadens*) for parasitoids (natural enemies), Dr Samira Mohamed was taken through a 2-week intensive taxonomic training exercise on fruit flies and their parasitoids (June 2005).

Dr B. Selvaraj of Sun Agro Company, India, who was also going on a similar exploratory trip to India as a complementary part to the Sri Lankan exploration, also received taxonomic training and hands-on exercises on trap setting (using methyl eugenol), insect collection, preparation and shipment of insects for identification (June 2005).

Oserian Development Company staff—Mr Herbert Masinde received a 2-week intensive training course on insect identification, with special emphasis on thrips identification (September 2005).

Two Sudanese MSc students (Suliman Abdalla Ali and Abdigadir Abdalla) received training in basic fruit fly taxonomy and identification and introduction to the SAS software programme (SAS Institute, 2001) for statistical analyses (March 2005).

A Belgian PhD student, Ms Nathalie Erbout, from the Ghent University and in collaboration with the Royal Museum for Central Africa (MRAC) in Tervuren, Belgium visited the AFFI project on an 8-week sampling visit and received an intensive taxonomic training exercise on African fruit flies to aid her in her sampling (May 2005).

ARPPIS training

A Basic Taxonomy and Systematics Course for ARPPIS MSc and PhD scholars was held at *icipe*, Nairobi in September 2005.

PhD students

I. Rwomushana (Uganda) Bioecology of the new invasive *Bactrocera invadens* (Diptera: Tephritidae) and its interaction with indigenous fruit fly species. Kenyatta University, Nairobi (ongoing).

F. M. Khamis (Kenya) Studies on the morphological and genetic diversity of the new invasive fruit fly species *Bactrocera invadens* in Africa. Kenyatta University, Nairobi (ongoing).

MSc students

E. A. Ouna (Kenya) Entomopathogenicity of hyphomycetes fungi to the new invasive fruit fly species *Bactrocera invadens* and their potential for biological control on mango. Kenyatta University, Nairobi (ongoing).

J. C. Awino (Kenya) Evaluation of the susceptibility of *Bactrocera invadens* to entomopathogenic fungi when reared on three varieties of mango. Kenyatta University, Nairobi (ongoing).

Impact

The BSU (together with AFFI), has helped train plant/port inspectors in Kenya, Uganda, Tanzania and Zanzibar on taxonomy and identification of fruit flies, leading to increased vigilance at the ports of entry in these countries and improved chances of early detection of invasive pests.

Technology Transfer and Training

1. Development of private sector service providers for the horticultural industry in Kenya

Background, approach and objective

Smallholder participation in the Kenyan horticulture export industry is threatened by a lack of efficient extension services. To ensure continued participation of smallholder producers in the sub-sector, a pilot study phase was conducted between April 2003 and March 2005 by the Technology Transfer Unit, to establish private service providers for advice, input supply and plant protection through hands-on training that can prepare and ensure that farmers comply with new rules and regulations. The course involved a multi institutional and multidisciplinary team approach in close collaboration with the Kenyan fresh horticultural produce export sub sector and smallscale outgrowers' farmer groups. The private service providers and farmers were trained in integrated pest management, which is a strategy to reduce pesticide usage and improve produce quality, food safety, human and environmental health. The training created awareness and facilitated some outgrowers groups to comply with EU market requirements. Fifteen private service providers graduated from the training. These are either self-employed or working with fresh produce export companies to prepare small-scale producers for EurepGAP certification.

Lessons learned in the pilot were used as a basis for the formulation, fine-tuning and implementation of an extension phase from April to December 2005. The emphasis in the extension phase was on strengthening farmer group organisation, management and setting up quality management systems that meet EurepGAP standard; and capacitating small and medium export companies to comply with the EurepGAP requirements. A six-months hands-on sandwich training that combined a residential and field attachment course was organised and implemented from May to December 2005.

Participating scientists: *B. Nyambo, A. A. Seif, A. M. Varela*

Assisted by: *J. Maundu*

Donor: *Department for International Development, United Kingdom*

Collaborators: *NRI, University of Greenwich; horticultural fresh produce export companies [InduFarm (K) Ltd, East African Growers Ltd, Kenya Horticulture Exporters Ltd, Greenlands Agroproducers Ltd, Myner Exporters Ltd, Ukulima East Africa Ltd, Freshlink Ltd, Frigoken and ADHEK Ltd)]; NGOs [Business Services Market Development Project-Kenya, Pact Kenya, TechnoServe-Kenya]; outgrowers farmers' groups in Central and Eastern provinces of Kenya*

Work in progress

The pilot phase, April 2003 to March 2005 was a learning phase for the project implementers, the beneficiaries and the development agency.

Awareness about the effects of the supply chain requirements, e.g. EurepGAP, EU MRLs and access to the export markets by smallscale producers, for a wide range of stakeholders at national and international policy levels was created. Some standard setters and donor agencies began to recognise the fact that smallscale producers are at risk of being excluded from the export markets due to stringent food requirements.

As a result some policy changes were initiated in early 2005:

- EurepGAP made some commitments to assist Kenya develop 'KenyaGAP' benchmarked on the EurepGAP standard, to make the standard user friendly for Kenyan growers. This initiative was taken up by FPEAK with funding from BSMDP.
- For the first time Kenya was allowed to nominate a representative to the EurepGAP committee.
- DFID pledged to co-finance the field-testing of the 'EurepGAP Smallholder Quality Manual' in collaboration with GTZ. This will be a starting point for Kenya to create own

quality manual by adopting contents according to local production situation with a view to preparing farmers for EurepGAP certification.

Some fresh produce export companies started to invest in the development of outgrower farmers groups in preparation for EurepGAP certification.

At producer level, farmers were informed about the EurepGAP standard. Nineteen farmer outgrower groups, each with 15–30 members, participated in the training, and were therefore the direct beneficiaries of the course. These were the role models for other growers in terms of EurepGAP and the EU MRLs requirements. By the end of 2004, the majority of the groups were in the process of implementing some of the requirements.

The emphasis during the extension phase, April–December 2005, was on strengthening farmer group organisation, management and setting up quality management systems that meet EurepGAP standard; and capacitating small and medium export companies to comply with the EurepGAP requirements.

Based on the experience gained in the pilot phase, the training curriculum was critically reviewed and fine-tuned. EurepGAP-certified smallscale outgrower groups developed during the pilot phase were identified and integrated in the extension period, thus saving on resources and time.

A six months hands-on sandwich training that combined a residential and field attachment course was organised and implemented from May to December 2005. The course contents emphasised extension communication skills and working with farmers' groups, small business management, good agricultural practices (IPM, safe and effective use of pesticides, pre- and post-harvest hygiene), HACCP, EurepGAP requirements and internal auditing).

Out of 14 participants, ten (10) completed the course successfully. Fourteen farmers' groups in Kirinyaga, Naru Moru, and Karatina, in Central Province of Kenya, participated in the training and these were the immediate beneficiaries of the course in terms of the EU MRLs and EurepGAP protocol. These will also serve as role models for other growers.

2. Maragua ridge organic mango pilot project

Background, approach and objectives

The Maragwa Ridge Organic Mango Group, (with 50 members), of Maragua District, Central Province, Kenya, approached *icipe* Technology Transfer Unit for training in mango IPM through Kenya Institute of Organic Farming (KIOF) in August 2002. Increased pest pressure and consequently spraying costs, reduced production and income from mango production prompted this. Mango is a major cash crop for the farmers in the area. The group was trying to convert to organic farming but it was becoming difficult due to the pest pressure and market quality demands, and as a result, farmers were spraying heavily using broad-spectrum pesticides.

In response to the request, an ex-ante baseline study on knowledge, practice and market access was organised and conducted in January–May 2003. The results of the study were used to plan a season long hands-on farmer field school (FFS) IPM training course for the growers.

The project was designed and implemented with the following specific objectives: (1) to train the Maragua Ridge group members in mango IPM and quality market requirements; (2) to raise awareness about current market quality needs among the growers and (3) to develop a mango IPM training module for smallscale mango growers in East Africa.

The module integrated *icipe*'s fruit fly baiting technology with other IPM components developed by other research institutions. The initiative addressed key constraints to production (major pests and agronomic) and market access.

To improve marketing and market access, the group was given a two-day course in costing and pricing of produce, after which they were introduced to potential buyers.

Participating scientists: *B. Nyambo, A. M. Varela, A. A. Seif*

Assisted by: *G. J. Gatama, J. Maundu*

Donors: *Biovision Foundation of Switzerland*

Collaborators: *The Kenya Institute of Organic Farming, Ministry of Agriculture and Rural Development (Horticulture Division, Extension Department) and Kenya Gatsby Trust*

Work in progress

The Mango FFS was conducted from June 2003 to March 2004. A total of 15 nominated group members completed the course successfully. These are now role models and master trainers for the other members of the group. Furthermore, a total of 30 nominated group members participated in the costing and pricing training course. These were expected to train the other group members.

An intermediate impact study of the training on farmer knowledge and practice will be conducted in March 2006, two years after the end of the FFS.

A mango IPM/ICM training module and manual, that integrates a holistic approach to quality mango production, was developed and printed for wider use within East Africa among small and medium mango growers.

A first hand experience on how to conduct a season long hands-on integrated mango production farmer field school (FFS) was gained by the FFS facilitators. Most successful farmer field schools in Africa, and even in Asia where the approach was conceived, have been on annual crops (with crop cycle of 3–4 months) thus providing continuous disturbance to the production system. In contrast, tree crops provide a more stable environment for the co-existence of pests and their potential natural enemies and are therefore more challenging.

The module, manual and FFS approach were tested in Malindi, Kenya North Coast, from January to December 2005. The idea was to field test the handbook and training format under a different production system (1) to collect additional information to update the handbook for wider use and (2) to impart IPM knowledge and practices to the smallscale mango growers along the Kenya coast. A total of 13 mango growers participated in the FFS.

The mango production system in Malindi, which is typical of the East African coastal mango zone, is basically a mango–cashewnut–coconut based system, in big contrast to the highland areas (Maragua District), where mangoes are grown in cereal/legume based systems. The mango pest complex and management strategies along the coastal belt are likely to be different because the associated tree crops share common pest problems with mango.

3. Monitoring and evaluation (M&E) plan to assess farmer learning

Participating scientist: *A. Pala Okeyo*

Donors: *icipe core fund donors, Rockefeller Foundation*

Collaborators: *Maseno University, Beyond Hunger Forum*

During June 2004 to June 2005, the Social Sciences Department participated in a monitoring and evaluation (M&E) team exercise funded by the Rockefeller Foundation under its Food Security Theme to assess farmer learning as a basis for addressing poverty reduction among rural farming communities in Africa. The project is being implemented across differing ecological zones and culturally diverse communities in four districts (Siaya, Kakamega, Bungoma, Butere/Mumias) in western Kenya by four NGO grantees.

icipe Social Sciences Department staff and an independent organisational learning expert have collaborated in implementing the M&E plan to monitor progress and identify successes and constraints in strategy implementation. A long-term impact assessment tool is also being put in place to provide longitudinal assessment of the process over a longer period. *icipe*'s participation focused on two areas of learning: first, the issue of farmers and farmer learning. The premise is that farmers' behaviour and response to technology will change according to conditions, situation, opportunities for learning, effectiveness of technology delivery, market access and improved financial resources. The second issue deals with farmers' and collective behaviour, namely that farmers need to be organised to gain improved access to markets and technology, including better access to inputs including new technology; bulking of outputs/storage and associated arbitrage opportunities; improved access to price information; improved access to credit; and improved transport. 'Cereal banks' are being piloted as the primary collective organisation for improved market and technology access.

Output

Donor reports

Project monitoring report 1 (1 April to 30 September 2004) submitted 19 October 2004.

PPR3 (1 October to 31 December 2004) submitted 20 January 2005.

PCSS 4 March 2005.

Nyambo B., Kinoti R., Kiriga J. and Maundu J. (2004) Awareness campaign for export horticulture producers and outgrower groups to comply with EurepGAP protocol: Knowledge and attitude baseline study 12–17 July 2004. *icipe*-BSMDP contract Number H-SP-03.

Macharia I., Akivaga F. and Ndenga E. (2004) Awareness campaign for export horticulture producers and outgrower groups to comply with EurepGAP protocol: Mid-term evaluation of the radio awareness programme, 20–26 September 2004. *icipe*-BSMDP contract Number H-SP-03.

Anonymous (2004) Awareness campaign for export horticulture producers and outgrower groups to comply with EurepGAP standard: Radio magazine themes, December 2004. *icipe*-BSMDP contract Number H-SP-03.

Anonymous (2005a) Awareness campaign for export horticulture producers and outgrower groups to comply with EurepGAP standard [July–November 2004]: Final report submitted to BSMDP, February 2005. *icipe*-BSMDP contract Number H-SP-03.

Anonymous (2005b) Development of Private Sector Service Providers for the Horticultural Industry in Kenya: Crop Protection Programme (CPP) R 8297(ZA 0569) Final Report, March 2005.

Pact-Kenya (2005a) Private sector service providers for the horticultural industry in Kenya: Organizational capacity needs for smallholder horticultural farmer groups in Naro-Moru, Karatina and Kirinyaga, April 2005. Pact-Kenya in collaboration with *icipe*, under the CPP/BSMDP projects funded by DFID.

Pact-Kenya (2005b) Private sector service providers for the horticultural industry in Kenya: Training of Trainers and Leadership and Governance Training Workshop Report, May 2005. Pact-Kenya in collaboration with *icipe*, under the CPP/BSMDP projects funded by DFID.

Pact-Kenya (2005c) Private sector service providers for the horticultural industry in Kenya: ADHEK Exporters Ltd Organizational Capacity Development Needs Assessment. Final Report, May 2005. Pact-Kenya in collaboration with *icipe*, under the CPP/BSMDP projects funded by DFID.

Pact-Kenya (2005d) Private sector service providers for the horticultural industry in Kenya: A report on technical support, mentoring and progress review of the PSSP trainees, September 2005. Pact-Kenya in collaboration with *icipe*, under the CPP/BSMDP projects funded by DFID.

Pact-Kenya (2005e) Private sector service providers for the horticultural industry in Kenya: A report on 3rd technical support, mentoring, and assessment visit of the PSSP trainees November–December 2005. Pact-Kenya in collaboration with *icipe*, under the CPP/BSMDP projects funded by DFID.

Mukhongo H. (2005a) *icipe* crop protection programme, Horticulture private service providers' development—ii. Business skills training activity report 1, July 2005.

Mukhongo H. (2005b) *icipe* crop protection programme, Horticulture private service providers' development—ii. Business skills training activity report 2, October 2005.

Mukhongo H. (2005c) *icipe* crop protection programme, Horticulture private service providers' development—ii. Business skills training activity report 3, October 2005.

Mukhongo H. (2005d) *icipe* crop protection programme, Horticulture private service providers' development—ii. Business skills training activity report 4, December 2005.

Maundu J. (2005a) Report on technical support offered to private service providers on the HACCP subject from 29 August–2 September 2005.

Maundu J. (2005b) Report on technical support offered to private service providers on the HACCP subject from 28 November–1 December 2005.

Seif A. A. (2005) CPP Phase two on training private sector service providers in export horticultural industry in Kenya. Horticulture sub-division *icipe*.

Varela A. M. and Seif A. A. (2005a) Report on follow-up and back-stopping on IPM to service provider trainees on attachment to farmers groups associated to selected exporters. 29 August–2 September 2005.

Varela A. M. and Seif A. A. (2005b) Report on follow-up and back-stopping on IPM to service provider trainees attached to farmers groups associated to selected exporters. 28 November–1 December 2005.

IPM manuals

Varela A. M. and *Seif A. A.* (2005) *A Guide to IPM in Mango Production in Kenya*. First edition. *icipe* Science Press, Nairobi. ISBN 92 9064 167 3.

Nyambo B. (2005) *Training Format for IPM in Mango Production in East Africa*. *icipe* Science Press, Nairobi. ISBN 92 9064 171 6.

Conferences attended

AAB Centennial Conference "Advances in Applied Biology: Providing New Opportunities for Consumers and Producers in the 21st Century". 15–17 December 2004, St Catherine's College, Oxford, UK. Attended by: B. Nyambo.

UK Food Standards, 12 December 2004, London, UK. Attended by: B. Nyambo.

Workshop on "Effective communication between agricultural research, extension and farmer", 18–22 October 2004, Bolzano, Italy. Attended by: B. Nyambo.

Research proposals

In reponse to the UK Department for International Development (DFID) Crop Protection Programme (CPP) Call, Category C, an application for a nine months extension for the Development of Private Sector Service Providers for the Horticultural Industry in Kenya was made. The application was favourably reviewed and approved for funding. The extension phase was funded under the Crop Protection Programme with matching funds from the Business Services Market Development Project (BSMDP)-Kenya.

Impact

Awareness about the effects of the supply chain requirements e.g. EurepGAP, EU MRLs and access to the export markets by smallscale producers, for a wide range of stakeholders at national and international policy level was created. Some standard setters and donor agencies have began to recognise the fact that smallscale producers are at risk of being excluded from the export markets due to stringent food quality requirements, and are addressing key issues to facilitate continued participation of the smallscale farmers in the sub-sector.

The overall quality of vegetables on the domestic market has improved, which is a spill-over from the export market initiative.

Many small-scale outgrower farmer groups have been EurepGAP certified, proof that with good facilitation and technical support through an efficient extension system, smallscale farmers can participate and benefit from the sub-sector.

C. Locusts and Migratory Pests

Development of Semiochemicals-Based Management Strategies for the Desert Locust, *Schistocerca gregaria* (Forskal)

Background, approach and objectives

Gregarisation—the ability of an insect to transform reversibly between two extreme phases (solitaria and gregaria)—is central to the biology and pest status of the desert locust and other locusts and aggregating/migratory insect pests. The goal of *icipe*'s locust semiochemicals research has been twofold:

- To explore the use of the insect's own communication signals to manipulate the process of gregarisation for control purposes; and
- To develop an understanding of gregarisation to assemble the components of a preventive intervention strategy.

The project initially started with behavioural and physiological studies relating to three important characteristics of gregarious locusts, i.e. cohesive behaviour, synchronous maturation, communal oviposition and characterisation of their mediating pheromone systems. One of the most interesting results of this phase of the study was the finding that different pheromone blends mediate the aggregation behaviour of nymphal and adult stages. Exposure of nymphs to the adult blend, or vice versa, resulted in a loss of aggregation behaviour. Phenylacetonitrile (PAN), the major component of the adult pheromone, elicits an immediate arrestment of the marching behaviour of hopper bands. Affected individuals become disoriented, hyperactive, feed less and gradually solitarise. The stressed insects become susceptible to enhanced predation and other mortality factors.

Participating scientists: *A. Hassanali, M. O. Bashir, P. G. N. Njagi, Y. Takao*

Assisted by: *Abdul Rahim W. Bashir, Haidar H. Korena*

Donors: *Food and Agriculture Organization of the United Nations/Emergency Prevention System, Italy; United States Agency for International Development/Assistance for Emergency Locust/Grasshopper Abatement, USA; International Fund for Agricultural Development; Swedish International Development Cooperation Agency; African Development Bank through Ministere de l'Agriculture de l'Elevage et de la Peche, Madagascar*

Collaborators: *Plant Protection Directorate, Sudan; Ministre de l'Agriculture, Madagascar; Malagasy Research Centre, Madagascar; Centre pour la Lutte Antiacridienne, Mauritania; Desert Locust Control Organisation for Eastern Africa, Nairobi; US Department of Agriculture-Agricultural Research Service, USA; Japan Society for the Promotion of Science, Japan; Japan International Research Centre for Agricultural Sciences, Japan; Plant Protection Directorate, Sudan; University of Nairobi, Kenya; Kenyatta University, Nairobi, Kenya; Jomo Kenyatta University of Agriculture and Technology; Egerton University, Njoro, Kenya; AGRHYMET, Niger; Swedish University of Agricultural Sciences, Sweden; Department of Plant Protection, Sudan; FAO-EMPRES, SIDA/SAREC; Projet de Lutte Preventive Antiacridienne, Madagascar (Madagascar migratory locust)*

Work in progress

1. The science underlying cross-stage pheromonal effects of the desert locust

The physiological basis of the behaviour of gregarious nymphs exposed to the major component of the adult pheromone, phenylacetronitrile (PAN), has been elucidated in two sets of experiments. Exposure of crowd-reared hoppers to PAN vapour was shown to substantively reduce their electrophysiological responses to their own aggregation pheromone (Figure 1) and to a plant component. Thus, the hoppers in a crowded state receive two conflicting sets of signals. They are physiologically in the gregarious phase and continue to experience mechanical and chemotactile stimulation normally associated with the gregarious phase. However, this is not accompanied by significant olfactory contact between individuals, which is equivalent to their physical isolation associated with solitarisation. This accounts for their abnormal behaviour including cessation of marching, random movements, enhanced cannibalism and reduced feeding. It is also reflected in their haemocyte levels (Table 1) and enhanced sensitivity to pesticides (*icipe* Annual Scientific Report 2002–2003, pp. 89–90). Further studies on the behaviour of crowd-reared hoppers with amputated antenna are expected to confirm the role of olfaction in triggering the remarkable chain of behaviour of hopper bands exposed to PAN.

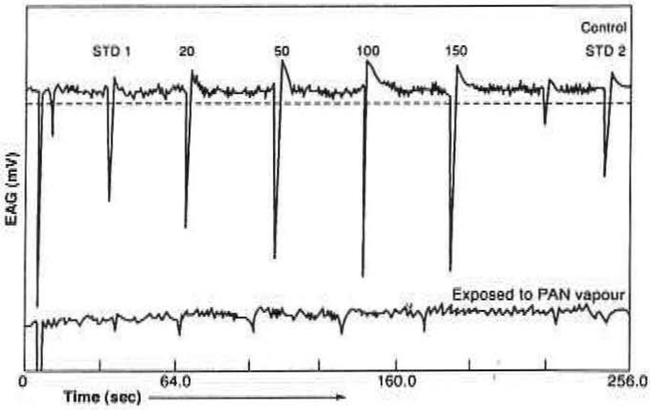


Figure 1. EAGs to nymphal pheromone blend (NPB, μg) after 6 h exposure to the major component of the adult pheromone (PAN)

Table 1. Effect of exposing 5th instar, crowd-reared (gregarious) nymphs to phenylacetonitrile (PAN) on haemocyte counts

Day	1	2	3	4	5
Granulocytes (x10⁵)					
Control	1.5 ± 0.1 a	1.55 ± 0.1 b	1.6 ± 0.14 a	1.4 ± 0.1 b	1.16 ± 0.1 b
Exposed	1.6 ± 0.1 a	2.39 ± 0.1 a	1.4 ± 0.13 a	1.7 ± 0.1 a	1.34 ± 0.1 a
Plasmatocytes (x10⁵)					
Control	2.4 ± 0.11 a	2.1 ± 0.1 a	2.3 ± 0.13 b	1.9 ± 0.12 b	1.9 ± 0.13 b
Exposed	2.6 ± 0.12 a	2.4 ± 0.1 a	1.6 ± 0.15 a	2.4 ± 0.13 a	2.3 ± 0.12 a
Coagulocytes (x10⁵)					
Control	7.4 ± 0.2 a	9.1 ± 0.3 b	9.88 ± 0.3 a	9.11 ± 0.3 a	7.1 ± 0.3 a
Exposed	7.5 ± 0.3 a	10.9 ± 0.2 a	11.0 ± 0.2 a	8.8 ± 0.1 a	6.9 ± 0.2 a

2. *Cross-stage pheromonal effects validated*

During 2004, the occurrence of large hopper infestations at Aeit, about 70 km north of Port Sudan, and in 2005 at Sofia, 380 km north of Sudan, provided a first opportunity to undertake large-scale field trials on field hopper populations since 1998. The 2004 trial was undertaken largely under the auspices of the FAO-EMPRES/CR funds. These studies laid down the groundwork for the 2005 trials, which were undertaken with substantial incremental input from IFAD TAG R714 *Icipe* (Environmental-friendly pheromonal Management of the Desert Locust: Technology Validation and Transfer) project funds and logistical and other support from Plant Protection Department of Sudan.

Infestations at Aeit

The infestation at one area of Aeit (designated as Aeit 1) was a large sea (~40 km long x 10 km wide) of nymphs (~350/m²) of mixed instars (2nd to 5th) continually marching in one direction with a lot of cross-mixing of hoppers between different locations. The target area for each treatment was one hectare. Immediately after each treatment, replicate collections of treated hoppers comprising 318–861 nymphs from different locations were placed in cages for further observations. At another location of Aeit (designated as Aeit 2), large non-marching groups were located in wadies in a series of small (20–25 m wide) Khors. On-site observations of treated bands (ranging from 1–3 hectares, depending upon the size of the distinct band groups) was possible. The effects of the following treatments were compared:

- recommended dose (500 ml/ha) of Marshal with 1/4 of this plus/minus PAN.
- recommended dose of Marshal with 1/8 of this plus/minus PAN.
- recommended dose (50 ml/ha) of Green Muscle with 1/4 of this plus/minus PAN.
- recommended dose of Green Muscle with 1/8 of this plus/minus PAN.

Figures 2 and 3 illustrate typical results obtained. Bands that were exposed to PAN and fractional doses of Green Muscle or Marshal gave levels of control comparable to the recommended doses of these pesticides and confirm the ability of PAN to enhance the susceptibility (sensitivity) of gregarious desert locust hoppers to the pesticides.

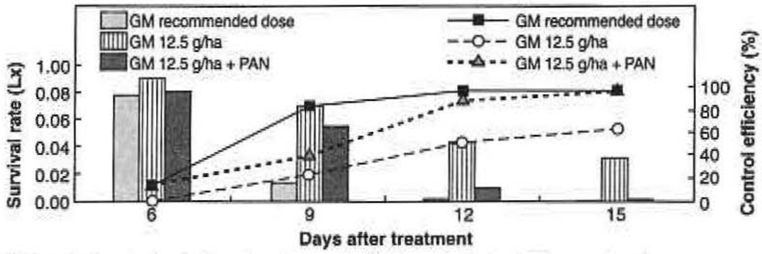


Figure 2. Survival rate (bars) and control efficiency (plots) of DL nymphs after treatment with different doses of Green Muscle (GM) and PAN (10 ml/ha) (Aiet area 2)

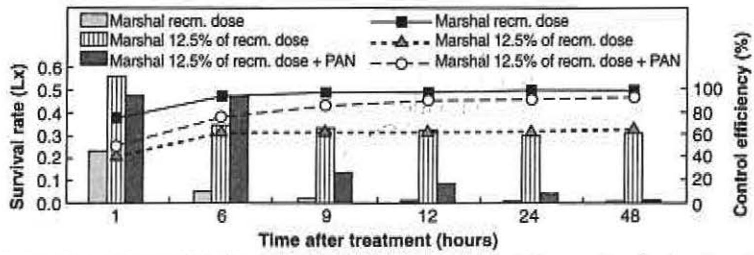


Figure 3. Survival rate (bars) and control efficiency (plots) of DL nymphs after treatment with different doses of Marshal and PAN (10 ml/ha) (Aiet area 2)

Sofia trials

During January and February 2005, a total infestation of over 4000 ha was located at Adreem (Wadi el Daeeb) (N21°38'38.1": E 36°07'47.2") area, at Sofia, 350–385 km north of Port Sudan. The total area that was treated with PAN with/without fractional doses of Green Muscle or Marshal was 1100 ha as follows:

- PAN alone (100 ha)
- PAN + 1/4 recommended dose of GM (100 ha)
- PAN + 1/4 recommended dose of Marshal (100 + 150 ha)
- PAN + 1/2 recommended dose of Marshal (200 +150 + 300 ha)

The first three treatments were made when nymphs were predominantly in their late 3rd instars with some 2nd and 4th instars. The last treatment was made when the nymphs were in their late 4th instar. Because of the slow action of PAN with/without Green Muscle, the first two could not be repeated (for fear by locust control personnel that fledglings might occur prior to substantial mortality).

PAN-alone treatment. Fragmentation of the band was evident by day 3 after treatment and by day 6, the band had largely fragmented and distributed somewhat randomly between the available bushes. Of the bushes sampled, there were clear signs of cannibalism (remains of cannibalised nymphs) by day 3. The proportion of sampled bushes with remains of cannibalised nymphs increased on day 6 and 9 before dropping by day 12. Figures 4a and b give mean numbers and percentages of remaining nymphs (using this different method of sampling), which indicate that more than 85% level of control was achieved by day 12.

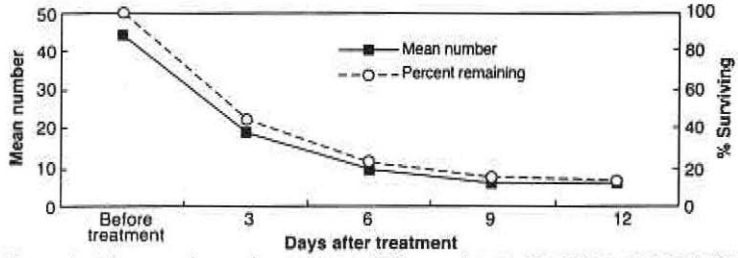


Figure 4a. Mean number and percentage of DL nymphs per 50 x 50 cm area and after treatment with PAN

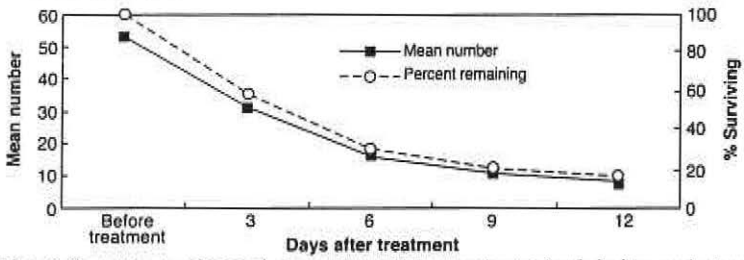


Figure 4b. Mean number and percentage of DL nymphs per bush before and after treatment with PAN

PAN + Green Muscle treatment. Figure 5a gives mean mortality of exposed nymphs that were collected from the field and kept in cages in the camp. Mortality of the nymphs was evident by day 6, and by day 10 most nymphs were dead. Figure 5b gives the mean number of dead nymphs in the treated field. As in PAN-alone treatment, there was an indication of disappearance of a large proportion of dead individuals through cannibalism and also by scavengery (by rodents and birds present). All sampling procedures provided evidence of complete control of treated hoppers in 12 days when 1/4 of recommended dose of Green Muscle is used with PAN.

PAN + Marshal treatments. Figure 6a gives the average number of nymphs with pre-mortality symptoms (convulsion, hopping sideways) observed under sampled bushes during the 24-hr period following treatments with Marshal (normal dose) and Marshal (fractional doses) with PAN. Figure 6b gives the percentage mortality in sampled bushes over the period. Initial mortality due

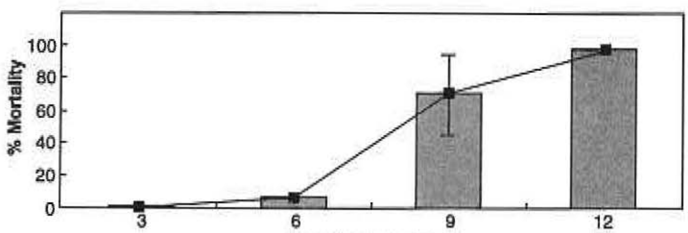


Figure 5a. Mean percentage mortality of DL nymphs collected from the field after treatment with PAN and 1/4 of the recommended dose of Green Muscle kept in cages

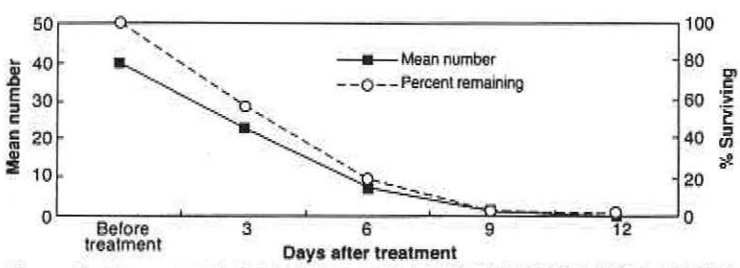


Figure 5b. Mean percent dead of DL nymphs per 50 x 50 cm area before and after treatment with PAN mixed with 1/4 of the recommended dose of Green Muscle

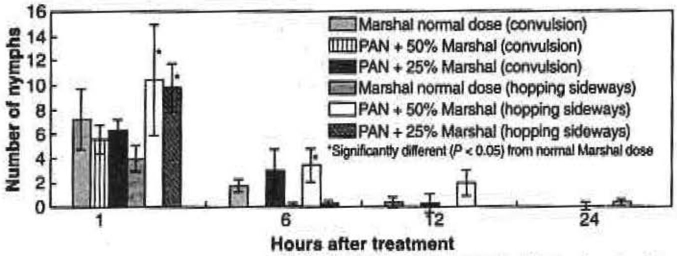


Figure 6a. Pre-mortality symptoms in nymphs treated with PAN mixed with fractional doses of Marshal based on number per bush

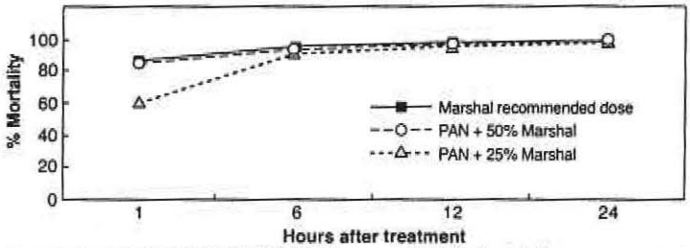


Figure 6b. Percentage mortality of DL nymphs treated with PAN mixed with fractional doses of Marshal based on number living or dead per bush

to PAN with 1/4 Marshal was lower compared to normal dose of Marshal and 1/2 dose of Marshal with PAN. However, the 1/4 dose caught up with the others by the 12th hour (no significant difference).

3. *Mechanism of gregarisation*

A better understanding of the mechanisms that underlie phase change in a solitarious locust population is an important prerequisite for the development of a quantitative gregarisation model and for predicting locust outbreaks. In our field and laboratory studies, we identified two sets of processes that are involved in the development of a gregarious population:

(i) clustering processes at diminishing spatial scales, which bring dispersed locusts together and which, in patchy micro-environment with concentration of plants preferred for oviposition and feeding by solitarious locusts, facilitate crowding and result in the shift to the gregarious phase and formation of pheromone emitting nuclei of gregarising locusts;

(ii) recruitment processes resulting from the positive responses of solitarious individuals to the pheromones of gregarising groups, which promote horizontal spread of gregarious traits across the populations.

A detailed quantitative understanding of the relation between habitat attributes (host/non-host/shelter plants, distribution pattern and densities) and solitary locust densities, and rate and degree of phase shift is expected to provide a basis for developing a simulation model for locust gregarisation and assessment of probability of outbreak. Two complementary sets of studies are needed to address the goal:

(a) Area-wide aerial and ground surveys in successive breeding seasons in the Red Sea area (and other important locust outbreak areas in West Africa, such as Mauritania) to document the plant community structures associated with solitarious populations and, particularly, distribution of plants preferred by solitarious individuals for egg laying, feeding and shelter, and the phase status of locust populations at different densities and spatial distribution;

(b) Semi-field controlled arena studies involving selected desert plant compositions and densities with different numbers of introduced solitarious locusts designed to monitor the rate and extent of gregarisation.

During 2004–2005, USAID/AELGA funded an exploratory project to study the relation between nymphal and host plant density in field arenas at the *icipe* field station in Port Sudan. Gravid solitarious females were allowed to lay 1, 2 or 3 egg pods in different arenas with different plant cover (10, 25 and 50%). The plants used were either millet or annual *Heliotropium* spp. (made up of *H. ovalifolium* and *H. arabiensis*), previously shown to be attractive to adult solitarious females for egg laying and for feeding by nymphal stages. The behavioural phase status of the nymphs (1st instar: day 1–4/5, 2nd instar: day 6–10/11, 3rd instar: day 12–17/18) in different experimental set-ups was monitored by aggregation/dispersion assays. Table 2 illustrates the results obtained.

Table 2. Day of (i) significant shift of behaviour; and (ii) onset of colouration change of nymphs in different *Heliotropium* plant configurations/cover at different nymphal densities

Plant configuration/cover and locust density	Day of shift of phase indicators: Aggregation behaviour	Dark spotted nymphs	Gregaria-coloured nymphs
Plant cover: 50%			
Nymphs from 1 pod	18*	20	-
Nymphs from 2 pods	14*	16	-
Nymphs from 3 pods	12*	16	-
Plant cover: 25%			
Nymphs from 1 pod	16*	20	-
Nymphs from 2 pods	12*	16	-
Nymphs from 3 pods	10**	12	16
Plant cover: 10%			
Nymphs from 1 pod	12**	16	-
Nymphs from 2 pods	8**	12	16
Nymphs from 3 pods	6**	8	12

*Statistically significant at $P < 0.05$, **significant at $P < 0.01$, compared with Poisson distribution.

Gregarisation thus occurs faster the lower the plant density and the higher the locust nymphal density. Since the presence of other plants that solitary hoppers encounter in the field may modify their behaviour and intra-specific encounters, the following series of follow-up studies are planned:

- Effects of different kinds of plants often associated with preferred host plants (*Heliotropium* spp.), roosting plants and plants that appear to be actively avoided by solitary nymphs, in different proportions relative to preferred host plants (the former may be equivalent to a higher host plant density; the latter an active 'push' effect);
- Construction of field arena chambers on selected sites in the field with blends of *Heliotropium* spp. (or ecophysiological equivalents) and more diverse desert plant composition during favourable weather, introduction of ovipositing females, monitoring phase changes at different nymphal densities and comparison with results obtained from manipulated plant densities; and
- Use of the results obtained above to guide area-wide aerial and ground surveys of key gregarisation and outbreak hotspots in successive seasons to develop a probability simulation model based on two key parameters—plant composition and density, and solitary locust numbers—to predict the genesis of gregarious populations.

4. *New initiatives*

Similar work has been initiated on the aggregation pheromones of the Malagasy migratory locust, *Locusta migratoria capito* (Saussure, 1884). Two PhD students will characterise the nymphal and adult locust pheromones and evaluate their cross-stage effects to determine whether these have similar effects as those found in the desert locust, *Schistocerca gregaria* (Forsk.).

Output

Journal articles

Hassanali A., Bashir M. O., Njagi P. G. N. and *Sidi Ould E.* (2005) Desert locust gregarization: A conceptual kinetic model. *Journal of Orthoptera Research* 14, 223–226.

Hassanali A., Njagi P. G. and *Bashir M.* (2005) Chemical ecology of locusts and related acridids. *Annual Review of Entomology* 50, 223–245.

Shi W. P. and *Njagi P. G. N.* (2004) Disruption of aggregation behaviour of oriental migratory locusts *(Locusta migratoria manilensis)* infected with *Nosema locustae. Journal of Applied Entomology* 128, 414–418.

Conferences attended

The 2nd National PM Conference on "Toward Preventive and Bio-rational Desert Locust Control" held at the University of Gezira, 6–9 December 2004, Wad Medani, Sudan. Attended by: Sidi Ould E., M. Bashir and A. Hassanali.

The 9th International Conference of the Orthopterists' Society, 14–19 August 2005, Canmore, Canada. Attended by: A. Hassanali, M. Bashir, P. Njagi, Sidi Ould Ely and C. Kane.

Control of Locust and Grasshoppers Stakeholders Workshop on "Use of Biopesticides for Control of Locusts and Grasshoppers", 10–11 October 2005, Dakar, Senegal. Attended by: A. Hassanali.

Stakeholders' Workshop on Use of Biopesticides for Control of Locusts and Grasshoppers, 10–11 October 2005, Dakar, Senegal. Attended by: A. Hassanali.

Research proposals

Toward preventive and environmentally-friendly management of the desert locust. Funded by Swedish International Development Cooperation Agency (SIDA).

Aspects of chemical ecology and pathology of Madagascar migratory locust. Proposal developed in collaboration with Ministere de l'Agriculture, Madagascar. Funded by African Development Bank.

Capacity building

PhD students

S. O. Ely (Mauritania) Reproductive behaviour of the solitarious desert locust, *Schistocerca gregaria* (Forskål) in relation to chemical attributes of desert plants. University of Khartoum, Sudan (completed in 2004).

C. M. H. Kane (Mauritania) Cross-stage physiological effects of desert locust, *Schistocerca gregaria* aggregation pheromones on their behaviour and susceptibility to control agents. Kenyatta University, Kenya (completed in 2005).

MSc student

F. Musieba (Kenya) Effect of *Metarhizium anisopliae* and its complementation with phenylacetonitrile pheromone on reproductive potential and mortality of gregarious nymphs (completed 2005).

Impact

The adult pheromone component (PAN) has been registered in Sudan following a successful registration trial and the Plant Protection Department are planning to incorporate it with fractional doses of bio- or chemo-pesticides in future locust control. In collaboration with FAO, plans are underway to expose other national locust control organisations to the pheromone-based technology.

D. Root and Tuber Crops Pests

PATHOGENICITY OF BEAUVERIA BASSIANA AND METARHIZIUM ANISOPLIAE TO SWEET POTATO WEEVIL CYLAS PUNCTICOLLIS

Background

Sweet potato weevil (SPW), *Cylas puncticollis*, is a major constraint to sweet potato production in East Africa as feeding adults cause numerous small holes on sweet potato tubers. Effective non-chemical control measures are needed for this pest to reduce harmful side effects of pesticides on public health and the environment. Although entomopathogenic fungi of the genera *Beauveria* and *Metarhizium* have been isolated from the SPW, no attempt has been made to use them to control this pest. The present study by the Arthropod Pathology Unit (APU) investigates the pathogenicity of different isolates of *B. bassiana* and *M. anisopliae* to adult *C. puncticollis* in the laboratory, and the effect of fungal infection on feeding and reproduction potential.

Participating scientist: *N. K. Maniania*

Assisted by: *E. O. Ouna, R. Rotich*

Donors: *icipe core fund donors, Rockefeller Foundation*

Collaborators: *KARI, University of Nairobi, Kenya*

Work in progress

1. *Pathogenicity of* Metarhizium anisopliae *and* Beauveria bassiana *to* Cylas puncticollis

Mortality in the controls was 16.7%. At standard concentration of 1.0×10^7 conidia/ml, both fungal species were pathogenic to adult *C. puncticollis*. Mortality varied between 62.5 and 89.2% with *M. anisopliae* and between 77.5 and 84.2% with *B. bassiana* (Table 1). There was, however, significant difference between the isolates (F = 23.3; df = 12,5; P < 0.0001). Dead insects showed signs of mycosis on the surface of the cadavers (Figure 1). The LT_{50} values ranged from 9.7 to 18.9 days for *M. anisopliae* and from 12.6 to 17.6 days for *B. bassiana* and were significantly different among fungal isolates of both species F = 4.4; df = 11, 5; P < 0.0001) (Table 1). Based on LT_{50} values and growth characteristics, *M. anisopliae* isolates *icipe* 18 and *icipe* 62 and *B. bassiana* isolates *icipe* 275 and *icipe* 114 were selected for dose-response mortality bioassays. The lethal concentration to 50% (LC_{50}) mortality for the four isolates ranged from 2.2×10^6 to 5.5×10^6 conidia/ml (Table 2).

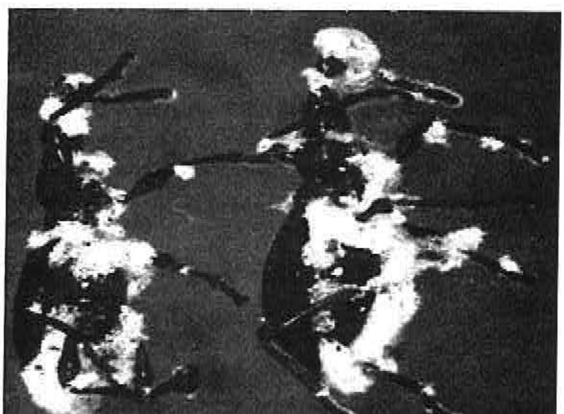


Figure 1. Dead sweet potato weevils showing mycosis by *Beauveria bassiana*

Table 1. Pathogenicity of *Metarhizium anisopliae* and *Beauveria bassiana* isolates against *Cylas puncticollis*. Percentage mortality and LT_{50} values

Fungal isolate	% mortality (± SE)	LT_{50} (days)	Slope
Control	16.7 ± 1.1 e		
Metarhizium anisopliae			
icipe 62	89.2 ± 1.5 a	9.7 d	0.14
icipe 21	85.0 ± 1.3 abc	11.0 cd	0.14
icipe 7	74.2 ± 3.0 c	13.5 bcd	0.15
icipe 18	85.8 ± 2.0 ab	10.8 cd	0.15
icipe 20	80.0 ± 2.9 abc	13.0 bcd	0.14
icipe 30	75.8 ± 1.5 bc	12.0 bcd	0.14
icipe 45	80.0 ± 5.2 abc	12.3 bcd	0.14
icipe 59	62.5 ± 5.0 d	18.9 a	0.14
Beauveria bassiana			
icipe 59	79.2 ± 2.4 abc	17.6 ab	0.20
icipe 114	84.2 ± 5.4 abc	12.6 bcd	0.15
icipe 275	80.8 ± 3.0 abc	13.0 bcd	0.15
icipe 51	77.5 ± 7.9 bc	14.8 abc	0.16

Means with columns followed by the same letters are not significantly different by Student-Newman-Keuls (SNK) test at P = 0.0001. Means were arcsine-transformed before analysis but values represent untransformed data.

Table 2. Lethal concentration values of *Metarhizium anisopliae* and *Beauveria bassiana* isolates against *Cylas puncticollis*

Fungal isolate	LC_{50} (95% fiducial limits)
Metarhizium anisopliae	
icipe 62	4.0×10^6 (3.3–4.8) 10^6
icipe 18	5.5×10^6 (5.0–6.2) 10^6
Beauveria bassiana	
icipe 114	5.2×10^6 (4.3–6.2) 10^6
icipe 275	2.2×10^6 (1.7–2.9) 10^6

2. *Effect of fungal infection by* B. bassiana *and* M. anisopliae *on adult* C. puncticollis *feeding, fecundity and egg hatchability*

Adult sweetpotato weevils treated at concentrations of 3.0×10^7 and 1.0×10^8 conidia/ml of *M. anisopliae* consumed significantly less food than weevils in the control and *B. bassiana* treatments ($F = 3.48$; df = 5,10; $P = 0.0001$) at 14 days post-treatment. Female weevils in the controls laid more eggs than fungus-treated females ($F = 60.1$; df = 4,16; $P = 0.0001$). However, the number of eggs laid by the weevils treated at concentration of 3.0×10^7 conidia/ml was lower than the one treated at the lowest concentration of 1.0×10^6 conidia/ml at all days, except on the fourth day post-treatment. The number of eggs laid by female weevils decreased 10 days post-treatment in all the treatments including the control. There was a significant difference in egg hatchability between controls and fungus-treated female weevils at all the concentrations used ($F = 42.0$; df = 4,16; $P = 0.001$). For instance, 97.5% of eggs hatched in the controls compared to 71.5% in fungus-treated at the 3.0×10^7 conidia/ml concentration.

Capacity building

MSc student

S. Ondiaka (Kenya) Pathogenicity of entomopathogenic fungi *Beauveria bassiana* (Balsamo) Vuillemin and *Metarhizium anisopliae* (Metsch.) Sorokin to *Cylas puncticollis* (Coleoptera: Curculionidae) on sweet potato tubers. University of Nairobi (submitted).

E. Population System Study and Management

Modelling the Population Dynamics of Insects

Background, approach and objectives

The Population Ecology and Ecosystem Science Department project deals with methodology development and applications and gives emphasis to the temporal dynamics (of *Aceria sheldoni* on citrus, *Tetranychus urticae* on tomatoes, *Thrips tabaci* on onion, *Plutella xylostella* on kale), spatial distributions (of olive fruit fly *Bactrocera oleae)* and interactions (of *Coenosia attenuta* and *Drosophila melanogaster)*.

The project also deals with multitrophic interactions. Increasingly, population modelling and systems analysis is being used to examine the complex issues that are at the heart of CP/IPM (crop production and integrated pest management) and biological control. The design of economically sound and sustainable crop management strategies requires a thorough understanding of the whole production system including arthropod pests, pathogens and weeds. The need to rely on system analysis and interdisciplinary collaboration was recognised two decades ago and led to the development of models that are employed in the analysis of physical systems and adapted to solve agroecosystem problems. In this project, we review the work of Prof. A. P. Gutierrez and Dr Johann Baumgärtner and demonstrate the applicability of physiologically based approaches to agroecosystem study and management.

Collaborators: *J. Baumgärtner, S. Ekesi, Getachew Tikubet, M. Knapp, B. Löhr, N. K. Maniania, (and C. M. Matoka, S. Sithanantham-2004); L. Gitonga, Jomo Kenyatta University of Agriculture and Technology, Kenya; G. Gilioli, Università Mediterranea di Reggio Calabria, Reggio Calabria, Italy; A. P. Gutierrez, University of California, USA; L. Limonta, University of Milan, Italy; R. Narla, J. Nderitu, University of Nairobi, Kenya; R. Petacchi, G. Ragaglini, Landscape Entomology Lab (LELab), Scuola S. Anna, Pisa, Italy; M. Severini, Istituto di Scienze dell'Atmosfera e del Clima, CNR, Rome, Italy; V. Vacante, Università Mediterranea di Reggio Calabria, Reggio Calabria, Italy; M. Waiganjo, Kenya Agricultural Research Institute, Thika, Kenya*

Collaborating projects: *African Fruit Fly Initiative, Diamondback Moth, Red Spider Mite, African Bollworm Egg Parasitoid (2004)*

Collaborating support unit: *Arthropod Pathology Unit*

Work in progress

The dynamics of *Aceria sheldoni* and citrus plant units has been followed in citrus groves and will be analysed on the basis of principles used in population ecology. Some of these principles are detailed in the review article of Gutierrez and Baumgärtner (2005). At mesoscale conditions, adult olive fly *Bactrocera oleae* population distributions are analysed by means of geostatistical methods and consideration of environmental factors including landscape features and agronomic practices. The spatio-temporal distribution has been divided into homogeneous zones and the resulting maps are used in monitoring networks. The predator–prey ratio dependent and supply–demand controlled functional response model described among others, in Gutierrez and Baumgärtner (2005), has been applied to the response of single *Coenosia attenuata* Stein female adults to *Drosophila melanogaster* (Meig.) adults. The observations were made at different but constant conditions of temperature and prey densities. The experiments were conducted in cages over a wide range of temperatures between 12 to 42 °C. At each experimental temperature, the number of attacks increases with increasing prey density up to a maximum attack rate referred to as demand rate. A ratio-dependent and demand-driven functional response model was appropriate to describe the attack rate at different temperatures. Both the demand and the search rate linearly increased with increasing temperatures throughout the range. Based on these results a temperature and prey density dependent bi-dimensional attack rate model was developed and parametrised. The resulting response surface shows that *C. attenuata* is active over a wide range of temperatures (from about 12 to 36 °C), and attacks occur up to 42 °C. Thus, *C. attenuata* may be a promising whitefly control agent in Mediterranean greenhouses. To support this conclusion, further studies including the evaluation of spatial scale effects on the search rate and the consideration of the economically relevant whitefly prey are recommended.

According to the review by Gutierrez and Baumgärtner (2005), a wide range of modelling approaches may be used to model field tritrophic dynamics, but of these, physiologically based approaches have yielded the most consistent results. An advantage of the physiologically based approach is its applicability to modelling a wide range of ecological systems using essentially the same model. The use of this modelling paradigm is aided by physiological and behavioural analogies that exist among species and trophic levels. The most basic one is that all organisms have the same imperative: maximise fitness by maximising resource acquisition and minimise costs and losses to predation. This biology is subsumed under the ambit of the metabolic pool paradigm. Organisms seek to satisfy a genetic demand for resources given current states and environmental conditions. Using a per capita approach, organisms search for resources (biomass, energy) that are allocated to egestion, respiration and growth and reproduction. The various components of this demand are easily identified aiding in gathering the appropriate data. In population dynamic models based on this paradigm, the vital rates of all species are scaled from the maximum by the ratio of actual rate of consumption of resources to the genetic maximal demand. Estimating growth rates in this manner may be used to predict geographic limits of favourability and phenologies.

The plant is the base trophic level and integrates many of the abiotic factors and provides the resource base for higher trophic levels (bottom-up effects), while higher trophic levels provide the top-down regulation on pests. The systems models are modular making inclusion of different species a simple matter because it is simply another model with known structure and its linkages to other species is via its role as a consumer and/or as a resource. Approaching modelling from this physiological perspective simplifies the problem and makes the model independent of the data one wishes to simulate. Of course, weather and abiotic factors help determine the demand and hence are forcing variables for the system. The use of object oriented programming further facilitates the programming of the system.

The models may be used in prospective and retrospective analyses of complex systems. The models may be used to evaluate natural and biological control programmes (e.g., cassava, coffee, grape) and to develop IPM strategies (alfalfa, cotton, cowpea). The model may also be used to evaluate the utility of genetically modified crops (GMOs, e.g. cotton, maize, rice) and to assess the potential for resistance development in pests and the collateral effects of the GMOs on natural enemies.

A systems model of crop systems may be viewed as libraries of what is known about the system and like any good library may be augmented as new information becomes available. The models should be independent of time and place because they describe physiological and population processes that are driven by observed weather and edaphic factors. This property allows them to be embedded in geographic information systems (GIS) that have to access spatially defined weather. Such models enable us to analyse on a regional basis crop–pest phenologies, crop yields, pest damage, biological control efficacy, assess new pest problems quickly as well as various other scenarios. A perceived weakness of the approach is that the models lack analytical solution and formulating the complexities of a biological system requires a minimum of data. This unifying approach greatly simplifies the ecological problems, and in some cases may permit analysis of complex systems where the barest of observational data are available.

Output

Journal article

Gilioli G., *Baumgärtner J., and* Vacante V. (2005) Temperature influences on functional response of *Coenosia attenuata* (Diptera: Muscidae) individuals. *Journal of Economic Entomology* 98, 1524–1530.

Review papers

The review prepared by Prof. A. P. Gutierrez and Dr J. Baumgärtner was concluded in 2005. A book chapter on modelling the dynamics of tritrophic population interactions is in press. Population models have been developed and used for *Tetranychus urticae* (in collaboration with Dr M. Knapp, *icipe* and Dr Gianni Gilioli, Università Mediterranea di Reggio di Calabria) and, in a recently concluded publication, for *Thrips tabaci* (in collaboration with a team of scientists working at *icipe*, Kenyan national institutions and Università di Reggio di Calabria scientists). The review paper is used as a basis for the development of *B. tabaci* study and management projects.

Capacity building

The dynamics of *Thrips tabaci* and *Plutella xylostella* populations is the subject of thesis studies currently undertaken at Addis Ababa University.

F. Mathematical Models of Population Dynamics of Pests

Development of Mathematical Models for the Description of Interaction Between Insects and Plants

Main activities of the Biostatistics Unit are the constructing and analysis of mathematical models of population/ecosystem dynamics and their application to the description of real biological processes. This includes the solution of various methodological problems of ecological modelling, creation of new statistical methods for analysis of non-linear population dynamics and development of ecological theories of insect population dynamics, among others.

Participating scientist: *L. Nedorezov*

Assisted by: *A. Wanjoya*

Collaborators: *KAZAKHSTAN: Ministry of Agriculture, Kazakhstan; Kazakh Scientific Research Institute for Plant Protection. RUSSIA: Novosibirsk State University, Novosibirsk; Institute of Molecular Biology and Biophysics, Novosibirsk; Institute of Systematics and Animal Ecology, Novosibirsk; V. N. Sukachev Institute of Forest, Krasnoyarsk. NORWAY: University of Oslo, CEES, Oslo, Norway*

1. Influence of periodic disturbances on population dynamics

Participating scientist: *L. Nedorezov*

Assisted by: *A. Wanjoya*

Work in progress

Analysis of single-species population dynamics models with overlapping and non-overlapping generations under the periodic disturbances was provided. Changing of population size at moments of impact was described with broken trajectory ('jump down'). Also it was assumed that fecundity of individuals is constant and quota of survived individuals depends on within-year population dynamics. The dynamic regimes of models, which are determined by the influence of intra-population self-regulative mechanisms, are analysed. For some particular cases the conditions of population extinction and its stabilisation at non-zero level are determined. It was proved with numerical methods that chaotic regimes can also be realised in some models. The conditions for deduction of models to some well-known discrete time models are obtained.

New models with discrete birth process

Let t_k, $k = 0,1,2\ldots$, $t_{k+1}-t_k = h = const > 0$, be the moments of impact. Denote as $x(t)$ the population size at moment t, as $x(t_k - 0)$ the number of survived individuals to moment t_k, as $x_k = x(t_k)$ the population size at the beginning of the next vegetation period, and as Q, $0 \le Q \le 1$, the quota of survived individuals. The amount $p = 1 - Q$ is equal to the probability to die during this period. Thus at moments t_k we have the following relation:

$$x(t_k) = Q_x(t_k - 0). \tag{1}$$

Within the framework of the model we shall assume that appearance of new individuals is realised at fixed time moments τ_k, $\tau_k \in (t_k, t_{k+1})$, that allows us to describe the changing of population size with broken trajectory. Denote as $x(\tau_k - 0)$ the number of survived individuals to moment τ_k. Let $Y = const$, $Y > 1$, be the coefficient of productivity: Y is equal to the average of new individuals which can be produced by one survived individual. Thus at moments τ_k the following relation is truthful:

$$x(\tau_k) = Yx(\tau_k - 0). \tag{2}$$

Population dynamics on every time interval $[t_k, \tau_k)$ and $[\tau_k, t_{k+1})$ we shall describe with the help of the following equation:

$$\frac{dx}{dt} = -xR(x). \tag{3}$$

where $R(x)$ satisfies the following conditions which are common for various models:

$$R(0) > 0, \frac{dR}{dx} > 0, R(\infty) = \infty. \tag{4}$$

$R(0)$ is an intensity of natural death rate, and an increase of values of $R(x)$ is a result of strengthening of influence of intra-population self-regulative mechanisms at increasing of population size.

In the model we shall assume that coefficient Q depends on average population size during the period $[t_k, t_{k+1})$, $Q = Q(u)$, where

$$u = \frac{1}{h}\int_{t_k}^{t_{k+1}} x(s)ds,$$

and at moments t_{k+1} we have

$$x_{k+1} = x(t_{k+1}) = Qx(t_{k+1} - 0). \tag{5}$$

Taking into account the real sense of coefficient $Q(u)$, we have to assume that Q is a monotonously decreasing function:

$$Q(u) \in [0,1], \frac{dQ}{du} < 0. \tag{5}$$

Relations (1)–(5) give us the model of population dynamics with discrete birth process and continuous-discrete death process. Note if coefficient of productivity $Y < 1$ then time series $\{x(t_k)\}$, $k = 0,1,2\ldots$, in model (1)–(5) is a monotonous decreasing sequence for all initial values of population size (population eliminates for all initial values).

Model (1)–(5) can be deduced to the following equation:

$$x_{k+1} = x(t_{k+1}) = Q\left(\frac{1}{h}\int_{t_k}^{t_{k+1}} x(s)ds\right)\Psi^{-1}(c_2 - t_{k+1}), \tag{6}$$

where

$$c_2 = \tau_k + \Psi(x(\tau_k)).$$

1. If $R(x) \equiv b = const > 0$ and $Q(u) = e^{-pu}$, $p = const > 0$, model (6) has the following form:

   $$x_{k+1} = \alpha x_k e^{-\beta x_k}, \tag{7}$$

   where positive constants α and β depend on b, Y, h_1, h_2 and p. Equation (7) is a well-known Moran-Ricker model.

2. If $R(x) \equiv b = const > 0$, $Q(u) = 1/(1 + pu)$ equation (6) is a well-known Skellam' model:

   $$x_{k+1} = \frac{\alpha x_k}{\beta x_k + \gamma},$$

where α, β, γ are positive parameters.

3. If $R(x) = \alpha x + b$, $a, b = const > 0$, $Q(u) = e^{-pu}$, model (6) has the following form:

$$x_{k+1} = \frac{K_1 x_k}{K_2 x_k + K_3} \left(\frac{K_4 x_k + K_5}{K_6 x_k^2 + K_7 x_k + K_5} \right)^{\frac{p}{ba}}, \tag{8}$$

where 'macro-coefficients' $K_i = const \geq 0$, $i = 1,\ldots,7$, are determined by the following formulas:

$K_1 = bY$, $K_2 = a(Ye^{bh_2} + (e^{bh_1} - 1)e^{bh_2} - Y)$, $K_3 = be^{bh}$, $K_4 = ab(e^{bh_1} - 1)$, $K_5 = b^2 e^{bh_1}$,
$K_6 = a^2(Y(1 - e^{-bh_1})(1 - e^{-bh_2}) + (1 - e^{-bh_1})(e^{bh_1} - 1))$, $K_7 = ab(2(e^{bh_1} - 1) + Y(1 - e^{-bh_2}))$.

It is important to note that equation (11) was obtained under the assumption that action of intra-population self-regulative mechanisms is described by Verhulst law when R is a linear function.

Stationary states of model (8) can be found from equation:

$$x = \frac{K_1 x}{K_2 x + K_3} \left(\frac{K_4 x + K_5}{K_6 x^2 + K_7 x + K_5} \right)^{\frac{p}{ba}}, \tag{9}$$

Obviously, $x_0 = 0$ is a root of this equation. If $K_3/K_1 < 1$ equation (9) has positive solutions. If $K_3 > K_1$, which is equal to $e^{bh} > Y$, the origin is global stable equilibrium for model (8). Under this condition the population eliminates for all initial values of population size. Analysis of the bifurcation diagram shows that various cyclic regimes can be realised for model (8). Numerical analysis of Diamond theorem conditions (Diamond, 1976: Chaotic behaviour of systems of difference//*International Journal of Systems Science*, 1976, pp. 953–956) shows that on a plane (a,b) there is the domain, which corresponds to dynamic regimes with chaotic trajectories.

New models with continuous birth process

Let us assume that population dynamics on the intervals $[t_k, t_{k+1})$ is described by the equation:

$$\frac{dx}{dt} = xR(x), \tag{10}$$

where function $R(x)$ describes the death process of individuals, birth process and influence of intra-population self-regulative mechanisms on population dynamics. The following conditions are typical for the function $R(x)$:

$$R(0) > 0, \frac{dR}{dx} < 0, R(\infty) = -\infty. \tag{11}$$

Amount $R(0)$ is the Malthusian parameter for population.

Like in a previous case, we shall assume that quota Q of survived individuals at moments t_{k+1} is determined by the food supply of individuals during a certain time interval:

$$Q = Q\left(\frac{1}{h}\int_{t_k}^{t_{k+1}} x(s)ds\right) \text{ and } x_{k+1} = x(t_{k+1}) = Qx(t_{k+1}-0). \tag{12}$$

Additionally, it is natural to assume that increase of average of population size leads to decrease of food supply for individuals, and the derivative of function (12) must be negative.

***Properties of model (10)–(12) for* Q = const**

1. Let K be a solution of equation $R(x) = 0$. If $x_0 = x(0) > K$ trajectory $\{x_k = x(t_k)\}$ of model (10)–(12) will belong to domain $x \leq K$ after finite number of time steps. If $x_0 = x(0) < K$ the sequence $\{x_k\}$ cannot intersect the boundaries of interval $[0, K]$. It means that for every time moment the population size is bounded and non-negative.

2. If

$$Qe^{R(0)h} < 1$$

the origin is global attractant.

3. Let $\psi(x)$ be the following function:

$$\psi(x) = \int \frac{dx}{xR(x)}.$$

If $0 < x < K$ then $\psi(x)$ is a monotonously increasing function, $\psi'(x) > 0$. When x changes from 0 to K the value of function $\psi(x)$ changes from $-\infty$ to $+\infty$. Thus, there exists the inverse function ψ^{-1} which is defined on the interval $(-\infty, +\infty)$ and bounded, $0 \leq \psi^{-1} \leq K$.

Formally, it is possible to present the solution of model (10)–(12) in the following form (with initial condition $x_k = x(t_k)$):

$$x_{k+1} = Q\psi^{-1}(\psi(x_k) + h).$$

Function in the right-hand side of the equation is a monotonously increasing function. Thus in model (10)–(12) there are the regimes of monotonous changing of population size only. The number of non-trivial stationary states is determined by the number of positive solutions of the functional equation:

$$\Psi\left(\frac{1}{h}\right) = \Psi(x) + h,$$

which is defined on the interval $0 < x < QK$. Taking into account that the second derivative of $\psi(x)$ can change the sign; in general the last equation has several non-zero solutions.

Particular cases

1. Let $R(x) = \tilde{\alpha} - \tilde{\beta}x$, where all parameters are positive, $\tilde{\alpha}, \tilde{\beta} = \text{const} > 0$. Coefficient $\tilde{\alpha}$ is a Malthusian parameter of population and $\tilde{\beta}$ is a parameter of self-regulation. Let $t_k + \tau$ be the time moment of population size fixations (after impact), $x_k = x(t_k + \tau)$. After all this we get the following discrete model:

$$x_{k+1} = \frac{\alpha x_k}{1 + Cx_k},$$

where

$$C = \frac{\beta}{\alpha}\left(e^{\alpha(h-\tau)} - 1 + Q(e^{\alpha\tau} - 1)e^{\alpha(h-\tau)}\right).$$

Finally, in considering a situation there is no correlation between kinds of model and moments of population size measurement.

2. Let us consider the situation when

$$Q = exp\left(-b\int_{t_k}^{t_{k+1}} x(s)ds\right). \tag{13}$$

Coefficient b is a positive parameter which corresponds to the 'sensitivity' of individuals on the food conditions. After calculations, formula (13) can be presented in the form:

$$Q = \frac{1}{\left(1-\frac{\beta}{\alpha}x_k + \frac{\beta}{\alpha}e^{\alpha h}x_k\right)^{\frac{b}{\beta}}}.$$

And, finally, we get the following discrete model of population dynamics:

$$x_{k+1} = \frac{Ax_k}{(1 + Bx_k)^{\frac{b}{\beta}+1}},$$

where

$$A = e^{\alpha h},\ B = \frac{\beta}{\alpha}\ (e^{\alpha h}-1).$$

It is a well-known Hassell model. Let $t_k + \tau$ be the moments of population size fixation, $x_k = x(t_k + \tau)$. If Q is determined by (13) we have

$$Q = \left(\frac{\alpha e^{\alpha\tau} - \beta x_k(e^{\alpha\tau}-1)}{\alpha e^{\alpha\tau} + \beta x_k(e^{\alpha h}- e^{\alpha\tau})}\right)^{\frac{b}{\beta}}$$

This expression gives us one-parametric (τ) family of discrete models which are 'produced' by the model (10)–(12) under the considering assumptions.

2. *General analysis of population dynamics*

Participating scientist: *L. Nedorezov*

Assisted by: *A. Wanjoya*

Work in progress

About a problem of selection of statistical criteria

The final results of analysis of experimental time series with the help of mathematical models depends on the selected model and also on the statistical criterions we use. Let us assume that we have time series $\{\tilde{x}_t\}$, $t = 0,1\ldots, N$, where $\tilde{x}_t$ is the population size at moment t; $N + 1$ is the sample size. Let $F(\cdot)$ be non-negative and non-linear function in the right-hand side of equation

$$x_{k+1} = F(x_k,\vec{\alpha}). \tag{14}$$

We have the following problem: It is required to estimate the value of parameters in the equation (14) on available sample $\{\tilde{x}_t\}$. In this case, for example, we can use the following criterion which we meet rather frequently in the literature;

$$LF(\vec{a})=\sum_{t=0}^{N-1} (\tilde{x}_{t+1}-F(\vec{a},\tilde{x}_t))^2 \longrightarrow \min_{\vec{a}}, \tag{15}$$

where $\vec{a}$ is a vector of parameters of equation (14). Let us note, first, that it is possible to construct the analog of expression (15) for the situation when we have the information about dynamics of some other variables. The second, the best values of model parameters correspond to global minimum of functional $LF(\vec{a})$ but taking into account the non-linearity of function F in general cases we might have a lot of local minimums for functional $LF(\vec{a})$.

Note that with the use of criterion (15) equation (14) does not play the role of *dynamic system* but it is used as a one-step non-linear *regression formula* only. In this case quite natural questions arise about possibilities to determine the model parameters with other modifications of criterion (15): What is the reason to use *one-step* regression instead of two-step, three-step or multi-step regression equations for the fitting of experimental time series? In all these situations we shall use the same equation (14) and the same time series, and, it is obvious, we shall have different results.

Additionally, in expression (15) we have 'double standards' for most elements from the experimental time series. For example, for the first element of sum (15) we assume that $\tilde{x}_i$ is a value of any stochastic variable which had been measured with stochastic error. But in the next component of this sum we assume that $F(\vec{a}, \tilde{x}_i)$ is the *theoretical value* of population size which we have to have if $\tilde{x}_2$ was measured without any errors. In other words, in the second component of sum (15) we assume that value $\tilde{x}_i$ had been measured without error.

Taking this into account we are sure that criterions of type (15) cannot be applied to the estimation of model parameters. Moreover, we are sure that various modifications of criterion (15) which can be obtained, for example, after the logarithmic transformation of datasets or functions, also cannot be applied to the solution of the problem: For initial datasets we can assume that errors in our measurements have normal distribution with zero average and any finite dispersion, but after the logarithmic transformation we do not have the basis for this assumption.

Other type of statistical criterions for determination of model parameters is the global fitting. When we use criterions of that type we try to find the best trajectory in a set of all solutions of model (14), which gives us the best approximation of empirical time series. Let $N_i^*(\vec{a}, N_0, Q_0, P_0)$ be the solution of model (14) which is observed for given vector of model parameters $\vec{a}$ and given initial values of model variables N_0, Q_0 and P_0. Then criterion can be presented in the form

$$LF(\vec{a},N_0,Q_0,P_0) = \sum_{t=0}^{N} (\tilde{x}_i - N_i^*(\vec{a},N_0,Q_0,P_0))^2 \longrightarrow \min_{\vec{a},N_0,Q_0,P_0} . \qquad (16)$$

Note that all elements in sum (16) were constructed in similar manner and we cannot say that in (16) we have any modification of 'double standards' as in (15). Additionally, if we have measurements for other variables, criterion (16) can be modified for a new situation. But for most of experimental time series we do not have other measurements and there are some additional time series, which have indirect relation to the model variables.

Some basic steps of analysis

1. In the first step we solve the problem about possibility to use simplest discrete time model (as Moran-Ricker model, or Smith model etc.) for fitting of given time series. For this purpose on experimental data with the criterion (16) we determine the set of model parameters, which gives the global minimum for loss-function (16).
2. For this set of parameters we analyse the sequence of deviations between theoretical and empirical trajectories. We test the normality of its distribution and the existence of correlation between residuals (Kolmogorov-Smirnov criterion, Shapiro-Wilcoxon criterion, Durbin-Watson criterion etc.). Also we analyse the behaviour of auto-correlation function for residuals. The main goal of testing is: to determine the quality of approximation of experimental trajectory by model trajectory. Moreover, minimum of loss-function (16) for primitive discrete time model gives us the 'origin' for all other (more difficult) models (as parasite–host system dynamics models).

   Some problems in explanation of population dynamics can arise in the situation when we cannot reject the hypothesis that primitive discrete time model can be applied for the fitting of experimental trajectories. If so, it means that fluctuations of populations can be explained as a result of influence of intra-population self-regulative mechanisms only. Consequently, if we add one more regulator to the system we cannot obtain new results because the primitive discrete time model is a particular case of model with the additional regulator. For this new situation we cannot say that fluctuations of population can be explained as a result of influence of this additional regulator only. Finally, the real sense in realisation of next stages exists if and only if we do not have a good correspondence between the theoretical and the experimental trajectories on all previous stages.

3. On the next stage we have to determine the global minimums for loss-function (16) for the cases when we have in the model two or more variables: We have to fit the time series with the help of trajectories of resource-consumer system, or parasite–host system etc.

Application of new methodology to analysis of larch bud moth fluctuations

For testing the methodology of population dynamics analysis we applied it to the following model of parasite–host–fodder plant dynamics (Turchin et al., 2003: *Ecology* 84, 1207–1214) and experimental time series on larch bud moth (*Zeiraphera diniana* Gn.) population fluctuations (Baltensweiler and Fischlin, 1979: The larch budmoth in the Alps. In *Dynamics of forest insect populations: Patterns, causes, implications* (Edited by A. A. Berryman) 1988, pp. 331–351):

$$N_{t+1} = \lambda_0 N_t \frac{Q_t}{\delta + Q_t} \exp[-gN_t - \frac{aP_t}{1 + ahN_t + awP_t}],$$

$$Q_{t+1} = (1 - \alpha)(1 - \frac{N_t}{\gamma + N_t}) + \alpha Q_t,$$

$$P_{t+1} = \phi N_t \{1 - \exp[-\frac{aP_t}{1 + ahN_t + awP_t}]\}, \qquad (17)$$

where N_t is the density of larch bud moth at the moment t, $t = 0,1,2,\ldots$, Q_t, is the index of food quality, $0 \le Q_t \le 1$, and P_t is the density of parasites at the same moment of time. Results are presented in Tables 1–3. Our numerical analysis and analytical investigations of model (17) properties showed that this model and all its sub-models cannot be applied for the description of larch bud moth dynamics and for identification of main population regulator. Also it allowed us to create a new hypothesis that combined influence of both factors lead to appearance of periodic oscillations of larch bud moth.

3. *Application of the new methodology to analysis of DBM dynamics*

Participating scientists and students: *L. Nedorezov, B. Löhr, D. L. Sadykova (PhD student, Oslo University, Norway), H. Tonnang (ARPPIS, DAAD scholarship, University of Nairobi)*

Operational costs funded by: *BMZ*

Work in progress

For fitting of experimental time series we used the following mathematical models:

$$x_{k+1} = \frac{ax_k}{1+bx_k} \text{ (Skellam)},$$

$$x_{k+1} = ax_k e^{-bx_k} \text{ (Moran-Ricker)},$$

$$x_{k+1} = ax_k(b-x_k) \text{ (discrete logistic model)},$$

$$x_{k+1} = \frac{ax_k}{1+bx_k^c} \text{ (Smith)},$$

$$x_{k+1} = \frac{ax_k}{(1+bx_k)^c} \text{ (Hassell)},$$

Table 1. Estimated values of parameters and loss-functions for model (17)

Models	N_0	P_0	Q_0	λ_0	Y_{max}	δ	g	a	h	w	ϕ	α	γ	LF[5]
MR[1]	74.1	-	-	-	118.2	-	1.4×10^{-4}	-	-	-	-	-	-	8.79×10^{10}
RC[2]	77.1	-	0.76	2818		11.34	1.5×10^{-4}	-	-	-	-	0.97	1.0	8.69×10^{10}
PH[3]	80.3	8.89	-	-	159.2	-	1.5×10^{-4}	3.1×10^{4}	9.8×10^{3}	5.3×10^{-11}	8.1×10^{-11}	-	-	8.68×10^{10}
PHFp[4]	70.7	9.08×10^{5}	0.64	6480	-	55.85	1.7×10^{-5}	0.55	3.1×10^{4}	0.11	0.23	0.88	0.35	7.45×10^{9}

[1]MR, Moran-Ricker model; [2]RC, Resource-Consumer model; [3]PH, Parasite-Host model; [4]PHFp, Parasite-Host-Fodder plant model; [5]LF, Loss-function.

Table 2. Characteristics of dynamical regimes in model (17) and its sub-models

	Amplitude of population size			Amplitude of food quality			Amplitude of parasites fluctuations		
Models	Minimum	Maximum	Difference	Minimum	Maximum	Difference	Minimum	Maximum	Difference
MR[1]	4.86×10^{-12}	311420.3	311420.3	-	-	-	-	-	-
RC[2]	238.7192	238.7192	0	0.004172	0.004172	0	-	-	-
PH[3]	2.31×10^{-18}	390417.9	390417.9	-	-	-	-	-	-
PHFp[4]	0.0054	554421.8	554421.8	0.15586	0.327326	0.171467	7.93×10^{7}	1006.29	1006.29

[1]MR, Moran-Ricker model; [2]RC, Resource-Consumer model; [3]PH, Parasite-Host model; [4]PHFp, Parasite-Host-Fodder plant model.

Table 3. Analysis of residuals for model (17) and all its sub-models

Models	Average	Left limit[5]	Right limit[5]	KS test[6]	SW test[7]	Skew/ stand er.	Kur/ stand er.	DW test[8]
MR[1]	20951.64	430.49	41472.8	0.34844/$P < 0.01$	0.66026 $P < 10^{6}$	4.5619	3.7132	2.034857
RC[2]	20963.32	581.0	41345.64	0.35408/$P < 0.01$	0.65336 $P < 10^{6}$	4.6261	3.8523	2.026737
PH[3]	21112.37	769.53	41455.21	0.35799/$P < 0.01$	0.64962/$P < 10^{6}$	4.6314	3.8616	2.011415
PHFp[4]	3821.22	-2448.32	10090.76	0.29183/$P < 0.01$	0.73369/$P = 10^{5}$	2.1289	8.6272	1.9745

[1]MR, Moran-Ricker model; [2]RC, Resource-Consumer model; [3]PH, Parasite-Host model; [4]PHFp, Parasite-Host-Fodder plant model; [5]Limits are presented for 5% confidence level; [6]KS test, Kolmogorov-Smirnov test; [7]SW test, Shapiro-Wilcoxon test; [8]DW test, Durbin-Watson test.

Table 4. Estimations of model parameters

Models	a	b	c	Carrying capacity	Loss-function
Skellam	1.34598	0.039298	-	34.2506	152.6286
Moran-Ricker 150.58177	1.326853	0.0330909	-	14.75094	
DL	1.312948	0.025035	-	39.94366	148.15768
Smith 128.41583	1.085835	7.094×10^{-13}	9.973403	12.96	
Hassell	1.35898	0.039298	1.03	30.19492	152.594

DL, discrete logistic model.

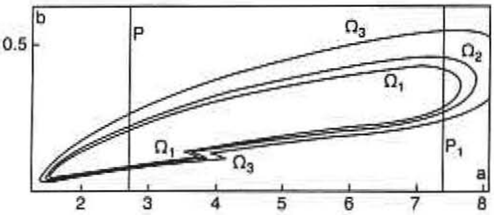


Figure 1. Moran-Ricker model: Behaviour of boundaries of confidence domains (at fixed value of $x_0 = 0.73$) and two bifurcation lines P and P_1. Ω_1 are the boundaries for 10% confidence level, Ω_2 - for 5% confidence level, Ω_3 - for 1% confidence level

Table 5. Estimations of model parameters and values of statistical criterions

Models	Maximum birth rate (a)	Coefficient of self-regulation (b)	Coefficient of correction of self-regulation (c)	Starting population size (x_0)	Carrying capacity	Loss-function*	Durban-Watson Criterion (d)	Value of (z)
Skellam	2.66398	0.260298	-	0.569	10.23435	496.75623	0.350739	-3.0632
Moran-Ricker	2.095853	0.11491	-	0.73	6.71	495.3168786	0.350356	-3.0632
DL	1.26868	0.033105	-	3.827	30.20666	542.04718	0.326806	-4.06216
Smith	1.5611835	0.001	3.404403	0.903	6.48	493.0322	0.349973	-3.36123
Hassell	2.79098	0.163298	1.434	0.399	5.35	495.38285	0.353017	-3.84819

DL, discrete logistic model; *squared deviations between empirical and theoretical time series.

and estimated the model parameters with loss-function (16). Results of numerical calculations are presented in Tables 4 and 5 and on Figure 1. These results allow us to conclude that we cannot explain the population dynamics as a result of influence of intra-population self-regulative mechanisms only. Also it means that for fitting of experimental time series we have to use more difficult models (in particular, with several variables which describe the interaction of DBM with other components of agri-ecosystem).

4. *Application of new methodology to analysis of green oak leafroller fluctuations*

Participating scientist and student: *L. Nedorezov, D. L. Sadykova (PhD student, Oslo University, Norway)*

The same models were applied for fitting of experimental time series of green oak leafroller (Rubtsov, 1992: Models of Oscillation Processes in Forest Ecosystems. Institute of Forest RAN, Moscow, 24 pp. [in Russian]). Numerical results showed that there is very good correspondence between experimental and model trajectories (see, for example, Figure 2). We also found that the probability of event that fluctuations of green oak tortrix correspond to asymptotic stabilisation is more than 0.9, the probability of extinction is less than 0.01, and there is enough big probability of event that observed dynamical regime is two-year cyclic regime (but it is less than 0.1; Figure 2).

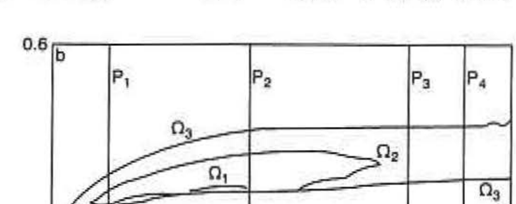


Figure 2. Borders of confidence domains for 10% (Ω_1), 5% (Ω_2) and 1% (Ω_1) confidence levels. P_1 is a bifurcation border that separates areas of monotonous stabilisation and stabilisation with fading oscillations near non-zero equilibrium; P_2 is bifurcation border which crossing leads to appearance of a stable cycle with length 2; P_3, the same, with length 4; P_4, the same, with length 8

Output

Journal articles

Nedorezov L. V. and Sadykov A. M. (2004) Influence of winter conditions on the dynamics of an isolated population dynamics. *Euro-Asian Entomological Journal* 3, 169–172. [in Russian].

Nedorezov L. V. and Sadykova D. L. (2005) A contribution to the problem of selecting a mathematical model of population dynamics with particular reference to the green oak tortrix. *Euro-Asian Entomological Journal* 4, 263–272.

Nedorezov L. V. and Volkova E. V. (2005) On the impact of winter conditions on the dynamics of a population with non-overlapping generations: A model approach. *Journal of General Biology* 66, 484–490.

Abstracts in proceedings

Nedorezov L. V. and Karlyuk A. (2004) Continuous-discrete model of plant community dynamics, p. 125. In *Abstracts of the Conference on Computational and Mathematical Population Dynamics*. 21–25 June 2004, Trento, Italy.

Nedorezov L. V. and Sadykov A. M. (2004) About influence of winter conditions onto isolated population dynamics, p. 126. In *Abstracts of the Conference on Computational and Mathematical Population Dynamics*. 21–25 June, 2004, Trento, Italy.

Nedorezov L. V. and Sadykov A. M. (2004) Isolated population dynamics with periodic disturbances, pp. 99–100. In *Abstracts of the Fourth European Conference on Ecological Modelling (ECEM 2004)*. 27 September–1 October 2004, Bled, Slovenia.

Nedorezov L. V. and Sadykova D. L. (2005) Application of simplest discrete models to the description of green oak tortrix fluctuations, pp. 138–139. In *Proceedings of the Fifth European Conference on Ecological Modelling-ECEM 2005* (Edited by A. S. Komarov). 19–23 September 2005, Pushchino, Russia.

Nedorezov L. V. and Ut'yupin Yu. V. (2004) About a model of isolated population dynamics with time lag, p. 126. In *Abstracts of the Conference on Computational and Mathematical Population Dynamics*. 21–25 June, 2004, Trento, Italy.

Nedorezov L. V. and Utyupin Yu.V. (2005) About continuous-discrete model of predator–prey system dynamics with saturation effect, pp. 140–141. In *Proceedings of the Fifth European Conference on Ecological Modelling-ECEM 2005* (Edited by A. S. Komarov). 19–23 September 2005, Pushchino, Russia.

Nedorezov L. V. and Ut'yupin Yu. V. (2004) Continuous-discrete model of bisexual population dynamics, p. 127. In *Abstracts of the Conference on Computational and Mathematical Population Dynamics*. 21–25 June, 2004, Trento, Italy.

Nedorezov L. V., Löhr B. L. and Sadykova D. L. (2005) DBM population dynamics: Toward a selection of mathematical model, p. 191. In *European Conference on Mathematical and Theoretical Biology, Book of Abstracts 1*. 18–22 July 2005, Dresden, Germany.

Sadykova D. L. and *Nedorezov L. V.* (2005) About application of discrete mathematical models to description of green oak tortrix dynamics, p. 99. In *European Conference on Mathematical and Theoretical Biology, Book of Abstracts 2*. 18–22 July 2005, Dresden, Germany.

Sadykov A. M., Volkova E. A. and *Nedorezov L. V.* (2005) About winter weather impacts onto isolated population dynamics, p. 98. In *European Conference on Mathematical and Theoretical Biology, Book of Abstracts 2*. 18–22 July 2005, Dresden, Germany.

Conferences attended

Conference on Computational and Mathematical Population Dynamics, Trento, Italy, 21–25 June, 2004. Attended by: L. Nedorezov.

European Conference on Mathematical and Theoretical Biology, Dresden, Germany, 18–22 July, 2005. Attended by: L. Nedorezov, D. L. Sadykova and A. Sadykov.

Fifth European Conference on Ecological Modelling-ECEM 2005, 19–23 September 2005, Pushchino, Russia. Attended by: L. Nedorezov.

Capacity building

H. Tonnang (Cameroon) Modelling of parasites host-system dynamics: Application to diamondback moth fluctuations. University of Nairobi (ongoing).

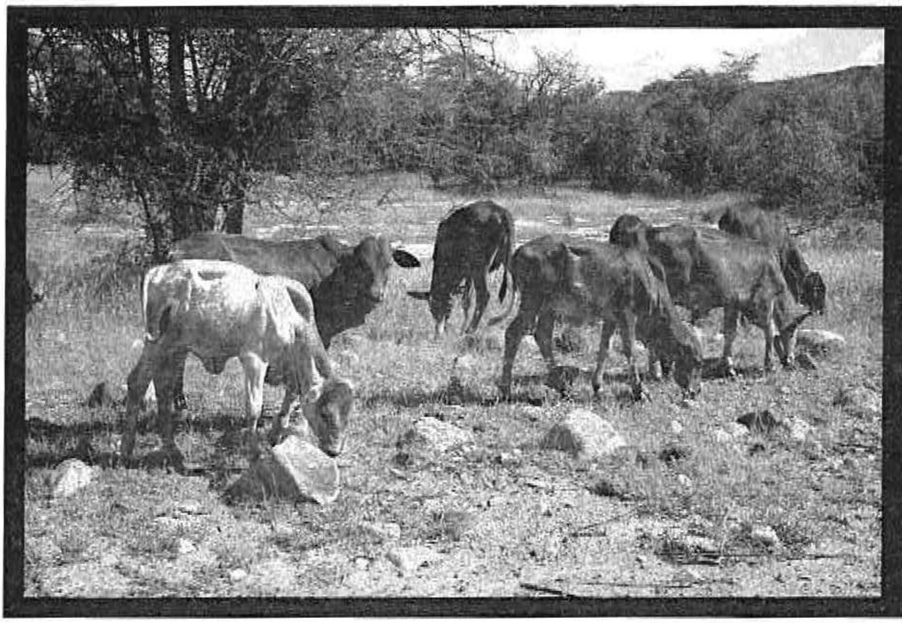


PHOTO: Santiago Escobar

Animal health

A. Tsetse

Further Refinement of the Waterbuck Repellent Blend (WRB)

Objectives

The previous Annual Report gave details of the work undertaken to identify the odour constituents specific to tsetse refractory waterbuck that contribute to repellency. The objectives of the current activities were to:

(a) determine the effect of the waterbuck repellent blend (WRB) on feeding efficiency of *Glossina pallidipes*;

(b undertake further subtraction assays of the WRB to determine the minimum composition that can reproduce the activity of the original 15-components blend;

(c) compare the optimised WRB with the synthetic repellent (SR) and explore any augmentative effects;

(d) optimise the release rate of the WRB and the dispenser design for long-term field deployment.

Participating scientists and students: *M. Bett (ARPPIS student, Moi University), P. Shem (MSc student, University of Nairobi), R. K. Saini, A. Hassanali*

Assisted by: *J. Andoke, P. Muasa, R. Tumba*

Donors: *International Fund for Agricultural Development, DGIS*

Collaborators: *Moi University, Eldoret; University of Nairobi, Kenya*

Collaborating department: *Behavioural and Chemical Ecology Department*

Work in progress

1. *Effect of the waterbuck repellent blend on feeding efficiency of* Glossina pallidipes

The feeding efficiency of *G. pallidipes* on animals treated with waterbuck repellent blend was determined using the method developed by Vale (1977: *Bulletin of Entomological Research*, pp. 635–649). In these experiments, an ox was tethered in the middle of an incomplete ring of five electric screens (1.5 x 1.0 m). The screens covered 20% of the circumference of the circle. These rings were constructed at two different locations. The experiment was a randomised complete block design and treatments were: (1) ox alone and (2) ox + total WRB, which were randomly assigned to the two sites. At the sites that received repellent treatment, sachets containing the repellent were placed on the post to which the animals were tethered. The animals were kept stationary while the treatments were rotated after each experimental period. At the end of the experiment, the numbers of flies caught inside and outside the ring were recorded. Flies were also classified as fed or unfed based on the presence of fresh blood visible through the abdominal wall. The number of flies approaching the target (animals) with or without a repellent were estimated and statistically analysed. The feeding efficiency was expressed as the percentage of fed tsetse caught on the inside of the ring relative to the total catch from the inside of the ring (fed + unfed flies).

Table 1. Mean catch and % feeding efficiency of *Glossina pallidipes* on cattle with or without waterbuck repellent blend

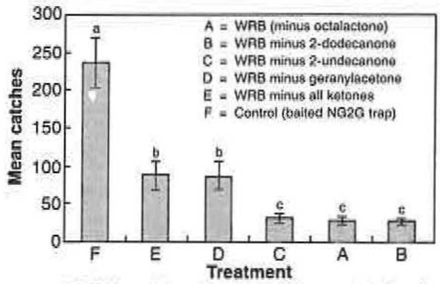
Treatment	Total catch (inside the screen)	Total catch (inside and outside the screen)	Total fed (inside the screen)	Feeding efficiency (%)
Ox alone	601 (± 23.0)[a]	1198 (± 6.4)[a]	330 (± 305)[a]	54.9
Ox + repellent	189 (± 6.2)[b]	277 (± 8.9)[b]	6 (± 0.5)[b]	3.2

Feeding efficiency is the total catch of fed flies from the inside of the ring of nets expressed as a proportion of the total (fed + unfed) catch.
Waterbuck repellent blend reduces feeding efficiency on cattle by >94%. Means followed by different letters are significantly different at $P < 0.05$ (F-Test) (N = 6).

The results (Table 1) showed that the waterbuck repellent blend significantly reduces the number of flies attracted to an ox (by more than 77%) and the proportion of tsetse that fed on an ox (from 54 to 3%, which represents a reduction of about 94%). These studies also indicate that the repellent blend affects both the long- and short-range behaviour of the flies towards a non-preferred/refractory animal.

2. *Further refinement of the 15-component waterbuck repellent blend*

The previous annual report gave details of the work undertaken to determine the key constituents of the waterbuck-specific compounds responsible for maximum repellency. These studies indicated some redundancy within multiple component classes of the 15-components blend. Thus, a blend made up of (i) any two of the lower carboxylic acid homologues (pentanoic, hexanoic and heptanoic acid), (ii) two of the three ketones (2-undecanone and geranylacetone), one of the two phenols (guaiacol), and δ-octalactone was able to reproduce the activity of the original blend.



NOTE: Means followed by the same letter are not significantly different ($P > 0.05$, LSD test).

Figure 1. Mean catches ± SE of *Glossina pallidipes* in baited NG2B traps treated with WRB (minus octalactone) with/without higher ketone homologues

Further Latin square field experiments undertaken with different blends in Nguruman indicated further redundancy within the multiple component classes of blend constituents. These studies have now shown that a 4-component blend (4-WRB) comprised of pentanoic acid, geranylacetone, guaiacol and octalactone is as effective as the original 15-component WRB blend. For example, of the three ketones, subtraction of geranylacetone led to a loss in repellency comparable to subtraction of all the three higher homologues, indicating that it is more important than 2-undecanone or 2-dodecanone (Figure 1).

3. *Comparative evaluation of the waterbuck repellent blend and the synthetic repellent*

Additional experiments were undertaken to determine the feeding efficiency of *G. pallidipes* on oxen treated with the synthetic repellent as described above. The results shown in Table 2 confirm *icipe*'s previous results that the synthetic repellent not only reduces the number of flies approaching an ox by > 80%, but also reduces feeding efficiency by > 80%.

Table 2. Mean catch and % feeding efficiency of *Glossina pallidipes* on cattle with or without synthetic repellent

Treatment	Total catch (inside the screen)	Total catch (inside and outside the screen)	Total fed (inside the screen)	Feeding efficiency (%)
Ox alone	445 (± 8.5)[a]	818 (± 23.5)[a]	120 (± 10.3)[a]	27.0
Ox + repellent	83 (± 4.5)[b]	154 (± 9.6)[b]	4 (± 0.2)[b]	4.8

Feeding efficiency is the catch of fed flies inside the ring of screens expressed as proportion of the total catch (fed + unfed). Synthetic repellent reduces the feeding efficiency on cattle by 82%. N = 6. Means followed by different letters are significantly different at $P < 0.05$, (F test).

Thus both the WRB and the synthetic repellent significantly reduce the number of *G. pallidipes* feeding on an ox. The WRB, however, was more effective in reducing the feeding efficiency (94% compared to about 80% with the synthetic repellent).

Augmentative effects

Table 3 shows the catches of *G. pallidipes* with baited NGU traps (cow urine + acetone) with the synthetic repellent or the 4-components waterbuck repellent blend. The results show that > 80% reduction in *G. pallidipes* catches was attained with the synthetic repellent or the waterbuck repellent ($F_{4,45} = 16.32$, $P < 0.0001$). A combination of the two repellents reduced fly catches by > 90%.

Table 3. The catch index of *Glossina pallidipes* from NG2B traps baited with cow urine (CU) and acetone (A), plus the synthetic repellent (SR), the waterbuck repellent blend (WRB) or a combination of the two

Treatment	n	Detransformed mean	Transformed mean ± SE	Catch P index	% reduction
Unbaited Trap	10	172.0942	2.236 ± 0.092	0.28[b]	72.2
Trap + CU + A (control)	10	616.5384	2.790 ± 0.071	1.0[a]	-
Trap + CU + A + SR	10	113.1188	2.054 ± 0.103	0.18[b]	81.7
Trap + CU + A + WRB	10	101.7962	2.008 ± 0.096	0.17[b]	83.7
Trap + CU + A + SR + WRB	10	57.4348	1.759 ± 0.063	0.09[c]	90.9

Note: The catch index is the detransformed mean catch expressed as a proportion of that from a standard CU + A- baited NG2B trap. n = number of replicates. Means followed by the same letters are not significantly different at $P < 0.05$ (F Test).

4. *Optimising the dispenser design*

Studies were undertaken to:

(i) Determine the release rates of the waterbuck-specific repellent compounds individually and in blends under laboratory conditions and under semi-field and field conditions.

(ii) Use the above knowledge to develop an appropriate dispenser for the WRB for on-host use.

The dispenser design was modelled on that used for the synthetic repellent. The upper part was a reservoir tube made of aluminium (or polypropylene), diameter 10 mm and length 10 cm,

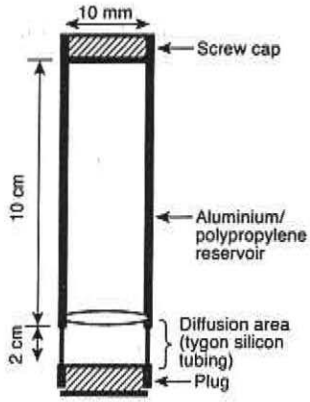


Figure 2. Diagram of the repellent dispenser

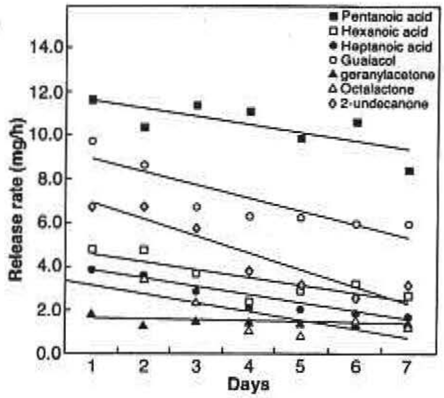


Figure 3. Release rates (mg/h) of the individual repellent compounds

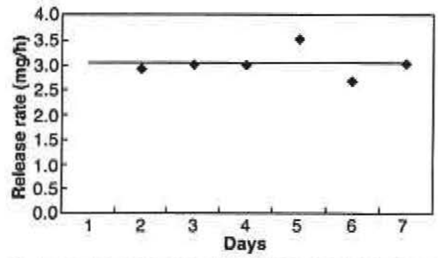


Figure 4. Release rate of the waterbuck repellent blend (WRB)

through which no significant diffusion of the repellent constituents takes place. The diffusion area was made from tygon silicon tubing of internal diameter 6.4 mm, outer diameter 9.6 mm, thickness 3.2 mm and variable length (Figure 2). The total surface area was determined by calculation to be 6.028 cm². The dispensing unit was closed with screw caps on both ends. The top end can be unscrewed for refilling.

From the initial results with individual constituents, an area of 6.028 cm² corresponding to 2 cm length of the diffusion area was used for further kinetic studies. At this specification, individual constituents were found to have diffusion rates varying from 1.45 ± 0.11 mg/hr for geranylacetone to 10.45 ± 0.44 mg/hr for pentanoic acid (Figure 3). A blend of the seven constituents in equal proportion was found to have constant release rate of 3.17 ± 0.12 mg/hr (Figure 4). No significant difference was found in the release rates of the dispenser placed in the sun and shade.

Based on the data collected so far, the metal propylene-tygon silicon tubing dispenser prototype can be effectively used to dispense the waterbuck repellent blend at zero-order kinetics. Two further optimisation steps need to be undertaken:

1. Determine the release rate of the blend that provides optimum protection to cattle in the field; and
2. Determine the composition of the blend in the reservoir that provides the desired release rates of individual constituents in the blend.

Output

Tsetse repellent technology publications

Saini R. K. (2004a) New technologies for tsetse control—Development of repellent collars. Agfax Resource Pack (http://www.agfax.net/). WREN Media.

Saini R. K. (2004b) Repellents: A harmonious approach, pp. 32–39. In *Recent Advances in Livestock Keeper-based Tsetse Control: The Way Forward* (Edited by S. Parrott and G. Ink). Pragat Offset Pvt Ltd and Sue Hainsworth Publishing UK.

Conferences attended

4th International Course on Trypanosomes (ICAT) sponsored by World Health Organization (WHO), International Atomic Energy Agency (IAEA), Medicines Sans Frontieres (MSF) and

Association Against Trypanosomiasis in Africa (ATA), 10–28 October 2005, Tunis, Tunisia. Attended by: R. K. Saini.

7th Conference of Ministers Responsible for Animal Resources, 31 October–4 November 2005 Kigali, Rwanda. Attended by: R. K. Saini.

International Workshop on "A Time to Heal, Cracking Africa's Killer Disease," organised by the Bill & Melinda Gates Foundation, Ford Foundation, Biovision Foundation, *icipe*, ILRI and DAAD, 21–24 March 2005, Nairobi, Kenya. Attended by: R. K. Saini.

28th meeting of the International Scientific Council for Trypanosomiasis Research and Control (ISCTRC), 26–30 September 2005, Addis Ababa, Ethiopia. Attended by: R. K. Saini.

Project proposals

Facilitating the up-scaling and uptake of the tsetse repellent technology: A key component of integrated vector and disease management for improved livestock health and productivity (submitted to IFAD).

Large scale validation trials of repellent-based tactics and their adaptation to the needs and circumstances of the target livestock keepers including pastoralists (submitted to IFAD for bridging funds).

Linking livestock and crops for health and wealth submitted to Wellcome Trust.

Capacity building

PhD student

M. Bett (Kenya) Identification of repellents from non-preferred hosts of tsetse for integrated management of tsetse. Moi University, Eldoret, Kenya (2000, finalising thesis).

MSc student

P. S. Musyoki (Kenya) Optimising the waterbuck repellent dispenser". University of Nairobi (ongoing).

Livestock Farmers' Perception and Epidemiology of Bovine Trypanosomosis in an Endemic Area of Kwale District, Kenya

Objective

Determine tsetse density, disease incidence and suitability of the area for tsetse and trypanosomosis control, based on repellents and bait technology.

Participating scientists and student: *S. O. Ohaga, R. K. Saini, A. Hassanali, E. D. Kokwaro[1], I. O. Ndiege[1]*

Assisted by: *J. A. Andoke, P. N. Muasa, R. O. Tumba*

Donor: *International Fund for Agricultural Development, German Academic Exchange Service*

Collaborators: *[1]Kenyatta University (Kenya), Kenya Veterinary Department, Veterinary Investigation Laboratories, Kenya*

Collaborating department: *Behavioural and Chemical Ecology Department*

Work in progress

1. Determination of the prevalence of trypanosomosis in cattle and tsetse populations in Shimba Hills, Kenya

Development of new technologies without involving the intended users, and without an adequate understanding of their farming systems and constraints has been blamed for poor adoption of new improved technologies. The project area, Shimba Hills, has been shown to have high trypanosomosis prevalence rates; however, information on the area's suitability for field trials, current animal health constraints, management practices and the relative importance of trypanosomosis were not clearly available. This cross-sectional study was conducted to determine the prevalence of trypanosomosis in cattle and tsetse populations in Shimba Hills. Participatory Rural Appraisal (PRA) was used to provide an understanding of the local livestock farming systems, disease constraints and farmers' decision-making process with respect to current tsetse and trypanosomosis control. The information was used primarily to determine the suitability of the area for the 'push-pull' trials and the relevance of the strategy for the area. This bottom-top approach is useful in planning disease and vector control strategies which take into account the end users' cultural values, socio-ethno practices and expertise.

Study area

Shimba Hills is located in Kwale District of Kenya (latitude 4°20′ S and longitude 39°31′ E in the coastal lowlands agroecological zones 2–4). Vegetation ranges from palm, pine and mango trees to scattered shrubs. The area receives poorly distributed and unreliable rainfall averaging 500–900 mm per year. The mean annual minimum and maximum temperatures are 24 and 36 °C, respectively. The area has a variety of wild game like elephant, buffalo, warthog and bush pig. Although the area is suitable for mixed farming, limiting factors such as high evapo-transpiration rates, unreliable rainfall, human–wildlife conflict and tsetse infestation make this difficult.

Study population

Mijikenda and Kamba communities are the main inhabitants of the area. They mostly engage in horticultural, subsistence and livestock production. The surveyed households border Shimba Hills National Reserve (SHNR) and fall in Kubo Division of Kwale District. SHNR covers > 90% of the total land surface area of the division and hence the settlements neighbouring the Reserve were targeted. All the 5 administrative locations (Mangawani, Mwaluphamba, Mkongani, Lukore and Mwaluvanga) were included in the survey. From each location, administrative sub-locations < 5 km from the SHNR fence were selected.

Livestock farmers' interviews

The survey was carried out between February–August 2004. A Participatory Rural Appraisal (PRA) toolkit comprising of semi-structured questionnaires and interviews was used. The interviews focused on general livestock and crop production; constraints to livestock production; farmers' descriptions of the local cattle diseases experienced and the management of herds; treatment given to the animals and the reasons for giving it and current tsetse and trypanosomosis control methods.

Tsetse monitoring and diagnosing of trypanosomosis in cattle

Tsetse populations were monitored by five baited (acetone + cow urine) NG2G traps set randomly in each sub-location in a variety of tsetse habitats based on vegetation. Traps were emptied after five days and caught flies sorted according to species and sex.

Selected cattle were screened for the presence of trypanosomal infections by buffy coat phase-contrast technique.

Household information

The survey was undertaken in 13 of the 17 sub-locations in Kubo Division that met inclusion criteria (Table 1). A total of 132 farmers were interviewed. Majority of the respondents 122 (92.4%) were males with 10 (7.6%) females. The level of literacy was intermediate with 62.9% of the respondents having attained up to primary level and beyond. Crop production was the main economic activity with almost all farmers cultivating commercial horticultural crops such as citrus fruits, mangoes, cashew-nuts, coconut and passion-fruit. Maize, beans and cassava were cultivated for subsistence. Livestock kept included cattle, sheep, goats and poultry. Most respondents kept local livestock breeds and the average cattle herd size was four per respondent.

Table 1. Average distance (± SE) of each sub-location from Shimba Hills National Reserve (SHNR), number of livestock owners and cattle head count in Shimba Hills

Location	Sub-location	Mean distance (km) ± SE	No. of farmers	No. of cattle
Kinondo	Kinondo	0.29 ± 0.08	7	83
Lukore	Lukore 11	0.50 ± 0.14	11	64
Mwaluphamba	Mlafyeni	0.60 ± 0.13	8	73
Mwaluvanga	Kichakasimba	0.80 ± 0.12	13	71
Mangawani	Lukore 1	1.00 ± 0.18	14	65
Majimboni	Makobe	1.00 ± 0.00	16	50
Majimboni	Msulwa	1.18 ± 0.25	13	78
Mwaluphamba	Kizibe	1.66 ± 0.13	10	63
Majimboni	Majimboni	1.62 ± 0.14	11	48
Mangawani	Magwasheni	1.96 ± 0.37	11	78
Mwaluphamba	Kinango	3.42 ± 1.06	6	56
Mkongani	Mkomba	4.80 ± 0.00	7	75
Mkongani	Tiribe	5.00 ± 0.20	5	75
Total			**132**	**879**

Livestock production constraints

Animal diseases were ranked highest among constraints associated with cattle production. This was followed by human–wildlife conflicts, drought, lack of institutional support to control diseases, poor infrastructure, lack of transport and marketing. Six major cattle diseases described by respondents were: trypanosomosis, East Coast fever, anaplasmosis, helminthosis, anthrax, and foot and mouth disease. Trypanosomosis was identified as the most important disease by 110 (83.33%) respondents, followed by tick-borne diseases (East Coast fever and anaplasmosis). Pneumonia and rinderpest were also cited by some farmers.

Knowledge of trypanosomosis clinical diagnosis

For trypanosomosis, 14 clinical signs were recognised by most farmers. These included starring coat (76.52%), lacrimation (72.73%), weight loss (65.15%) and swollen lymph nodes (63.64%). Other symptoms included excessive salivation, nasal discharge and general weakness.

Knowledge of cattle trypanosomosis aetiology

Seventy-one respondents (53.79%) were aware of the transmission of trypanosomosis by tsetse flies, while 30 (22.73%) had no idea of what caused the disease. Some associated trypanosomosis with tick bites, worms, weather, grazing hours and watering at certain rivers or streams. Tabanidae and *Stomoxys* spp. that also transmit trypanosomes were recognised by 51.52% of the respondents.

Farmers' animal health management practices

Overall, trypanocides (91.67%), followed by antihelminthics (61.36%) and antibiotics (59.85%), were the most commonly administered drugs in response to perceived cattle illness. Fifty-four (40.91%) and 21 (15.91%) of the respondents used multivitamins and traditional medicinal plants, respectively, to treat their animals.

Tsetse and trypanosomosis control techniques

Nineteen (14.39%) and 18 (13.64%) of the respondents practised traditional methods of tsetse control by avoiding grazing in high risk areas such as woodland and bushes and burning of bushes/pastures. Pour-on (Spot-on®) was the most commonly used treatment for ectoparasites. Forty-five respondents used a synthetic pyrethroid-based insecticide (Ectomin®) as hand spray wash, while only nine farmers (6.82%) used traps/targets for control.

Relative tsetse densities

The density of tsetse species in all the sub-locations is summarised in (Table 2). *Glossina pallidipes, G. brevipalpis* and *G. austeni* were caught in traps during the survey. *Glossina pallidipes* found in all sub-locations was the most abundant. *Glossina brevipalpis* and *G. austeni* were caught in low numbers.

Table 2. Relative tsetse density (flies/trap/day) in sub-locations of Shimba Hills National Reserve (SHNR)

Sub-location	Mean distance (km) from SHNR	*Glossina pallidipes*	*G. brevipalpis*	*G. austeni*	Tabanids
Kinondo	0.29	0.52	0.12	0.32	0.00
Lukore 11	0.50	1.56	0.28	0.00	0.12
Mlafyeni	0.60	54.32	0.64	0.00	0.48
Kichakasimba	0.80	147.6	0.76	0.32	0.16
Makobe	1.00	1.16	0.00	0.00	0.04
Lukore 1	1.00	14.72	0.24	0.68	0.24
Msulwa	1.18	3.60	0.20	0.00	0.00
Majimboni	1.62	2.8	0.12	0.04	0.16
Kizibe	1.66	1.84	0.00	0.00	0.24
Magwasheni	1.96	1.76	0.08	0.00	0.52
Kinango	3.42	4.40	1.00	0.20	0.28
Mkomba	4.80	0.12	0.00	0.00	0.04
Tiribe	5.00	0.04	0.00	0.00	0.08

Prevalence of cattle trypanosomosis

Blood samples from 879 animals, consisting of 712 (81%) males and 167 (19%) females were examined. Trypanosomal infections were diagnosed in 160 (18.20%) animals (Table 3). Infections were due to *Trypanosoma congolense* 96 (60%) and *T. vivax* 64 (40%).

Packed cell volume (PCV)

The mean PCV varied between 23.00–28.88% and 25.54–32.67% in trypanosome-positive and negative cattle, respectively (Table 4). The average PCV of parasitologically-negative cattle (29.58 ± 0.91%) was significantly higher ($F_{1,18}$ = 8.61, P < 0.001) than that of the positive ones (25.68 ±

1.65%). PCV is an indicator of the disease status of a trypanosome-infected animal. The average cattle herd PCV decreases with an increase in trypanosomosis prevalence and vice-versa. The results indicate that tsetse and trypanosomosis is a major hindrance to livestock production in the area. Consequently, this survey found push-pull technique relevant to the area. Therefore, eight suitable sites that met inclusion criteria were selected for the push-pull trials.

Table 3. Prevalence of trypanosomosis in cattle in sub-locations of Shimba Hills

Sub-location	No. of cattle screened	No. positive	% infection	*Trypanosoma congolense* (%)	*T. vivax* (%)
Kinondo	83	5	06.20	40.00	60.00
Lukore 11	64	15	23.44	13.33	86.67
Mlafyeni	73	13	17.81	30.77	69.23
Kichakasimba	71	18	25.35	66.67	33.33
Makobe	50	11	22.00	9.09	90.91
Lukore 1	65	11	16.92	72.73	27.27
Msulwa	78	18	23.08	83.33	16.67
Majimboni	48	11	22.92	63.64	36.36
Kizibe	63	16	25.40	62.50	37.50
Magwasheni	78	18	23.08	88.89	11.11
Kinango	56	11	19.64	90.91	9.09
Mkomba	75	13	17.33	69.23	30.77
Tiribe	75	0	0.00	0.00	0.00

Output

Conferences attended

DAAD Higher Education Forum on Capacity Building and Development Research in Sub-Saharan Africa and the Summer School on Resource Use, Agriculture, Environment and Rural Development for Sub-Saharan African Countries, 24 September–7 October 2005, Giessen/Bonn, Germany. Conducted by Centre for Development Research (ZEF) at the University of Bonn, the Department of Regional Planning at the University of Giessen and the German Academic Exchange Service (DAAD). Attended by: S. Ohaga.

Table 4. Mean packed cell volume ± SE (%) of trypanosomosis positive and negative cattle in sub-locations of Shimba Hills

Sub-location	Mean PCV ± SE positive cattle (n)	Mean PCV ± SE negative cattle (n)
Kinondo	23.00 ± 0.09 (5)	30.16 ± 1.47 (78)
Lukore 11	23.81 ± 0.92 (15)	31.81 ± 0.44 (49)
Mlafyeni	25.42 ± 1.66 (13)	25.54 ± 3.09 (60)
Kichakasimba	25.42 ± 1.16 (18)	32.67 ± 0.09 (53)
Makobe	22.33 ± 1.08 (11)	29.98 ± 0.84 (39)
Lukore 1	25.55 ± 1.01 (11)	26.68 ± 1.11 (55)
Msulwa	26.14 ± 4.47 (18)	31.43 ± 1.34 (60)
Majimboni	23.96 ± 2.78 (11)	25.75 ± 0.01 (37)
Kizibe	25.95 ± 1.93 (16)	31.68 ± 1.49 (47)
Magwasheni	29.50 ± 1.74 (18)	31.54 ± 0.07 (60)
Kinango	28.88 ± 1.12 (11)	29.00 ± 1.17 (45)
Mkomba	28.16 ± 1.89 (13)	28.54 ± 0.14 (62)
Tiribe	-	29.78 ± 0.52 (75)

The 1st National Biological Postgraduate Scientific Conference, 2–5 August 2005, Kenyatta University, Nairobi, Kenya. Attended by: S. O. Ohaga.

Project proposal

Tsetse flies and the control of African sleeping sickness submitted to EU Inco.

Capacity building

PhD student

S. Ohaga (Kenya) Optimisation of semio-chemicals for savannah tsetse control in 'pull', 'push' and 'push-pull' tactics in Kenya. Kenyatta University, Kenya (2003, ongoing).

Preliminary Evaluation of Repellents and Baits in 'Push-pull' Tactic for Tsetse and Trypanosomosis Suppression

Objective

Evaluate the efficacy of the 'push-pull' tactic in enhancing tsetse suppression rates and disease levels using on-host repellents to 'push' and baited traps to 'pull' the flies.

Participating scientists and student: *S. O. Ohaga, R. K. Saini, A. Hassanali, E. D. Kokwaro[1], I. O. Ndiege[1]*

Assisted by: *J. A. Andoke, P. Muasa, R. Tumba*

Donors: *International Fund for Agricultural Development, German Academic Exchange Service*

Collaborators: *[1]Kenyatta University (Kenya); Kenya Veterinary Department, Veterinary Investigation Laboratories, Kenya*

Collaborating department: *Behavioural and Chemical Ecology Department*

Work in progress

1. Evaluation of the efficacy of the 'push-pull' tactic at the Kenya coast

The objective here has been to evaluate how tsetse repellents can be integrated with the existing control techniques to design improved integrated control strategies that rely less on drugs. Of particular interest is the 'push-pull' strategy that uses repellents (to 'push' flies) and baited traps/ targets (to 'pull' flies) to reduce tsetse suppression rates and disease levels. A variant of this may involve the use of a proportion of cattle with pour-on insecticides as live baits. This trial evaluated the efficacy of the 'push-pull' tactic at the Kenya coast.

This study was conducted in Shimba Hills, Kwale District of Kenya. *(See previous section for details.)*

The eight trial sites selected border the Shimba Hills National Reserve (SHNR) and include Mangawani, Mlafyeni, Mauya, Msulwa, Lukore, Kizibe, Katangini and Tsangatamu. These sites were selected based on the following criteria: (i) they were at least 10 km away from the neighbouring site, (ii) about 10 km^2 in area, (iii) < 5 km from SHNR, and (iv) easily accessible during the rainy season and with high tsetse and trypanosomosis challenge. Farmers' willingness to participate in the trials and commitment to provide sufficient cattle for at least 12 months was also taken into consideration.

The synthetic repellent identified by *icipe* and supplied by Ecologia e Tecnologia (EMEL T s.r.l), Italy and/or synthesised in BCED laboratories (*icipe*) was used in the trial. The repellent dispensers were as described in the previous *icipe* Annual Report Highlights (2004/5). The dispensers were serviced monthly and their physical conditions recorded.

The eight sites were randomised into four treatment regimes as shown in Table 1. Prior to the start of the trial, all animals were blanket treated with diminazene diaceturate (Veriben®) at doses of 3.5 mg/kg, by intramuscular injection, body weight being estimated by weighing bands. This is a curative treatment with no lasting protection against reinfection. The trial was conducted for 10 months (December 2004 to September 2005).

Trypanosome infections were monitored monthly by dark-ground buffy coat phase-contrast technique.

In November 2004, a total of 163 baited (acetone + cow urine) NG2G traps were deployed in 'pull' and 'push-pull' sites at intervals of 250 m (4 per km^2), in lines 1–1.5 km apart. In Msulwa, Mauya, Tsangatamu and Katangini, 39, 41, 41 and 42 traps, respectively, were deployed. Tsetse populations were monitored monthly over the entire period by five NG2G traps per site. Trapping was carried out for five consecutive days per month in marked positions. Cages from the traps were emptied daily; flies were sorted according to species and sex.

Table 1. Summary of the randomised four treatment regimes

Treatment	Sites	No. of cattle	No. of traps
Cattle with repellent dispenser collars and the area in which they graze having traps (push-pull)	Msulwa Mauya	69 80	39 41
Unprotected cattle grazing in an area with baited traps (pull)	Katangini Tsangatamu	97 80	41 42
Cattle protected with synthetic repellent dispenser collars and grazing in an area without traps (push)	Mlafyeni Mangawani	86 126	- -
Unprotected cattle grazing in an area without traps (control)	Lukore Kizibe	114 81	- -
Total		**733**	**163**

Tsetse populations

Figure 1 shows the mean monthly relative density of the flies over the trial period and Figure 2 shows the corresponding percentage reduction in the four treatment regimes. 'Push-pull' and 'pull' treatments were significantly different ($\chi^2 = 6.40$; df = 1; $P < 0.01$) from controls and 'push' (Figure 2). With 'push-pull', the overall percentage reduction in fly density was about 77% compared to 58% with traps alone (pull) (Figure 3). However, these were not significantly different. (This can be attributed to nearly 50% of the traps not working due to either theft or vandalism and to the rapid fading of the cloth material.) As expected, very minimal fly reduction was observed with repellents alone ('push').

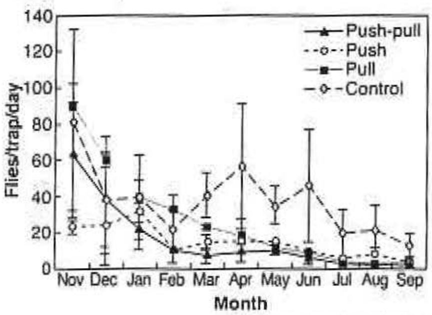


Figure 1. Mean (± SE) monthly relative density (flies/trap/day) of *Glossina pallidipes* at Shimba Hills for the period November 2004 to September 2005

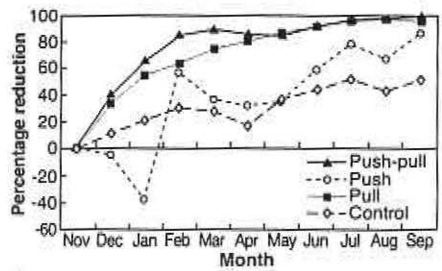


Figure 2. Monthly percentage tsetse population density reduction at Shimba Hills for the period November 2004 to September 2005

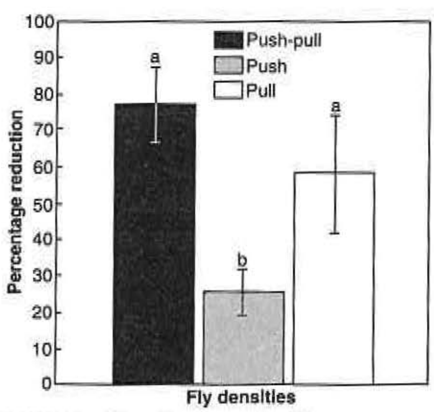


Figure 3. Overall mean (± SE) percentage reduction in fly density after 10 months of trial. Means followed by the same letter are not significantly different ($P > 0.05$, LSD test)

Disease incidence

Figure 4 shows the monthly mean disease incidence, while Figure 5 shows the corresponding percentage reduction in trypanosomosis over the trial period. The results clearly confirm preliminary results of trials in Nguruman that the synthetic repellents can provide substantial protection to cattle against trypanosomosis. Similarly, in sites with traps alone ('pull'), significant reduction ($\chi^2 = 65.39$; df = 1; $P < 0.0001$) in trypanosomosis incidence was obtained (Figure 6). 'Push-pull' treatment gave significantly higher reduction in disease incidence compared to 'pull' ($\chi^2 = 23.37$; df = 1; $P < 0.0001$) (Figure 6). (These results were, however, affected by loss, vandalism and rapid fading of trap cloth materials.) In addition, during the trial, about 20% of the cattle were not adequately protected with the repellents due to breakage, leakage and loss of prototype dispensers.

These experiments indicate that 'push-pull' may be a more effective way of reducing tsetse population and trypanosomosis incidence compared to 'push' or 'pull'. Further large-scale trials are in progress to confirm this. In addition, assessment of livestock farmers' perceptions on the efficacy of repellents and baits for vector and disease control is in progress.

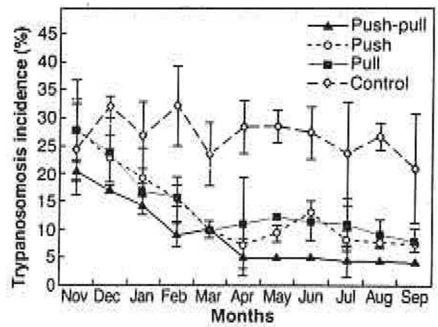


Figure 4. Mean (± SE) monthly trypanosomal incidence (%) in cattle at Shimba Hills for the period November 2004 to September 2005

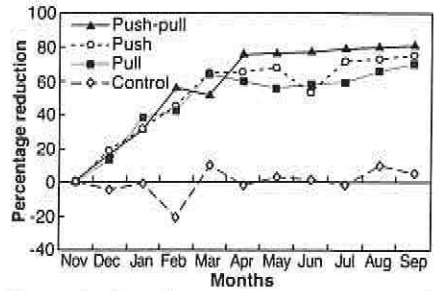


Figure 5. Monthly percentage trypanosomal incidence reduction in cattle at Shimba Hills for the period November 2004 to September 2005

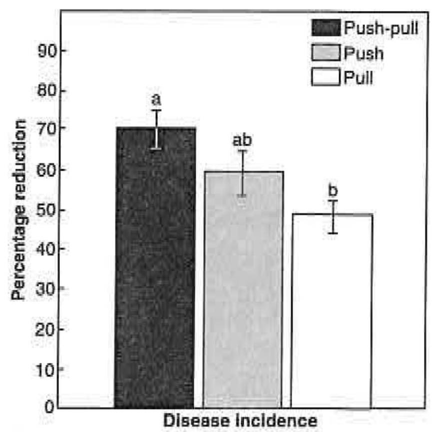


Figure 6. Overall mean (± SE) percentage reduction in disease incidence after 10 months of trial. Means followed by the same letter are not significantly different ($P > 0.05$, LSD test)

Capacity building

PhD student

S. Ohaga (Kenya) Optimisation of semio-chemicals for savannah tsetse control in 'pull', 'push' and 'push-pull' tactics in Kenya. Kenyatta University, Kenya (2003, ongoing).

Toxicological Assessment of a Tsetse Repellent Developed for Smallholder Indigenous Communities of Sub-Saharan Africa on the Health of Exposed Animals

Background

Before the repellent technology is adopted for use, there is need to generate adequate safety data to support its widespread use. This study was therefore undertaken to generate toxicological data of the repellent in exposed animals. (This is also a standard requirement for the registration of the product for use in animal husbandry.)

Objective

The toxic effects of the synthetic repellent on the health of exposed animals were investigated by determining:

(i) signs of acute toxicity, median lethal dose, and undertaking dermal and ocular irritation tests in laboratory animals;
(ii) chronic effects of exposure of the repellent on haematological and biochemical parameters in goats;
(iii) effects of the repellent on weight gain in exposed goats; and
(iv) histopathological effects of the repellent in goats after nine months of continuous exposure.

Participating scientists and student: *P. Munyua[1] (MSc student), J. M. Gathuma[1], J. M. Mbaria[1], F. M. Njeruh[1], R. K. Saini*

Donor: *The International Fund for Agricultural Development*

Collaborators: *[1]Department of Public Health Pharmacology & Toxicology, University of Nairobi*

Work in progress

1. *Evaluation of effects of a tsetse repellent on the haematological, biochemical and post-mortem changes in goats*

To evaluate the effects of the repellent on the haematological, biochemical and post-mortem changes in goats, 45 goats were randomly assigned to three treatment regimes as follows:

(i) exposure to a high dose of the repellent (4 mg/hr),
(ii) exposure to a low dose of the repellent (2 mg/hr), and
(iii) a control group with no exposure to the repellent.

During the 9-month study, the three groups of goats were physically separated to avoid cross-exposure to the volatile repellent, but were put under similar environmental, dietary and management conditions. The repellent was administered in specially made dispensers tied around the neck of the goats similar to those used for cattle under field conditions. Animals in the control group received one dispenser each with liquid paraffin. Levels of three liver enzymes [alkaline phosphatase (ALP); gamma-glutamyl-transferase (GGT) and aspartate aminotransferase (AST)], the total red blood cell counts (RBC), the total white blood cell counts (WBC) and the differential leucocyte counts in goats exposed to the repellent were monitored monthly. Standard toxicological methods and haematological and biochemical analyses were also used to determine the intraperitoneal LD_{50} in mice and dermal and ocular irritation in rabbits. At the end of the study two animals from each treatment group were sacrificed for gross post-mortem examination.

Dermal irritation tests performed on rabbits indicated that the repellent is not a primary skin irritant (primary irritation index, PII = 2.4). As is expected with most phenolic compounds, instillation of the repellent to the eyes of rabbits caused eye irritation affecting the cornea, iris and conjunctiva. The 24-hour median lethal dose (LD_{50}) after intraperitoneal injection of the synthetic repellent in mice was 40.2 mg/kg body weight (Table 1). Exposure of the animals (goats) to low (2 mg/hr) or high doses (4 mg/hr) of the vapours of the repellent through repellent collars as with cattle, over a nine-month experimental period indicated no adverse effects on the health of the exposed animals. The three liver enzymes [(gamma glutamyl transpeptidase (GGT), alkaline phosphatase (ALP) and aspartate aminotransferase (AST)], monitored monthly over the experimental period, showed no significant differences between the treated and the control animals and were within the normal reference values for the treated and the control animals and for the species (Figure 1). Similarly, haematological parameters—red blood cell count (RBC) and white blood cell count (WBC) (Figure 2), granulocytes and lymphocytes counts (Figure 3)—were also within normal ranges for the species and did not differ between control and treated animals. The synthetic repellent also did not affect the weight of the treated animals (Figure 4). Histopathological analysis of the treated and control animals át the end of the nine-month trial also showed no adverse effects of the synthetic repellent on exposed animals.

Table 1. Percentage mortalities in mice after intraperitoneal injection with the synthetic repellent at the end of 24 hours and calculation of LD_{50}

Dose (mg/kg body weight)	Log. dose	No. died	No. survived	Accumulated deaths/survival: Died	Survived	Total	Percentage mortality
30	1.4771	0	10	0	25	25	0.0
35	1.5440	8	2	8	15	23	34.8
40	1.6020	4	6	12	13	25	48.0
45	1.6532	7	3	19	7	26	73.1
50	1.6989	9	1	28	4	32	87.5
55	1.7403	9	1	37	3	40	92.5
60	1.7781	8	2	45	2	47	95.7
65	1.8129	10	0	55	0	55	100.0

From the table, the 24-hour intraperitoneal LD_{50} for the repellent was determined to be 40.2-mg/kg body weight.

The synthetic repellent can thus be used to protect livestock as our studies indicated no adverse effects on exposed animals. However, since the repellent is a mild skin irritant and caused eye irritation it should be handled with care.

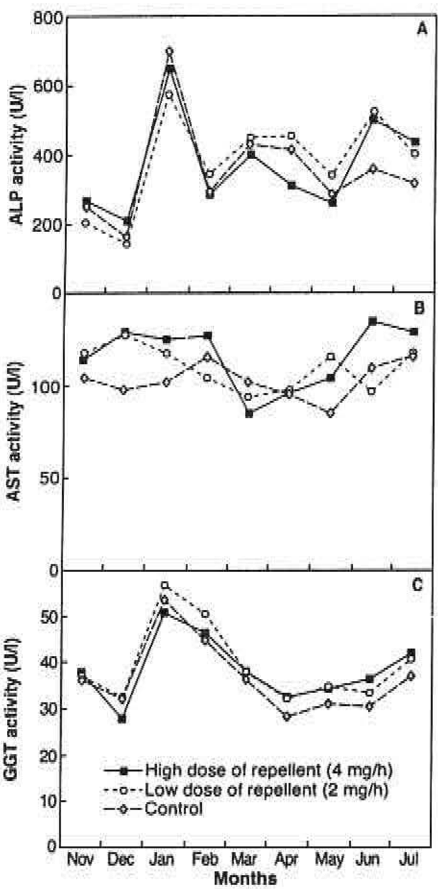


Figure 1. Mean monthly levels of three liver enzymes: (A) alkaline phosphatase (ref value 93–387 U/l), (B) aspartate aminotransferase (ref. value 167–513 U/l) and (C) gamma glutamyl transpeptidase (ref. value 20–56 U/l) in goats exposed to the synthetic repellent (N = 15)

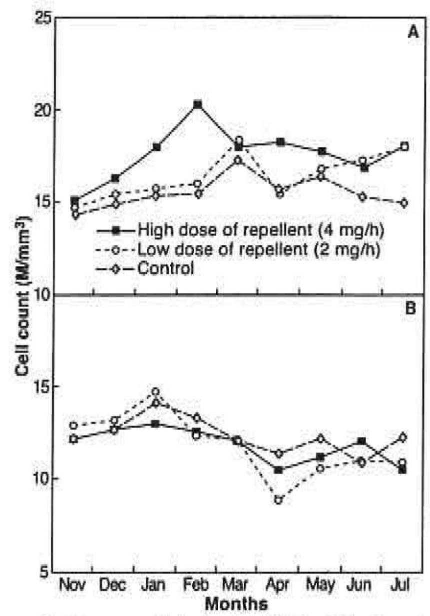


Figure 2. Mean monthly levels of (A) white blood cells (WBC) (ref value 4–13 x 10^9/l) and (B) red blood cells (RBC) (ref value 8–18 x 10^{12}/l) in goats exposed to the synthetic repellent (N = 15)

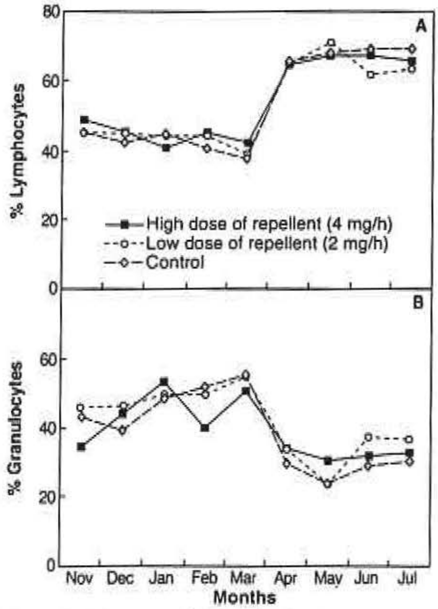


Figure 3. Mean monthly levels of (A) lymphocytes (ref. value 50–70%) and (B) granulocytes (ref. value 30–48%) in goats exposed to the synthetic repellent (N = 15)

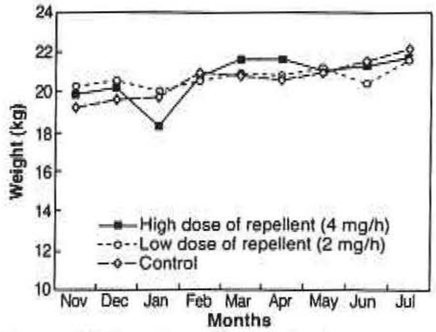


Figure 4. Effect of repellent on body weight in goats exposed to the synthetic repellent (N = 15)

Capacity building

MSc student

P. Munyua (Kenya) Toxicological assessment of a tsetse repellent developed for smallholder indigenous communities of sub-Saharan Africa, on the health of exposed animals". University of Nairobi (ongoing).

Characterisation of Olfactory Receptor Proteins Associated with Attractancy/Repellency in Savanna Species of Tsetse Flies

Objectives

This Molecular Biology and Biotechnology Department project aims at applying emerging techniques in vector molecular biology and functional/comparative genomics to identify and characterise olfactory receptor proteins in tsetse fly associated with attractancy and repellency. The objectives are to develop and sequence an antennal cDNA library of *Glossina pallidipes*; identify candidate odourant binding proteins (OBPs) homologues by computational approaches; express a subset of OBPs genes in baculovirus expression system and undertake functional and binding assay to determine the relative affinity and specificity of selected attractants and repellents.

Participating scientists and student: *S. G. Nyanjom, P. Lomo[1], D. Masiga, A. Hassanali*

Donors: *UNICEF/UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases, Netherlands Programme for Cooperation with International Institutions*

Collaborators: *[1]Jomo Kenyatta University of Agriculture and Technology; the Wellcome Trust Sanger Institute, Cambridge UK; South African National Bioinformatics Institute*

Collaborating department: *Behavioural and Chemical Ecology Department*

Work in progress

Antennal cDNA library was constructed from both male and female *G. pallidipes*. The library was plated to approximately 20 plaques per plate which were eluted, screened using vector specific primers and purified for sequencing. The double strand complementary DNA for *Glossina pallidipes* female and male had a band smear between 500 and 3000 base pairs (Figure 1) while the screened colonies from eluted plaques amplified a band size of approximately 500 base pairs (Figure 2).

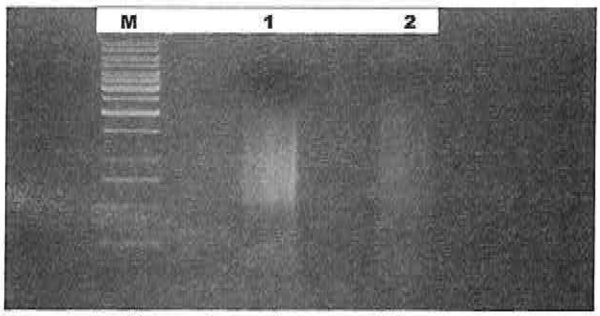


Figure 1. Double strand complementary DNA agarose gel analysis for *Glossina pallidipes* female (1) and male (2). M = 1 kb molecular marker

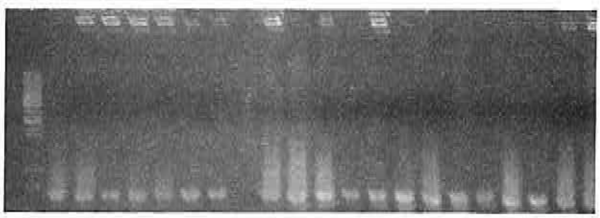


Figure 2. Screened colonies from *Glossina pallidipes* male library

Current ongoing work involves analysing the generated sequences by Stand Alone Bioinformatics Analysis Tool then blasting against insects' olfactory receptor protein database from NCBI. The generated sequences will also be assembled into contigs to be used for searching GenBank Non-redundant Protein Database and Conserved Domains Database (CDD), which includes all pfam and SMART protein domains.

Capacity building

PhD student

S. G. Nyanjom (Kenya) Characterisation of olfactory receptor proteins associated with attractancy/repellency in savannah species of tsetse flies. Jomo Kenyatta University of Agriculture and Technology (2005, ongoing).

Expression Profiles of Glossina Proteolytic Lectin Gene in Tsetse Midguts

Background, approach and objectives

Tsetse flies are obligate blood-feeding arthropods that transmit African trypanosomes, which cause trypanosomosis in man and livestock. The life cycle of trypanosomes (genus: *Trypanosoma*), in its invertebrate vector begins when the tsetse fly feeds on an infected mammalian host. During the life cycle of trypanosomes in the vector a crucial event is the establishment of tsetse midgut infection, which involves transformation of bloodstream-form trypanosomes into procyclic forms. This process is mediated by a wide variety of factors. Tsetse midgut factors involved include lectins, trypsin-like molecules, lysins and lectin–trypsin complex. A *Glossina* proteolytic lectin gene (*Gpl*) that encodes for a protein with both lectin and trypsin activities in *Glossina fuscipes fuscipes* was recently isolated in this laboratory. *Glossina* proteolytic lectin induces transformation of bloodstream-form trypanosomes to procyclic forms *in vitro*. The gene is induced by the bloodmeal and expressed in members of *Glossina* species but no homologues have been found in other haematophagous insects. This suggests that it may be playing an important role in the interactions between tsetse and the trypanosomes and hence having an effect on the vectorial capacity of tsetse.

The present study was undertaken by the Molecular Biology and Biotechnology Department to gain insight into the effect of trypanosome parasites on the expression of *Gpl* gene and how its expression compares in different *Glossina* species. Quantitative competitive reverse transcriptase polymerase chain reaction (QC-RT-PCR) was used to assess the expression levels of *Gpl* gene in infected and uninfected *G. f. fuscipes* at 24, 48 and 72 h post feeding. Expression levels were also compared in *G. pallidipes* and *G. f. fuscipes* at 0, 24, 48 and 72 h post feeding.

Participating scientists and student: *E. Osir, L. Abubakar, B. Mbatia*

Donor: *UNICEF/UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases*

Collaborator: *University of Nairobi*

Work in progress

Expression levels of *Gpl* gene remained high throughout the digestion cycle following both infective and uninfective bloodmeal. However, the expression was parasite responsive, with the expression being lower in trypanosome infected *G. f. fuscipes* ($P < 0.05$). Down-regulation of *Gpl* gene expression by trypanosomes might be a possible mechanism used by the parasites to survive and establish themselves in the hostile midgut environment. Expression of *Gpl* gene varied significantly in *G. pallidipes* and *G. f. fuscipes* with *G. pallidipes* expressing lower levels of the transcripts ($P < 0.05$). In both species a linear increase in the gene expression was observed with teneral flies expressing low transcript levels. This trend suggests regulation at transcription level. Higher *Gpl* gene transcript levels in *G. f. fuscipes* may be among the factors contributing to their refractoriness to trypanosome infection as opposed to the susceptible *G. pallidipes*.

Although several factors have been implicated in the successful transformation and establishment of trypanosomes in tsetse, down regulation of expression of *Gpl* gene in refractory *G. f. fuscipes* and the variation of its expression in susceptible (*G. pallidipes*) and refractory (*G. f. fuscipes*) tsetse flies suggest that there is an optimal concentration of *Gpl* required for the establishment of midgut infection. Trypanosomes could be playing a key role in the modulation of these levels, and therefore enhancing their own transmission.

Capacity building

MSc student

B. Mbatia (Kenya) Expression profiles of tsetse (*Glossina* sp.): *Glossina* proteolytic lectin (Gpl) gene. University of Nairobi, Kenya (2005, completed).

Studies on the Midgut Lectin Gene of Glossina austeni

Background

African trypanosomosis, a debilitating parasitic disease, takes a heavy toll on health and socioeconomic output of sub-Saharan Africa. The disease-causing agent, *Trypanosoma*, is transmitted from one vertebrate host to the next, in most cases, through the bite of tsetse (*Glossina*). There is now a search for more effective disease-containing measures to supplement the existing control methods. An important potential avenue is the reduction of tsetse's ability to transmit trypanosomes, which may come from a better understanding of the interplay between tsetse and trypanosomes.

Participating scientists and student: *E. Osir, G. Muluvi[1], J. Machuka[1], D. Amin*

Donor: *DAAD*

Collaborators: *[1]Kenyatta University, Kenya*

Work in progress

In this project by Molecular Biology and Biotechnology Department, a midgut lectin, implicated in tsetse–trypanosome interactions, from *Glossina austeni* was characterised. Following isolation and sequencing of the encoding gene, the recombinant protein was expressed (in *E. coli* and *Sf* 21 cells), purified and characterised biochemically (post-translational modification and interaction with D-glucosamine—an inhibitor of the protein). The effect of the protein on trypanosomes was also tested *in vitro*.

The baculovirus-expressed lectin was found in the medium of baculovirus-infected *Sf*-21 cell cultures, indicating that the tsetse fly-derived signal peptide was recognised and cleaved by the *Sf*-21 cells. The baculovirus-expressed protein also was glycosylated despite the absence of classical O-linked and N-linked sugar attachment motifs. Both the baculovirus- and bacterium-expressed lectin proteins were shown to agglutinate trypanosomes and rabbit red blood cells *in vitro*. This agglutination was strongly inhibited by D-glucosamine. D-Glucosamine also inhibited the action of the native and recombinant lectins on the chromogenic substrate Chromozym TRY. Interestingly, both baculovirus- and bacterium-expressed lectins showed no significant differences in terms of these activities, indicating that a sugar moiety is not essential for biological activity. These results lay a good basis for further studies on the *in vivo* activity of *Glossina* proteolytic lectin.

Output

Conferences attended

Africa Genome Initiative Conference held in Nairobi, Kenya, March 2005. Attended by: D. N. Amin, J. Machuka, G. Muluvi and E. Osir.

JOBIM (Journee ouvertes aux Biologie, Informatique et Mathematique) conference in Lyon-France from 4–8 July 2005. Attended by: D. Amin.

Capacity building

PhD student

D. N. Amin (Cameroon) Functional analysis of the midgut gene of *Glossina austeni*. Kenyatta University (2006, ongoing).

Mwea National Reserve Community-Based Tsetse Control

Background, approach and objectives

The Mwea National Reserve, covering an area of 42 km², is located in Mbeere District, Eastern Province and is jointly managed by Mbeere County Council and the Kenya Wildlife Service (KWS). The Reserve is surrounded by communities that carry out livestock keeping and farming for their livelihoods. Due to the proximity of the reserve to the settlements, there is conflict between human activities and the wild animals. The reserve is also regarded as a breeding ground for tsetse flies that not only transmit cattle trypanosomosis but are also a nuisance because they bite livestock and humans. To reduce the conservation–human conflict in the area, KWS approached *icipe* to assist in the introduction of the NGU tsetse trapping technology, which is simple and conservation friendly. In response to this request, a three-year community-based tsetse-trapping project was initiated in April 2003 to end in March 2006.

The objectives of this Technology Transfer Unit project are to promote community-based environmentally friendly tsetse control technologies and conservation-based income-generating enterprises for communities to contribute towards sustainable use of natural resources.

Community members were trained on how to make the NGU trap, trap deployment, servicing and maintenance in August 2003 by *icipe*'s Animal Health Division. The course graduates deployed traps within the reserve and established and managed barrier traps around the reserve from August 2003 onwards. Thereafter, monitoring of the tsetse fly population within and outside the reserve and frequent servicing of the traps was carried out.

A socioeconomic baseline study was conducted in 2003. Furthermore, baseline information on the status of cattle trypanosomosis in the project area was collected from October 2003 to October 2004.

Participating scientist: *B. Nyambo*
Assisted by: *J. K. Kariuki, J. A. Andoke, P. N. Muasa*
Donor: *Biovision Foundation of Switzerland*
Collaborators: *Kenya Wildlife Service, Mbeere County Council and farming communities in the environs of the Mwea National Reserve, Kenya*

Work in progress

Immediately after the training conducted in August 2003, 326 traps were deployed in the reserve at a density of 4 traps per km². In addition, a total of 161 barrier traps were deployed by the community around the National Reserve to prevent escaping tsetse reaching homesteads in the reserve neighbourhood.

The population trend within the Reserve and near homesteads at Reserve borders for the period August 2003 to September 2005 is summarised in Figures 1 and 2. Overall, there has been a tremendous reduction in the population of the flies within the Reserve, the source of flies that attack community livestock (Figure 1) and also in the population of flies reaching the homesteads (Figure 2).

Daily fly catch fluctuations as indicated by the SD bar lines were generally high throughout the trapping period (Figures 1 and 2).

The baseline study on the status of cattle trypanosomosis in the project area indicated that about 18% of the sampled cattle were infected. Infected animals were treated with Veriben®, one of the recommended drugs and recovered well within three months of treatment. Following these results, it was concluded that the drug could be used in the area for treatment of infected animals.

To generate income (part of which could be used to sustain tsetse trapping) and also to motivate the community to continue with trap servicing, training in modern beekeeping and wild silk farming

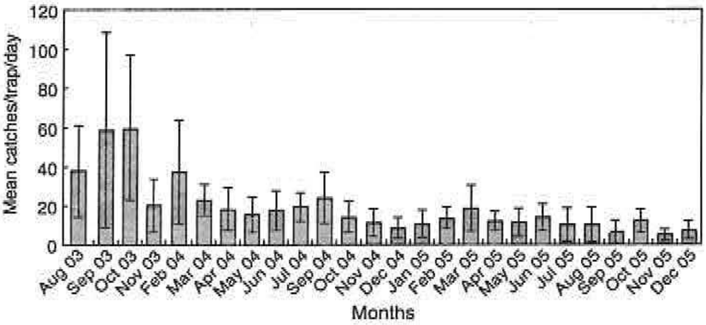


Figure 1. Tsetse population trends in Mwea National Reserve (monthly tsetse fly catches, August 2003 to December 2005)

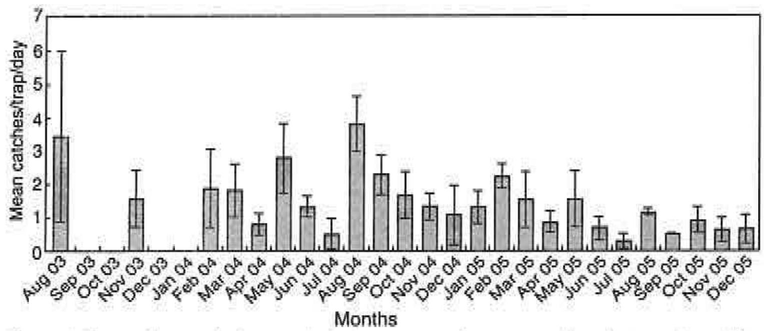


Figure 2. Tsetse fly population trends in the community-managed barrier traps (monthly fly catches, August 2003 to December 2005)

was initiated. *icipe*'s Commercial Insects Programme conducted a Training of Trainers (ToT) in beekeeping in August 2004 and February 2005 for 12 nominated members of the community to create a critical capacity within the community to practice modern beekeeping. ToT in wild silk farming started in June 2005 and is still in progress. A total of 12 nominated farmers participated in the training. This capacity building motivated the community and resulted in frequent trap servicing.

Output

Donor reports

Mungai P., Kariuki J. M., Maina E. W. and Kariuki J. (2004a) Report on the prevalence of animal trypanosomosis in areas adjacent to Mwea National Reserve 12–17 July 2004.

Mungai P., Kariuki J. M., Maina E. W. and Kariuki J. (2004b) Report on the prevalence of animal trypanosomosis in areas adjacent to Mwea National Reserve 11–15 October 2004: Progress report, October 2004.

Ndung'u M. (2005) Internal Evaluation Report on Mwea National Reserve Community Tsetse Control Project, August 2005.

Nyambo B., Ouma M., Maundu J. and Kabunyi J. K. (2005) Mwea tsetse. In *icipe* Education and Dissemination Unit Quarterly Report: January–March 2005, p. 3.

Nyambo B., Maundu J. and Kabunyi J. K. (2005) Mwea Tsetse. In *icipe* Education and Dissemination Unit Quarterly Report: April–June 2005, pp. 3–4.

Nyambo B., Maundu J. and Kabunyi J. K. (2005) Mwea tsetse. In *icipe* Education and Dissemination Unit Quarterly Report: July–September 2005, pp. 1–2.

Nyambo B. (2005) Mwea National Reserve: Community-based tsetse control. September–December 2005.

Adaptive Management of Ecosocial Systems. I. Historical Perspective and Introduction of Ecosocial Systems

Background, approach and objectives

The Population Ecology and Ecosystem Science Department project briefly reviews both the history of integrated pest management (IPM) and some elements of system theory that are used to represent the structure and functioning of social and ecological systems. This approach allows the schematisation of social systems including the composition and role of institutions engaged in IPM. In social systems, an increasing number of levels from farmers to policy makers are involved in IPM activities. The social systems are organised horizontally with institutions operating on the same level, and vertically with institutions assigned to different levels. Finally, the project deals with examples of integrated crop and livestock pest management in industrialised and developing agricultural systems to illustrate the role of institutions.

Waltner-Toews and collaborators (*Frontiers in Ecology and the Environment* 1, 23–30) refer to 'people' and 'communities' firmly embedded as integral elements in *ecosocial systems* where the social subsystems interact with ecological subsystems to become components of a unified whole.

Opportunities for ecosocial system management are explored in a conference contribution on land use for multiple purposes. Specifically, we study the development of a multifunctional agriculture aiming at objectives of ecosystem service provision *(see aforementioned connectivity enhancement project)* including food production, biodiversity conservation and provision of services relevant to ecotourism.

In both studies, we explore opportunities for adaptive management, i.e. *management seen as a systematic, cyclic process for continually improving management policies, strategies and tactics based on lessons learned from operational activities* (Comiskey J. A., Dallmeier F. and Alonso A., 1999. In: Levin, S. (Ed.), *Encyclopedia of Biodiversity*, Vol. 3. Academic Press, New York, pp. 63–73).

Adaptive management deals with uncertainties and views management as experiments rather than solutions (en.wikipedia.org).

Collaborators: *A. Pala Okeyo, J. Baumgärtner, Getachew Tikubet; G. Gilioli, Università Mediterranea di Reggio di Calabria, Italy; J. Hartmann, Amt für Natur und Umwelt, Chur, Switzerland; P. Trematerra, Università degli Studi del Molise, Campobasso, Italy*
Collaborating department: *Social Science Department*

Work in progress

1. Managing sustainable ecosocial systems

The approach permits extension of IPM into comprehensive agricultural production systems management and subsequently, into ecosocial management schemes. In traditional IPM schemes, the institutions are seen as managers of ecological systems. In ecosocial systems, however, the social systems interact with ecological systems and both become components of unified wholes. For two reasons, the book chapter by J. Baumgärtner, A. Pala-Okeyo and P. Trematerra is not limited to social systems but considers the structure and functioning of ecological systems as well. First, the use of common concepts for representing both socioeconomic and ecological systems facilitates research and implementation. Second, it addresses the concerns of anthropologists, who consider current socioeconomic approaches insufficient because they do not satisfactorily take into account the complexities of ecological systems.

In Africa, livestock disease-transmitting tsetse are highly mobile and can efficiently be controlled at the community level by precision targeting mass-trapping operations. To implement adaptive tsetse management technologies, Ethiopian communities set up tsetse control teams that interact with researchers and operate within political and administrative community organisations. Their integration into regional and national institutions is a prerequisite to successful programme execution.

The case study 'Bündner Rheintal' (Canton of the Grisons, Switzerland) demonstrates opportunities for re-orienting the traditional agriculture towards multiple objectives in an ecosystem service provision context. It shows that use of marginal land greatly enhances the opportunities of farmers to re-orient farm management towards ecosystem service provision including services of interest to the tourism sector. Geographers showed great interest in the design of land use strategies on the basis of ecosystem theories, while Ethiopian national institutions further explore opportunities provided by ecotourism.

In the cases under study, we deal with ecosocial systems, and their inherent complexity requires the use of adaptive management procedures detailed in the next section.

Output

The review undertaken is a continuation of a previously concluded project on IPM in Africa, while a conference contribution has been prepared to summarise ecosocial system management for multiple objectives in the Alps as a case study for geographers and Ethiopian institutions interested in ecotourism.

Study and Adaptive Management of Ecosocial Systems. II. Theory

Background, approach and objectives

The perspectives of ecosocial systems are configurations in which systems composed of social and ecological subsystems are mentally viewed. Traditionally, ecological and social systems have separately been dealt with, and interactions were largely disregarded. In *agronomy* and *ecology*, a wide range of actors is assumed to manage ecological systems characterised by complexity and non-linear dynamics principles. Ecosystem science relies on several complementary approaches seen as necessary to explain the evolution, structure and function as well as responses to perturbations of ecosystems. The enhancement of ecological sustainability is seen as the overall objective of ecological system management. In *sociology* applied to ecological systems management, the hierarchical structure of institutions and actors is seen as a key element. A new orientation of extension is seen as a prerequisite for enhancing synergies between institutions and augmenting innovative performance.

Recently, agronomists and ecologists give more emphasis to the interactions between social and ecological systems than previously done. Assuming that overall sustainability is composed of ecological, economic and social sustainability, several approaches may be appropriate to seek its enhancement. Assumptions of constructionist epistemology may guide research activities that yield design principles for sustainable agricultural systems and produce methods for adaptive management. The latter may improve the insight into ecosocial system evolution, structure and dynamics and moreover, identify resources for placing ecosocial systems on trajectories to enhanced sustainability. The authors rely on these concepts in their ongoing projects aiming at enhancing ecological, economic and social sustainability of ecosocial systems.

Collaborators: *J. Baumgärtner; G. Gilioli, Università Mediterranea di Reggio di Calabria, Italy*

Work in progress

1. Establishing a basis for ecosocial system management

In many parts of the world, increasingly, human populations are faced with the problem of obtaining resources from deteriorating ecological systems. The reversal of this trend is an objective for many institutions involved in development cooperation. This has profound anthropological, economic and ecological implications, and the selection of adequate approaches is a great challenge to the scientific community. In many cases, the stress results from the combined effect of adverse environmental conditions, vector-transmitted diseases and limited food. Under conditions of multiple stresses, an ecosocial systems approach is indispensable and research on adaptive management appropriate.

The essential qualities of this approach are being defined in ongoing projects on human health improvement and poverty alleviation in Africa. A community-based tsetse and trypanosomosis management project in Ethiopia is the entry point. We observe that a linear cause and effect chain is inappropriate to represent the consequences of the operations, and multiple effects can be derived from a schematised representation of the system. The incidence of malaria is an additional stressor that seriously constrains human health and limits access to resources. Hence, the development of a community-based mosquito and malaria control system is considered as necessary. To assure food security, habitat degradation has to be reversed and sustainable agricultural systems have to be developed as a participatory effort.

Nevertheless, the emphasis will shift from theory development to applications *(see next project)*.

STUDY AND ADAPTIVE MANAGEMENT OF ECOSOCIAL SYSTEMS. III. APPLICATIONS

Background, approach and objectives

To overcome some limitations in traditional human health and poverty reduction schemes, we introduced the ecosocial system concept into our work and re-oriented management aims towards sustainability enhancement.

Collaborators: *J. Baumgärtner, Getachew Tikubet, G. Gilioli, Melaku Girma, A. Sciarretta, Shifa Ballo; P. Trematerra, Università degli Studi del Molise, Campobasso, Italy*

Assisted by: *Lulseged Belayehun, Teame Hagos*

Donors: *Ethiopian national institutions, Swiss Agency for Development and Cooperation, Biovision Foundation*

Work in progress

1. Adaptive management of tsetse

The deployment of four odour-baited traps per km² is used as a standard in tsetse control projects and was used at two sites in Ethiopia. At the Luke site in southwestern Ethiopia, we deployed 216 traps on 17 paths crossing a 50 km² wide area. The geostatistical analysis showed that reliable information on spatio-temporal tsetse occurrences can be obtained by using every second trap resulting to a decrease in labour costs. Moreover, the method allowed detection of hot spots similar to the ones detected with the standard method. At the Asossa site in western Ethiopia, the application of geostatistical methods to the analysis of data obtained by the standard method also showed that reduction in labour and reliable information on tsetse occurrences can be obtained by using every second trap. Likewise, no loss of information on hot spots occurred when reducing the number of traps by 50%. At both the Luke and the Asossa sites, 50% of the traps used in the standard deployment strategy could be used for either extending the area under monitoring or for hot spot control purposes. The design and implementation of a cost-efficient monitoring system is the first step in an adaptive tsetse management system. This system has been tested at the Luke site where it resulted to cost-efficient tsetse control trap deployment, reduction in tsetse occurrences and disease prevalence in cattle, and increase in cattle productivity expressed as milk production, calving rates, and in areas being ploughed.

The objective for ecosocial system management is to place the ecosocial system on a trajectory to increased sustainability in ecological, economic and social dimensions ('navigation', according to adaptive planning as described by Carlman in *Ambio*, 34, 163–168, 2005).

Here, we present a few concepts that proved to be useful and may be necessary but probably insufficient to meet the objective. During project execution, we increasingly took into account the interactions between actors and ecological systems. Thereby, we replaced the concept of external operators acting on an independent ecological system by the concept of ecosocial systems that includes compartments of both ecological sub-system and social sub-systems. The addition of natural science input into the facilitation model used in agricultural extension allows key constraint identification, efficient integration of technologies into ecosocial system management and priority setting for management activities. Moreover, we rely on adaptive management to deal with complexity and limited predictability of ecosocial systems dynamics and accept complementary methodologies to meet the objective. Because of unclear objectives, limited predictability of ecosocial system dynamics and complementary methodologies for study and management we are unable to specify in precise quantitative terms a target for management activities and focus on changes in sustainability instead. Accordingly, management practices should keep the ecosocial system on a trajectory to enhanced sustainability in ecological, economic and social dimensions. This concept is related to the navigation concept used in adaptive planning where a safe voyage is more important than a predefined destination. The concepts listed by Baumgartner and Gilioli

(2005) are seen as components of an emerging conceptual framework for ecosystem study and management.

Output

Journal article

Sciarretta A., Melaku G., Getachew T., Lulseged B., Shifa B. and *Baumgärtner J.* (2005) Development of an adaptive tsetse population management scheme for the Luke community, Ethiopia. *Journal of Medical Entomology* 42, 1006–1019.

Paper published in proceedings

Baumgärtner J. and *Gilioli G.* (2005) Some concepts in ecosocial system management for sustainability enhancement. PRAXIS Ethiopia Conference Proceedings, Addis Ababa, Ethiopia, 27–29 September 2005. PRAXIS Ethiopia Foundation, Kansas, USA. www.praxisethiopia.org.

Community-Driven Tsetse and Bovine Trypanosomosis Management at Different Model Sites in Ethiopia

Background

After successful project execution at Luke, Gurage Zone, *icipe* was requested to initiate three additional projects: Keto (Western Oromia), Beko (Eastern Wollega) and Asossa (Benshangul Gumuz). These are high challenge areas where over 40% disease prevalence has been observed. This situation prevented the use of animal traction for field preparation. Each site corresponds to one woreda with an average human population of 150,000 in each and an average area of about 500 km^2 of tsetse-infested land.

Gurage sites

In Gurage we are operating in four Kebeles (Luke, Doba, Shumoro, Wedesha). Activities at the Luke site started in 1995. This is a continuation of the 2004 activities. Activites in the other three sites started in January 2005 in collaboration with Enemor and Ener woreda administration and the Meger Development Association. Meger contributed 500 NGU tsetse traps and accessories for the tsetse control operation.

Benshangul Gumuz sites

The Asossa site in Benshangul Gumuz Regional Government was started in 2003 with the request of the regional government and the communities at Asossa. It is operating in six Kebeles (Amba 7, 8, 9, Tsetse Adurunu, Agusha and Kushmengel).

Oromia sites

The tsetse–trypanosomiasis roll back initiative in Oromia region was initiated by *icipe* and Oromia Agriculture and Rural Development Bureau to tackle the growing trypanosomosis challenge in animal husbandry. The problem is even worse in the new settlement areas where it is impossible to keep animals for any purpose.

The operation started in October 2004 and is operating in two settlement Kebeles—Bako and Gosh Amba—in Eastern and Western Wollega zone, respectively.

The main objective is to facilitate animal health improvement at model sites.

Participating scientists: *T. Getachew, J. Baumgärtner, G. Melaku, Shifa Ballo, Teame Hagos, Leulseged Belayhun, G. Gilioli, A. Sciarretta*

Assisted by: *Girma Gulilat, Murad Yirga, Tesfaye Alemu, Assefa Admike, Mrs Etsegenet Muluneh, Ms Gibson Kelifa, Mrs Tobyawseged Teshome, Mrs Alemstsehay Wudeneh*

Collaborators: *Gurage Zone Administration, Oromia, Gurage Zone, Benshangul Gumuz Bureau of Agriculture, Addis Ababa University, Ethiopian Social Rehabilitation and Development Fund*

Donors: *Swiss Development Cooperation, Biovision Foundation, Helvetas/BioEconomy Association, World Vision, Regional Governments and in-kind contributions of communities*

Work in progress

1. *Adaptive management of tsetse populations and chemotherapy for infected animals*

In all the sites, a total of 1229 monitoring traps (Gurage 289, Benshangul Gumuz 740, and Oromia 200) have been deployed according to standard procedures. Traps were set at 500 meters by 500 meters spacing and fly catches were collected biweekly with community participation. Currently, the monitoring system is made more cost-efficient using geostatistical analysis and community participation.

In Luke, the tsetse management strategy relies on additional trap deployment in hot spots. In the three new areas, farmers preferred herd management over control trap deployment, i.e. they refrain from grazing in hot spot areas. The strategy selected by the farmers is under evaluation with respect to tsetse spatial–temporal dynamics and trap deployment.

In Benshangul Gumuz and Oromia sites traps were deployed and fly catches registered biweekly and tsetse distribution in space and time were geostatistically analysed and fly distribution contour maps constructed. However, additional traps deployment based on hotspot identification was not done because of logistical problems. This activity will be conducted in the next season.

The main activity of the project includes community mobilisation and capacity building, tsetse population adaptive management and chemotherapy of infected animals, and socioeconomic data collection and impact assessments.

Gurage sites

At Luke, the previously reported disease prevalence of 11% has been maintained with minimal monitoring and intervention. In the other sites in Wodesha, Doba and Shimoro, disease prevalence rate of 27.8, 28 and 37%, respectively was reduced, correspondingly, to the initially observed 12, 11.1 and 11.5% trypanosome prevalence rate.

The increase in numbers of cattle, and specifically oxen, allowed the ploughing of about 505 ha in 2005. Crop production, the number of cattle (3296), the milk yield (1.29 litres per cow per day) and the calving rate (0.566) increased from previous years and made available resources for the construction of a school. We expect that the resources will provide opportunities for the private sector. The establishment of tsetse management committees increases institutional diversity and contributes to sustainability.

Farmers were selected from all the sites and practical training in community-based integrated tsetse and trypanosomosis management was given to 125 farmers. Community Project Committees were formed for Wodesha, Doba and Shimoro. The issue of institutional diversity is being addressed.

Benshangul Gumuz sites

In Asossa, the tsetse population abundance is decreasing through time (see Table 1). The disease prevalence has also been reducing (see Figure 3) and availability of oxen resulted in an increase in ploughed land. A socioeconomic analysis is being carried out. For the scaling up of the project, 3000 traps are ready for deployment in collaboration with World Vision and the Benshangul Gumuz Regional Government.

Oromia sites

At Keto (Gosh Amba) and Beko, the deployment of tsetse-baited traps by *icipe* and Ministry of Agriculture have minimised the trypanosomosis challenge to a certain degree as has been mentioned by local settlers during surveys. Fly monitoring work showed that *Glossina morsitans submorsitans* and *G. fuscipes fuscipes* tsetse species are present along with other biting flies such as *Tabanus, Stomoxys* and *Hematopota* spp. The results of fly monitoring data are geostatistically analysed and fly distribution maps were constructed (see Figures 1 and 2). Since the tsetse control programme is in its early stages, more data are being collected for further impact assessment.

In both sites practical training in tsetse control and income generation was given to about 1000 farmers and 5 development agents.

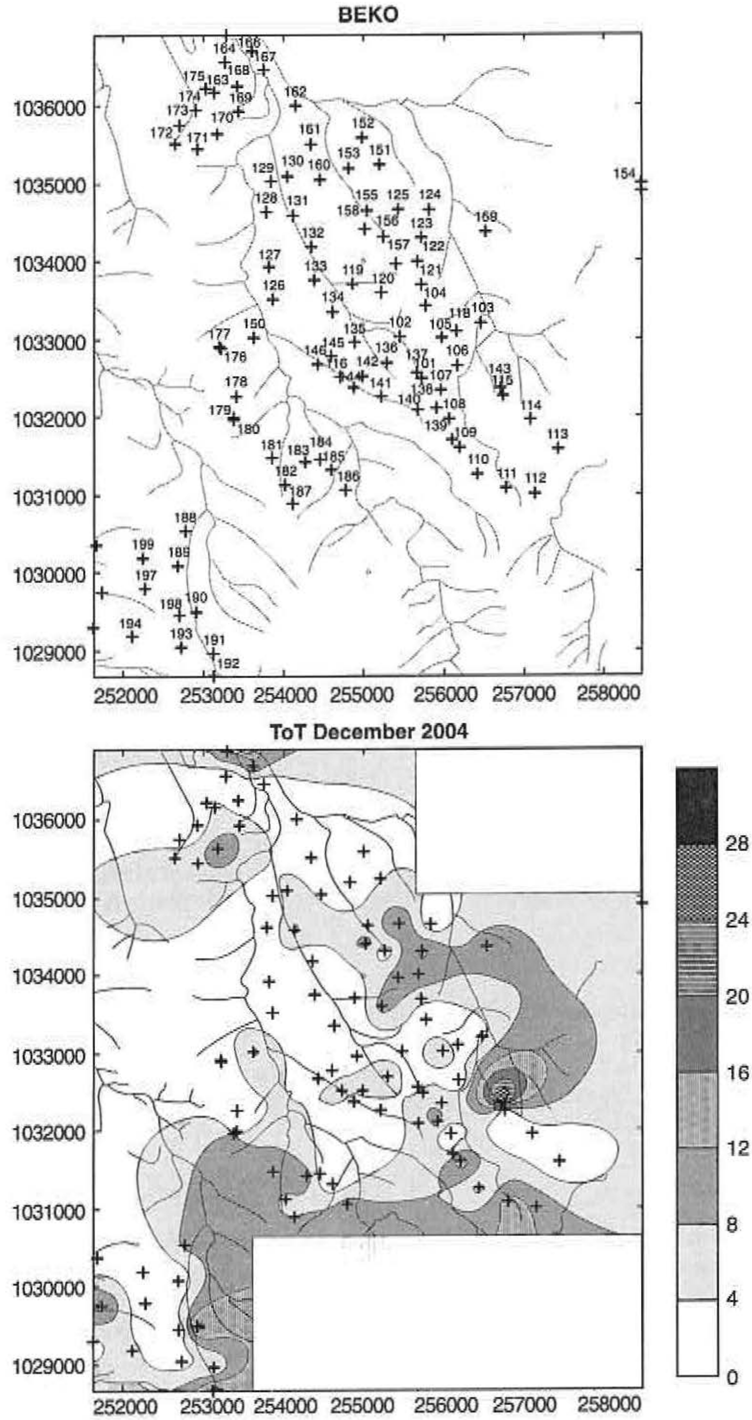


Figure 1. Tsetse trap positions and fly distribution contour map for Beko site

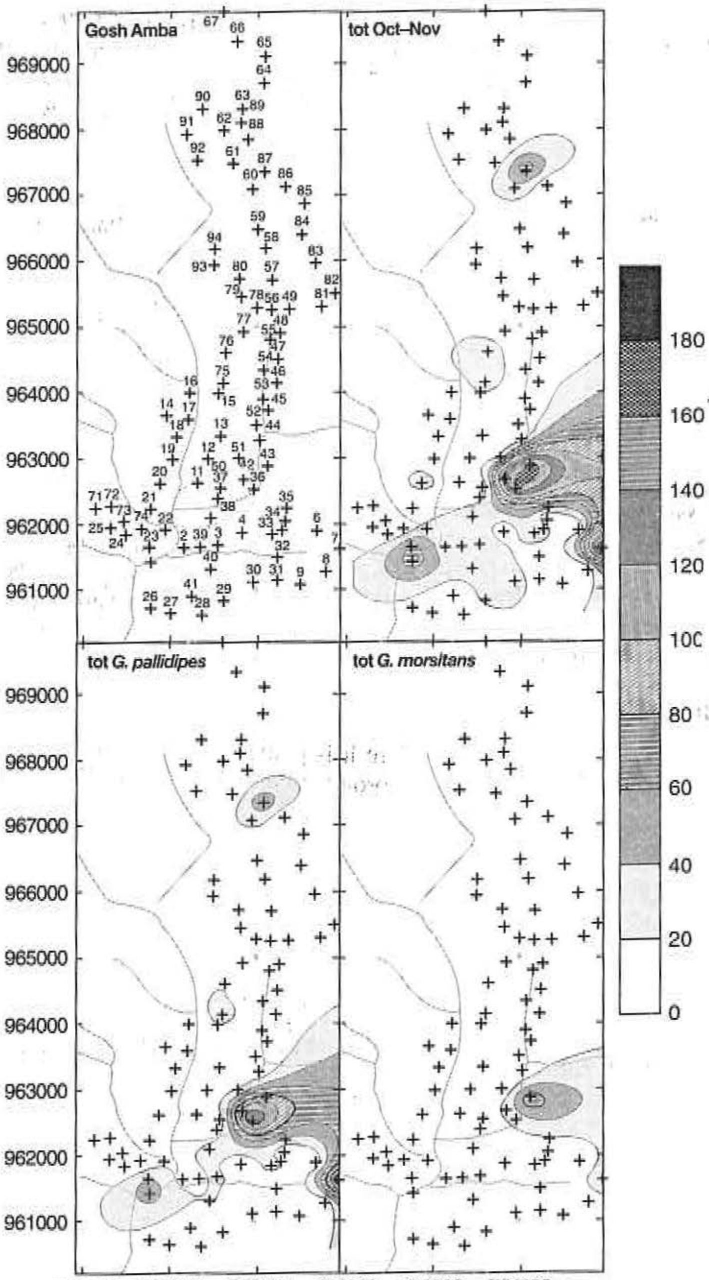


Figure 2. Tsetse trap positions and fly distribution contour map for Gosh Amba

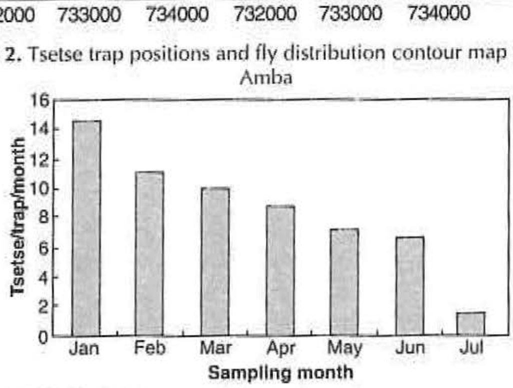


Figure 3. Average monthly catches of tsetse in Asossa from January to July 2005

Table 1. Trypanosomosis prevalence and species occurrence in Asossa between 2003–2005

Years	No. of cattle examined	No. of infected cattle	Percentage infected cattle	Species of trypanosome detected
2003	263	73	27.76	*Trypanosoma congolense* (27) 10.27 % *T. vivax* (38) 14.45 % *T. brucei* (8) 3.04 %
2004	353	94	26.63	*T. congolense* (16) 4.53 % *T. vivax* (50) 14.16 % *T. brucei* (28) 7.93 %
2005	89	8	11.12	*T. congolense* (1) 1.01 % *T. vivax* (2) 3.01 % *T. brucei* (5) 7.10 %

Future plans

Gurage sites

The Gurage sites will scale up their activities to cover more areas and will work to hasten the activities to sustain the operation. Studies on the population dynamics of other biting flies and their role in disease epidemiology with reference to biting fly population before, during and after tsetse suppression will be carried out. Studies on the characterisation of hotspots in terms of agroecology and its association with different cropping patterns will be analysed to come up with simple rules (to translate the complex non-linear model to simple straightforward rules).

Benshangul Gumuz and Oromia sites

In partnership with the regional government it is planned to scale up the operations to cover more area and communities. More training programmes will be conducted to benefit farmers and extension agents.

Output

Journal article

Sciarretta A., Melaku G., Getachew T., Lulseged B., Shifa B. and *Baumgartner J.* (2005) Development of an adaptive tsetse population management scheme for the Luke community, Ethiopia. *Journal of Medical Entomology* 42, 1006–1019.

Biofarming at Model Sites With Community-Driven Tsetse and Bovine Trypanosomosis Management in Ethiopia

Background, approach and objectives

After successful tsetse and trypanosomosis control operations for animal health improvement at Luke (Gurage, Zone), Keto (Western Oromia), Beko (Eastern Wollega), Asossa and Belles valley (Benshangul Gumuz), measures are being undertaken to improve human health and bring about sustainable development. At Addis Ababa, habitat restoration projects with similar objectives are being undertaken. Two-hundred women groups are involved in the project.

The overall approach is adaptive management of eco-social systems, i.e. systems with interacting ecological and social system components. In both the habitat restoration project and at Luke, a series of monitoring data falling into ecological, economic and social categories have continuously been collected and used for decision support in management activities. At Keto and Asossa, collection of monitoring data has begun. At the first two sites, farmers have been trained in biofarming, while at the other sites training activities have started.

The main objective is human health improvement.

Participating scientist: *T. Getachew*

Participating organisations: *BioEconomy Association, Integrated Biofarm Centre, Regional Agriculture Bureau (Gurage, Oromia, Benshangul Gumuz)*

Donors: *Stanley-Johanson Foundation, Biovision Foundation, Helvetas/BioEconomy Association Regional governments and in-kind contributions of communities*

External collaborator: *G. Gilioli, University of Reggio di Calabria, Gallina di Reggio di Calabria, Italy*

Work in progress

At the Luke and the habitat restoration sites monitoring data have been analysed to: (1) obtain better insight into eco-social system development, and (2) guide management operations. Publications for submission to peer-reviewed journals are being written.

At Keto, Asossa and Beles, biofarming activities have been initiated and will be intensified during the next reporting period.

At Luke, a total of 200 farmers have been trained in biofarming. At the habitat restoration sites, 700 farmees including women groups from Mekelle (Tigray Regional State), Asella (Oromia Regional State) and Benshangul Gumuz Regional State. At Keto, biofarming was taught to 200 farmers, while 350 farmers were trained at Asossa.

At all the sites, a total of 800 farmers have been trained and each of them is expected to train 10 farmers, so that we reach 8000 farmers.

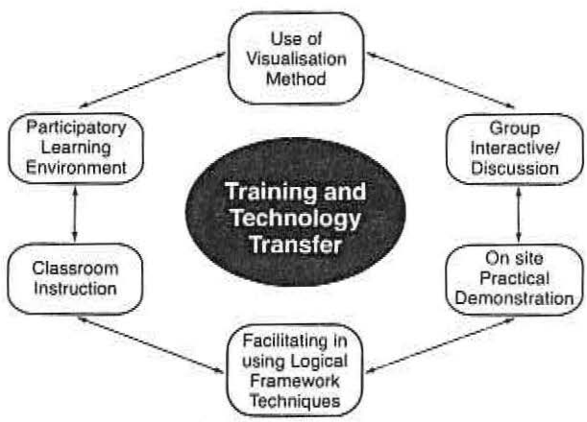


Figure 1. Training and technology transfer procedure

B. Ticks

Repellency of Essential Oils of Some Plants from Bungoma District, Western Kenya Against Rhipicephalus appendiculatus Neumann 1901 (Acarina: Ixodidae)

Objective

Identify candidate plants with potential of reducing livestock tick–vector contact and as sources of tick repellent essential oils which can be used to develop tick management strategies based on behavioural manipulation.

Participating scientists: *W. Wanzala, R. W. Mukabana[1], W. Takken[2], J. C. Van Lenteren[2], A. Hassanali*

Donor: *International Foundation for Science*

Collaborators: *[1]Department of Zoology, University of Nairobi, [2]Laboratory of Entomology, Wageningen University and Research Centre*

Collaborating department: *Behavioural and Chemical Ecology Department*

Work in progress

1. *Identification of candidate plants with potential for livestock ticks control and management*

Eight plants (*Tagetes minuta, Tithonia diversifolia, Juniperus procera, Solanecio manii, Senna didymobotrya, Lantana camara, Securidaca longepedunculata* and *Hoslundia opposita*), were systematically selected and their hydrodistilled essential oils screened against *Rhipicephalus appendiculatus* adults (Table 1). Two plants (*T. minuta* and *T. diversifolia*) whose repellency activities against *R. appendiculatus* were found to be relatively high, were selected and their dose-response studied and chemical composition of their essential oils evaluated by gas-chromatography-mass spectrometry and direct comparison of their mass spectra to the Wiley NBS database with authentic standards. In a tick-climbing repellency bioassay, the oils of the two plants exhibited a repellency effect, which at the highest doses, was higher than that of previously evaluated commercial arthropod repellent, N,N-diethyl toluamide (Figure 1a and b). *Tagetes minuta* essential oil (RD_{50} = 0.00213 mg) was more repellent against *R. appendiculatus* than that of *T. diversifolia* (RD_{50} = 0.26292 mg), probably due to differences in the nature and number of respective constituent compounds, whose synergism effect in the two plants may be different. Of the identified constituent compounds in *T. minuta* essential oil (Table 2a), *cis*-tagetone occurred in largest amount (9.42%), followed by 2-pinene-4-one (8.41%), 1-acetoxy-*p*-menthan-3-one (7.62%), verbenone (5.69%), carvone (4.42%) and 1,3,3 trimethyl cyclohexene (2.28%). While in *T. diversifolia* essential oil (Table 2b), α-pinene occurred in largest amount (14.44%) followed by β-pinene (10.21%) and *cis*-caryophyllene (8.21%). The study demonstrates that *T. minuta* and *T. diversifolia* essential oils have the potential for livestock ticks control and management.

Table 1. The eight candidate anti-tick plants selected for screening from the Bukusu community in western Kenya

Botanical name	Local name(s) [Bukusu name(s)]	Family name	Mention frequency of local use by farmers	Plant parts used	Reported plant uses in literature
Hoslundia opposita Vahl.	Bifwofwo	Labiatae	1	Whole plant	T, A
Juniperus procera procera Hochst. ex Endlicher	Kumutarakwa	Cupressaceae	5	Leaf/root/bark	I, B
Lantana camara L.	Lantana/mukhekhe	Verbenaceae	2	Whole plant (Pour-on or steaming)	B, F, C, I
Securidaca longepedunculata Fres.	Kumulandamwombe/ Kumunyakasia/ kumuyanjabakeni	Polygalaceae	2	Whole plant	I, C, B, F, Ps
Senna didymobotrya (Fresn.) Irwin & Barneb	Kumubumbu/ Kumupinupinu	Caesalpiniaceae	1	Leaf/bark/root-suspension	T, B, I
Solanecio manii (Hook. f.) C. Jeffrey	Nandebe	Asteraceae	5	Whole plant	A, C
Tagetes minuta L.	Nanjaka	Asteraceae	9	Leaf/flower/dust, suspension and hanging bouquet	T, P, A, B, I
Tithonia diversifolia (Hemsl.) Gray	Kamang'ulie/Kamaua/ Kiming'ulie	Asteraceae	4	Whole plant–paste of the plant	I, P, T, B, F. Af

A, Plants that were found in literature to demonstrate *acaricidal* activities/compounds.
B, Plants that were found in literature to have *bioactive* compounds.
P, Plants that were found in literature to demonstrate *pesticidal* activities/compounds.
I, Plants found in literature to be resistant to attack by *insects* or found to demonstrate *insecticidal* activities/compounds.
T, *Taxonomic* affinity to plant species (at **genus** and **family** levels) known to possess *bioactive*, insecticidal, *acaricidal* activities/compounds.
F, Human *food* plants, unless otherwise stated.
Af, Plants with *antifeedant* activities.
C, Plants with *cultural* implication and applications.
Ps, *Poisonous* plants.

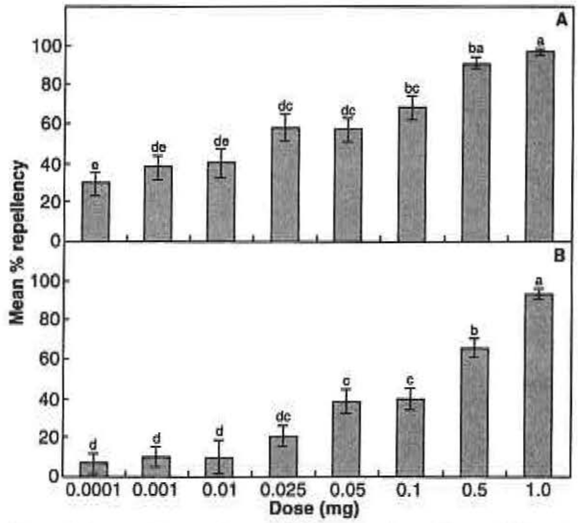


Figure 1. Mean % repellency of *Tagetes minuta* (A) and *Tithonia diversifolia* (B) essential oils against newly emerged *Rhipicephalus appendiculatus* adults in climbing bioassay. Means with the same letters are not significantly different at $P < 0.0001$

Table 2a. GC-MS identified major constituents in the essential oil of *Tagetes minuta*

Peak no.	Compound name	Molecular formula	RT	M⁺ (g/mol)	Base peak	Major peaks	Relative % abundance
1	2-pinene-4-one	$C_{10}H_{14}O$	22.70	150.22	93	41, 77, 79, 91, 93	8.41
2	carvone	$C_{10}H_{14}O$	23.13	150.22	69	41, 42	4.42
3	β-ocimene	$C_{10}H_{15}$	25.85	136.24	121	77, 79, 91, 105, 136	0.98
4	*cis*-tagetone	$C_{10}H_{16}$	26.48	152.00	95	43, 47, 77	9.42
5	1,3,3 trimethyl cyclohexene	C_9H_{16}	28.33	124.22	91	*	2.28
6	1-acetoxy-*p*-menthan-3-one	$C_{12}H_{19}O_2$	29.08	212.00	63	*	7.62
7	piperitenone	$C_{10}H_{14}O$	29.40	150.22	107	*	0.41
8	verbenone	$C_{10}H_{16}$	34.68	136.24	189	41, 91, 105, 119, 113, 147	5.69
9	caryophyllene	$C_{15}H_{24}$	35.70	204.36	41	41, 53, 55, 67, 69, 133	0.33
10	epoxy-ocimene	$C_{10}H_{16}O$	37.73	152.00	121	43, 46, 77, 104	1.11

M^+, Molecular weight; RT, retention time (min.).

Table 2b. GC-MS identified major constituents in the essential oil of *Tithonia diversifolia*

Peak no.	Compound name	Molecular formula	RT	M⁺ (g/mol)	Base peak	Major peaks	Relative % abundance
1	α-pinene	$C_{10}H_{16}$	18.98	136.23	93	39, 77, 79, 121, 136	14.44
2	β-pinene	$C_{10}H_{16}$	20.43	136.24	93	41, 69, 121, 136	10.21
3	limonene	$C_{10}H_{16}$	22.20	136.23	68	39, 41, 53, 67, 93	1.38
4	α-copaene	$C_{15}H_{24}$	34.10	204.36	105	91, 93, 119, 161	0.91
5	*cis*-caryophyllene	$C_{17}H_{28}$	35.48	232.41	93	41, 69, 79, 91, 105, 133	8.21
6	tetradecene	$CH_3(CH_2)_{11}CH=CH_2$	36.88	196.40	55	41, 43, 55, 57, 57, 69, 83, 97	1.28
7	nerolidol	$C_{15}H_{26}O$	38.65	222.37	69	41, 43, 55, 93, 107	1.33

M^+, Molecular weight; RT, retention time (min.).

Capacity building

PhD student

W. Wanjala (Kenya) An evaluation of anti-tick ethnobotancials and their strategic application in tick control and management. University of Nairobi, Kenya (ongoing).

Epidemiology Modelling of East Coast Fever of Cattle

Background, approach and objectives

A disease transmission model for tick-borne East Coast fever (ECF) of cattle is parametrised and prepared for guiding adequate management of the vector *Rhipicephalus appendiculatus*, the protozoan disease parasite *Theileria parva* and the cattle host system by the Population Ecology and Ecosystem Science Department. The formal structure of the model is similar to previously published epidemiological models of tick-borne diseases. Accordingly, the host and the vector populations are classified as infected or uninfected. The tick population is further assigned to sedentary (off-host) or feeding (on-host) classes, while the host population falls into categories of uninfected animals, infected animals and recovered disease-carrying animals. The procedures for estimating the lumped parameters of the models are detailed. Thereby, an extensive body of literature has been consulted for parametrising the tick population model component, estimating disease epidemiology parameters and obtaining demographic parameters for cattle in Kenya and Ethiopia.

Collaborators: *J. Baumgärtner; M. Groppi and M. P. Vesperoni, Università di Parma, Italy; P. Guerin, Université de Neuchâtel, Switzerland; V. Maurer, Research Institute for Organic Farming, Frick, Switzerland; G. Gilioli, Università Mediterranea di Reggio Calabria, Italy*

Work in progress

The model is used to analytically investigate threshold conditions for the persistence of the tick population and the existence of stable coexistence equilibria. Thereafter, threshold conditions for ECF persistence are derived and shown to be dependent on both tick and host population parameters as well as on transmission rates of the parasites both from ticks to cattle and vice-versa. The persistence and non-persistence conditions for both the tick population and ECF are investigated, some limitations of the current model for addressing additional aspects of integrated disease control are discussed and opportunities for further model development identified. Such analysis is supported by an extensive numerical simulation of the behaviour of the system.

The current approach is seen as an important component in the development of an adaptive animal health management system in East Africa. The objective of such project is to gradually improve the insight into the epidemiology of both tick- and tsetse-transmitted diseases for guiding integrated control operations aiming at animal health improvement. Moreover, animal health management has been identified as an entry point into a management scheme that aims at ecological, economic and social sustainability of ecosocial systems by relying on appropriate system control measures.

Output

Journal articles

A publication has been submitted to a peer reviewed journal, while a publication on parameter estimation procedures is under preparation.

Proposal written

In collaboration with Prof. Guerin and Dr V. Maurer, *icipe*'s Population and Ecosystem Science Department wrote a proposal on an adaptive integrated pest management system for both tsetse and ticks.

Conferences attended

5th International Conference on Ticks and Tick-borne Pathogens (TTP5), 28 August–2 September 2005, University of Neuchâtel, Switzerland. Attended by: G. Gilioli and J. Baumgärtner.

Impact

The model improves the understanding of East Coast fever transmission by *Rhipicephalus appendiculatus*. The conditions for coexistance allow the design of integrated control strategies. The model is an important element in the development and implementation of adaptive vector/ disease control systems.

PHOTO: Santiago Escobar

HUMAN HEALTH

A. Malaria Mosquitoes/Malaria

ECOLOGY OF ANOPHELES MOSQUITO SPECIES AND LARVAL HABITAT DIVERSITY IN IRRIGATED RICE-VILLAGE COMPLEXES IN MWEA, KENYA

Background, approach and objectives

Africa's population was projected to reach 1.58 billion by the year 2005 with the current growth rate of nearly 20 million people annually. This population growth rate outstretches food production and many African countries are seeking ways of expanding agricultural production. However, this is limited by the fact that almost half of the potential arable land in Africa is too dry for rainfed agriculture and large areas experience rainfall that is sparsely distributed and highly variable. Irrigation agriculture is encouraged as a way of increasing food production such as rice. Although irrigated rice-cultivation results in improved economic status that enables community members to have more disposable income directed towards disease control measures, high mosquito densities in these areas increase the problem of malaria transmission and related burden particularly in areas of unstable transmission where majority of the people are non-immune.

This research involves the development and implementation of an integrated vector management strategy (IVM) that focuses on the immature stages of vector *Anopheles* species to reduce the transmission of malaria at two rice-village complexes in Kenya. To a large extent control of malaria vectors has continued to rely almost exclusively on treating indoor sites with residual insecticides and the use of insecticide-impregnated bednets.

The ecological complexity of the rice agro-systems and the key components that affect malaria vector production, distribution and composition are poorly understood and form the basis of this research. Only isolated data exist on the bionomics of *Anopheles* vector species in rice agroecosystems. The information generated from these studies in Mwea, Kenya, will guide the development of strategies geared towards comprehensive management of the pre-adult stages of malaria vectors.

The project had the following specific objectives:

- To determine the spatial and temporal distribution and abundance of *Anopheles* larval habitats and their adult productivity in irrigated rice-village complexes.
- To determine the key environmental, agricultural, and ecological factors that regulate vector productivity and non-target abundance and diversity in the larval habitats.
- To develop, evaluate and register a new bacterial larvicide formulation(s) designed for effective residual control of anopheline larvae.
- To implement and evaluate the long-term impact of larval mosquito management programmes in rice-village complexes.

Participating scientists and students: *J. Githure, J. Shililu, [1]R. Novak, [2]C. Mbogo, W. Gu, [1]B. Jacob, J. Mwangangi (PhD student), S. Muriu (PhD student), E. Muturi (PhD student)*

Assisted by: *J. Wauna, E. Mpanga, P. Barasa*

Donor: *National Institutes of Health, USA*

Collaborators: *[1]University of Illinois, USA; Valent BioSciences, USA; JKUAT, Kenya; [2]KEMRI, Kenya*

Work in progress

SEASONAL DISTRIBUTION, PRODUCTIVITY OF LARVAL HABITATS AND POPULATION DYNAMICS OF ADULT ANOPHELES MOSQUITOES

The objectives of this study were to:

- determine the spatial distribution of *Anopheles* species in Mwea rice irrigation complex;
- determine the species composition of malaria vectors;
- determine the spatial and seasonal distribution of *Anopheles* larval habitats.

1. Mosquito species diversity and abundance in relation to land use

The diverse mosquito species occurring in rice agro-systems have been scarcely studied despite the strong link between irrigation agriculture and malaria transmission. Where studies have been conducted in irrigated rice growing areas of Africa focus has mainly been given to specific malaria vectors ignoring other mosquito species thriving in rice agro-systems, many of which could become important vectors of malaria and other diseases with the current changes in climate. This study investigated the species diversity of mosquito fauna in the Mwea Rice Irrigation Scheme in Central Kenya in relation to land use. Adult mosquitoes were sampled bimonthly both indoors and outdoors over a period of 12 months in 3 villages representing different rice cropping regimens and coverage. The mosquitoes were identified morphologically to species using taxonomic keys. At least 25 species belonging to five genera were observed. The entomological results further showed that irrigation had a marked effect on the mosquito diversity and abundance in 17 species (n = 66,828) collected in the planned rice growing village of Mbuinjeru, 22 species (n = 21,074) in the unplanned rice growing site (Kiamaciri) and 20 species (n = 10,808) in the non-rice growing village (Murinduko).

Catches inside houses using pyrethrum spray collection (PSC) and outdoors using CDC light traps indicated that the numbers of the main malaria vector, *Anopheles arabiensis* and other anophelines was higher in the rice field environments than in the non-irrigated sites. The predominant species collected indoors were *Anopheles arabiensis* (80.05%), *Culex quinquefasciatus* (18.15%), and *A. funestus* (1.52%) whereas outdoors common species included *C. quinquefasciatus* (54.65%), *A. arabiensis* (25.95%), *A. pharoensis* (10.27%), *A. coustani* (2.61%), *C. annulioris* (1.76%), *C. poicilipes* (1.18%), *A. maculipalpis* (1.09%) and *A. funestus* (1.05%). *Anopheles arabiensis, A. pharoensis* and *C. quinquefasciatus* were mainly associated with rice cultivation and occurred in significantly higher densities in the village with the planned rice cultivation than in the unplanned one. *Anopheles funestus* and *A. maculipalpis* were significantly higher in the non-rice village than in the other village types.

The mosquito species diversity (H) and evenness (E_H) in the non-rice growing site (Shannon diversity index, $H = 1.507$, $E_H = 0.503$) was much higher than in the sites with rice cultivation ($H = 0.968$, $E_H = 0.313$, Kiamaciri; and $H = 1.040$, $E_H = 0.367$ Mbuinjeru). The non-rice growing site not only had a greater number of species present, but the individuals in the community were distributed more equitably among these species (Table 1). Lag cross correlation analysis showed that rainfall was not significantly associated with *A. arabiensis*, *A. pharoensis* or *C. quinquefasciatus* densities in the rice growing villages suggesting that the build up of the three mosquito species is mainly dependant upon the rice cropping practices. It is inferred from the data that different levels of habitat disturbance with regard to rice cultivation have different effects on mosquito diversity and this provides an understanding on how mosquito diversity is impacted by different habitat management and rice cropping strategies. This information is critical in understanding the mosquito community structure and targeting control strategies in rice agroecosystems where the vector species is most predominant.

Table 1. Species diversity and evenness in three ecological sites in Mwea, Kenya (April 2004–March 2005)

		Anopheline species	Non-anopheline mosquito species	All mosquito species
Shannon's Diversity Index (H)	Planned rice cropping and irrigation (Mbuinjeru)	0.484 (6)*	0.209 (11)	1.045 (17)
	Unplanned rice cropping and irrigation (Kiamaciri)	0.197 (8)	0.469 (14)	0.978 (22)
	Non-rice village (Murinduko)	1.074 (7)	0.519 (13)	1.524 (20)
Shannon's Equitability (E_H)	Planned rice cropping and irrigation (Mbuinjeru)	0.270 (6)	0.202 (11)	0.369 (17)
	Unplanned rice cropping and irrigation (Kiamaciri)	0.101 (8)	0.073 (14)	0.316 (22)
	Non-rice village (Murinduko)	0.552 (7)	0.415 (13)	0.509 (20)

*The values in parentheses represent the number of species collected in the survey.

2. *Larval habitat diversity and temporal variation in densities of pre-adult stages of* Anopheles *mosquitoes in Mwea, Kenya*

Studies were conducted to examine habitat dynamics and ecological factors affecting productivity of aquatic stages of malaria vectors in three agroecological settings in Mwea, Kenya. Aquatic habitats were sampled once fortnightly in 3 villages to generate stage-specific estimates of mosquito larval densities, relative abundance and diversity. Records of distance to the nearest homestead, vegetation coverage, surface debris, turbidity, flow rate, habitat permanence, habitat type, rice growth stage, number of rice tillers and percent *Azolla* cover were taken for each habitat.

Captures of 1st–2nd, 3rd–4th instars and pupae accounted for 78.2, 10.9 and 10.8% of the total *Anopheles* immatures sampled (n = 29,252), respectively. One-way ANOVA showed that there was significant variation in larval abundance between sites ($F_{(12, 2016)} = 11.822$, $P < 0.01$).

The village with 'planned' rice cultivation had relatively lower *Anopheles* larval densities compared to the villages where 'unplanned' or limited rice cultivation was undertaken (Table 2). Species composition and richness was similarly higher in the 2 villages with either 'unplanned' or limited rice cultivation, an indication of the importance of land use patterns on diversity of larval habitat types. Rice paddies and associated canals were the most productive habitat types while water pools and puddles were important for short periods during the rainy season. Multiple regression analysis showed that presence of other invertebrates, percentage *Azolla* cover, distance to nearest homestead, depth and water turbidity were the best predictors for *Anopheles* mosquito larval abundance. The data generated provide critical information on habitat diversity and productivity of immature stages of *A. arabiensis* based on rice husbandry and water management practices that may be utilised for developing targeted larval control strategies for rice agroecosystems.

Table 2. Productivity and diversity of *Anopheles* larval habitats in three ecologically varied villages in the Mwea Rice Irrigation Scheme (MRIS)

	Habitat category	No. habitats sampled	% habitats with water	% habitats positive *Anopheles* larvae	Larval density (no./ (10 dips)	Larval density (no./ 10 dips)
Kiamaciri	Canal	30	62.7	39.7	1.9	0.2
('Unplanned'	Marsh	27	48.3	48.7	2.1	0.3
rice cultivation;	Paddy	108	52.7	56.3	4.1	0.2
≈ 25% area	Temporary pool	59	50.0	44.9	2.8	0.4
under rice)	Water reservoir	2	46.2	25.0	0.7	0.7
Mbuinjeru	Canal	19	83.0	31.6	1.1	0.0
('Planned'	Marsh	6	19.5	47.1	1.7	0.2
rice cultivation;	Paddy	80	57.6	46.8	2.2	0.4
> 80% area	Temporary pool	96	14.4	36.1	2.4	0.2
under rice)	Water reservoir	2	23.1	16.7	0.4	5.6
Murinduko	Canal	9	97.1	65.4	6.7	0.7
(Subsistence	Marsh	22	85.7	79.6	7.8	2.7
farming;	Paddy	83	86.4	69.3	8.8	0.7
< 5% area	Rock pool	4	35.5	72.7	5.9	15.9
under rice	Stream pool	10	93.9	76.9	8.5	0.6
on valley	Temporary pools	35	90.7	76.9	9.9	0.6
bottoms)	Tree hole	3	44.4	75.0	2.9	3.8
	Water reservoir	4	61.1	28.6	3.4	21.6

'Planned' rice cultivation, rice cropping based on a predetermined schedule by the MRIS; 'unplanned' cultivation, no predetermined schedule followed.

3. *Dynamics of immature stages of* Anopheles arabiensis *and other mosquito species (Diptera: Culicidae) in relation to rice growth cycle*

Studies were conducted to determine changes in species composition and densities of immature stages of *Anopheles arabiensis* in relation to rice growth cycle to generate data for developing larval control strategies in rice ecosystems. Experimental rice paddies (6.3 x 3.15 m) exposed to natural colonisation of mosquitoes were sampled weekly for 2 rice growing cycles between February 2003 and March 2004. Overall, 21,325 *Anopheles* larvae were collected of which 91.9% were 1st and 2nd instars and 8.1% were 3rd and 4th instars. *Anopheles arabiensis* was the predominant species (84.1%) with other species, *A. pharoensis* (13.5%), *A. funestus* (2.1%), *A. coustani* (0.3%) and *A. maculipalpis* (0.1%) accounting for only a small proportion of the anophelines collected. *Culex quinquefasciatus* (65.7%) was the predominant species among the non-anopheline species. Other species collected included *C. annulioris* (9.9%), *C. poicilipes* (7.3%), *C. tigripes* (7.2%), *C. duttoni* (0.6%), *Aedes aegypti* (5.3%), *A. cumminsii* (3.5%) and *A. vittatus* (0.7%). The densities of the major anopheline species were closely related to rice stage and condition of the rice field (Figure 1). *Anopheles arabiensis,* the predominant species, was most abundant over a 3-week period after transplanting. Low densities of larvae were collected during the late vegetative, reproductive and ripening phases of rice (Figure 2). Increase in larval density 10 days post-transplanting was found to correlate with the application of fertiliser (sulphate of ammonia).

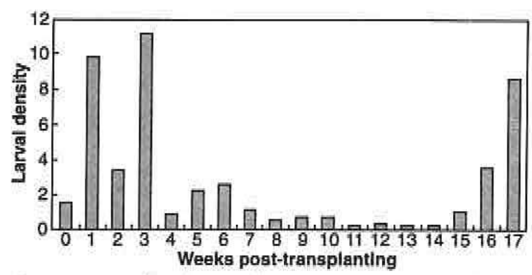


Figure 1. Weekly density fluctuation in mosquito larvae over two rice growing seasons

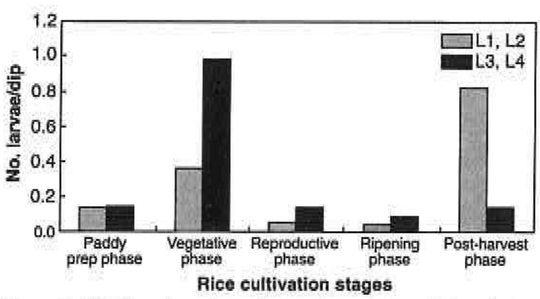


Figure 2. Relative densities of immature stages of *Anopheles* mosquitoes at different rice cultivation stages

A bimodal distribution pattern of *Anopheles* larvae was evident over the 17 weeks (120 days) of rice growth (Figure 1). Overall, larval densities of *Anopheles* species increased in early stages of rice vegetative growth (tillering stage) and during late ripening and harvesting stage. During paddy preparation (denoted as week 0) the densities were low but rose in week 1 to reach a peak in week 3 with a mean density of 11.2 anophelines per 10 dips. A second peak was recorded in week 17 with a mean density of 8.7 anophelines/10 dips. A slight increase in density was observed from week 4 to week 6. From week 7 to week 14 the density of anopheline larvae was generally low, averaging less than 1 larva per 10 dips. A similar bimodal trend was observed for the non-anopheline mosquito species but with densities being greatest during the late stages of rice growth (peak density 5.6 larvae per dip in week 17). The non-anopheline larval densities remained generally low between week 4 and week 15 (mean density 3.8 larvae/ 10 dips). The data shows that the distribution of the major anopheline vector species, *A. gambiae* s.l., followed a pattern closely linked to rice crop phenology and condition of the rice field.

Application of sulphate of ammonia fertiliser (18.5 g/m^2) at day 10 post transplanting (week 2) tended to promote larval productivity thereby leading to the peak seen in week 3 (11.2 larvae per 10 dips). Low larval densities were found during the late vegetative, reproductive and maturation phases of rice between tillering and harvesting. Figure 2 shows the densities of immature stages of mosquito species at different stages of rice growth. Culicine and aedine species favoured the post harvesting period when the rice paddies were fallow as evidenced by the increase in larval abundance.

Rice height showed a significant negative association with both *Anopheles* ($r = -0.434$, $P < 0.01$) and culicine larval densities ($r = -0.191$, $P < 0.01$). The effect, however, was greater among the early immature stages (1st and 2nd instars) during mosquito development. Equally, the number of rice tillers showed significant negative association with *Anopheles* and culicine larval density. However, water depth was only significantly associated with density of *Anopheles* larvae but not with the culicine larvae. This shows that rice height, number of tillers (shoots) and water depth were important in explaining changes in productivity of anopheline and culicine mosquitoes in rice paddies as exemplified by the significant association between the two factors and pupal density in these habitats (Table 3). Our results suggest that the transplanting stage was favourable for growth of immature stages of *A. arabiensis* and provides a narrow window for targeted larval intervention in rice.

Table 3. Correlation coefficients between mosquito larval abundance and physical parameters in the experimental rice plots

Variables	Mean ± SE	*Anopheles* early instars	*Anopheles* late instars	*Anopheles* total	Culicine early instars	Culicine late instars	Culicine total	Pupae
Rice height (cm)	73.5 ± 0.760	-0.426**	-0.245**	-0.434**	-0.217	0.041	-0.191*	-0.068*
Number of tillers (shoots)	22.2 ± 0.250	-0.384**	-0.225**	-0.391**	0.208**	0.037	-0.186**	-0.086*
Water depth (cm)	8.5 ± 0.087	-0.144**	-0.095**	-0.149**	-0.004	0.106**	0.028	0.017

4. Diversity of culicine mosquitoes in the Mwea rice agroecosystem

Whereas several studies have demonstrated the relationship between malaria vectors and irrigation, little work has been done on culicine mosquitoes despite their significant nuisance densities in these areas and their potential in transmission of filariasis and arboviruses. This study examined the diversity of culicine mosquito fauna and their larval habitats at two sites in Mwea Kenya over a 12-month period. The habitat types present at each site within a 200 m radius around the study village, including randomly selected paddies and canals, were sampled bimonthly to examine the relationship between vegetation cover, water depth, turbidity and culicine larval densities. Fifteen culicine species belonging to 4 genera were identified with *C. duttoni*, *C. quinquefasciatus* and *A. aegypti* accounting for 81.8% of the total collection. Other species collected included *C. annulioris*, *C. poicilipes*, *C. cinereus*, *C. tigripes*, *C. trifilatus*, *A. taylori*, *A. leesoni*, *A. vittatus*, *A. cumminsi*, *A. albocephalus*, *Coquilettidia fuscopennata* and *Ficalbia splendens*. Murinduko was more diverse than Kiamachiri in terms of species richness (15 versus 10 species) and larval habitat diversity (11 versus 8 habitat types). Paddies, canals and rain pools were the most diverse habitats in terms of species richness while ditches, rock pools and tree holes were the least diverse.

Principal components (PC) and correlation analyses revealed a strong association between four culicine species and the measured habitat characteristics. Three principal components explained 83.7 and 70.7% of the total variance based on the five environmental variables measured in Kiamachiri and Murinduko, respectively (Table 4). The first principal component (PC 1) was a linear combination of high loads on the floating vegetation cover namely *Azolla* and other types of floating vegetation describing a strong gradient of floating vegetation cover. The second principal component was a linear combination with high loads on emergent vegetation on the positive side in Murinduko and on the negative side in Kiamachiri. This separated habitats with emergent vegetation from those without. The third principal component separated habitats with clean water from those with turbid water.

Table 4. Principal component analysis of habitat variables and interpretation of derived principal components

	Kiamachiri			Murinduko		
	PC 1	PC 2	PC 3	PC 1	PC 2	PC 3
% *Azolla* cover	0.862	0.319	0.153	0.8	-0.059	0.014
Emergent vegetation	0.360	-0.689	0.432	-0.009	0.875	0.104
Floating vegetation	0.867	0.315	0.139	0.793	-0.188	-0.084
Turbidity	0.383	-0.052	-0.863	-0.044	-0.211	0.966
Depth (cm)	-0.366	0.64	0.210	0.444	0.440	0.222
% variation explained	38.1	25.3	20.4	29.5	20.9	20.0

Culex poicilipes was strongly associated with floating vegetation, *C. annulioris* with clean water containing floating and emergent vegetation, *C. quinquefasciatus* with turbid water while *A. aegypti* was negatively associated with emergent vegetation. Seasonal changes in larval density in water reservoirs, pool and ditch habitats were closely associated with rainfall. A significant association between the three principal components and 4 culicine species was observed (Table 5). *Culex poicilipes* was positively associated with PC 1 in Kiamachiri indicating a strong association with floating vegetation. *Culex annulioris* was negatively associated with PC 1 and positively associated with PC 2 in Kiamachiri whereas in Murinduko it was negatively associated with PC 3. This means that this species is abundant in habitats with clean water, and floating and emergent vegetation. *Culex quinquefasciatus* was positively associated with turbid water (PC 3), while *A. aegypti* was associated with habitats devoid of emergent vegetation (PC 2). The other culicine species were not significantly associated with any of the three principal components probably because of their catholic nature of breeding. These findings provide important information on larval habitat preference for different culicine species useful in designing and implementation of larval control operations.

Table 5. Results of Pearson correlation analysis between mosquito densities and derived principal components

	Kiamachiri			Murinduko		
Species	PC 1	PC 2	PC 3	PC 1	PC 2	PC 3
Culex quinquefasciatus	-0.007	+0.020	+0.041	-0.025	-0.024	+0.060*
C. poicilipes	+0.062*	-0.001	+0.020	-0.025	+0.012	-0.041
C. annulioris	-0.071*	+0.060*	+0.020	-0.017	-0.012	-0.067*
C. duttoni	-0.028	+0.021	+0.018	+0.115	+0.203	-0.004
Aedes aegypti	-0.013	+0.101**	+0.030	+0.009	+0.002	-0.014
n	1221	1221	1221	1082	1082	1082

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).
+ and – signs indicate the direction of change with increasing principal component.

5. *Anopheline and culicine species succession in a riceland ecosystem in Mwea, Kenya*

In Africa, few studies have demonstrated a strong relationship between rice cropping cycle and mosquito species succession. In Mali, *Anopheles gambiae* s.l. and *A. pharoensis* dominated the first 6–8 weeks of the rice cycle followed by a sharp decline thereafter and dominance of *A. rufipes* and *A. funestus*. In the Gambia, succession of different mosquito genera in the rice fields was demonstrated. In this study *A. gambiae* s.l., *A. rufipes* and *C. neavei* were predominant during the early stages of rice development, *C. ethiopicus* and *C. poicilipes* around the middle of the rice cycle while *A. ziemanni* peaked as the rice matured. In addition, *C. antennatus; Mansonia uniformis* and *M. africana* occurred throughout the growing season, but had little relation with the cycle of rice growth.

In Kenya, the only documented attempt to relate the rice cycle and mosquito species succession was conducted three decades ago in Kisumu. Like in the Gambia, this study documented *A. gambiae* s.l. and *A. pharoensis* to occur during the early growing cycle while *M. uniformis, M. africana* and *Mimomyia splendens* had no relation with rice cycle. In contrast, however, *A. ziemmani* was abundant during the middle of rice cycle together with *C. poicilipes* while *C. antennatus* occurred towards the end of the cycle. The replacement of *A. gambiae* by *A. funestus* as the rice develops may ensure continued transmission of malaria and filariasis throughout the cropping cycle. In this respect, having precise knowledge of the phenology of mosquito vectors in relation to rice growing cycle would facilitate target control of the vector species. This study investigated the relationship between rice cropping cycle and mosquito species succession prior to implementation of an integrated vector control strategy based on microbial formulations.

Eight (8) paddy plots each consisting of 8 subplots measuring 6.3 x 3.15 m were established in a 1 acre (0.4 ha) paddy. The plots were hydrologically isolated using unidirectional inflow and outflow canals to avoid water mixing between plots. Rice was planted in all the 64 sub plots and then monitored weekly for mosquito larvae throughout the rice growing cycle.

A total of 8278 anopheline larvae were collected during the study period with early instar stages predominating (85%). Of the 1936 specimens identified morphologically, 15 mosquito species comprising of 7 species were recorded. *Anopheles gambiae* s.l. was the predominant species accounting for 77.2% of the total followed by *A. funestus* (14.7%), *A. pharoensis* (3.9%) and *A. rivulorum* (1.97%). Other anopheline species rarely encountered were *A. maculipalpis* (0.9%), *A. rufipes* (0.74%) and *A. coustani* (0.74%). Two peaks were observed for immature stages, the first one during the early stage of rice development (0.569 ± 0.115) and the second peak during the post-harvest period (0.758 ± 0.184) (Table 6). Figure 3 shows the changes in mosquito species composition in relation to rice growing cycle. *Anopheles gambiae* s.l. was common throughout the rice growing cycle but their densities were 4–16-fold higher during the early stage of rice development than in the other periods. *Anopheles funestus* was common during the middle and post-harvest period but in densities much lower than the corresponding density of *A. gambiae* s.l. The other anophelines

Table 6. Density of anopheline (± SE) larvae collected in different stages of rice development

Rice stage	Early instars	Late instars	Pupae
Land preparation	0.131 ± 0.017	0.015 ± 0.003	0.01 ± 0.003
Early stage	0.569 ± 0.115	0.126 ± 0.023	0.02 ± 0.006
Middle stage	0.194 ± 0.019	0.043 ± 0.012	0.01 ± 0.004
Late stage	0.034 ± 0.003	0.006 ± 0.001	0.00 ± 0.001
Ratoon	0.758 ± 0.184	0.039 ± 0.012	0.04 ± 0.016
Total	**0.192 ± 0.017**	**0.035 ± 0.005**	**0.01 ± 0.002**

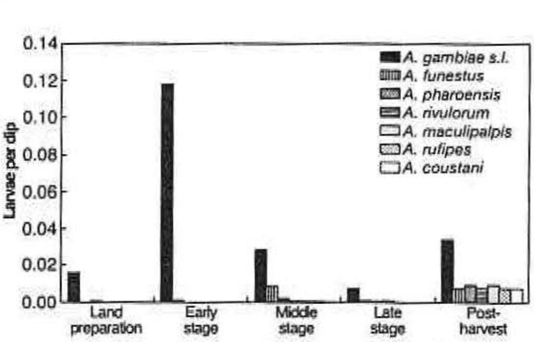


Figure 3. Changes in *Anopheles* species densities in relation to rice growth stage in Mwea, Kenya

including *A. pharoensis*, *A. rivulorum*, *A. coustani* and *A. maculipalpis* were encountered mainly during the post-harvest period and in low numbers.

Output

Conferences attended

53rd Annual meeting of the American Society of Tropical Medicine and Hygiene, Miami, USA, November 2004. Attended by: J. Shililu, J. Githure.

54th Annual meeting of the American Society of Tropical Medicine and Hygiene, Washington, USA, December 2005. Attended by: J. Shililu, J. Githure.

Capacity building

PhD students

J. Mwangangi (Kenya) The environmental and agricultural factors that regulate malaria vector productivity and diversity in Mwea irrigation scheme, Kirinyaga district, Kenya. Kenyatta University, Kenya (ongoing).

S. Muriu (Kenya) Impact of vector control on malaria transmission in a riceland ecosystem, Mwea Kenya. University of Nairobi, Kenya (ongoing).

Impact

- The project has led to improved understanding of *Anopheles* larval ecology and habitat productivity leading to effective targeting of larval habitats.
- Interest has been raised among communities on the role of larval management in the control of malaria vectors.
- PhD level training for 1 student on *Anopheles* ecology and control conducted.

Ecosystem Approach to Human Health: Integrating Malaria Control Interventions with Development Strategies in Kenya

Background, approach and objectives

Malaria is widely recognised as a major health and social problem among rice farming communities in Mwea, arising principally from agricultural associated activities which provide suitable conditions for mosquito breeding. The *icipe*/IWMI project (2004–2006) in its multidisciplinary approach embraces the need to develop strategies for empowering communities to undertake vector control actions at community and household levels.

The IVM approach implemented has played a significant role in reducing the burden of malaria among communities in the study sites. The incidence of febrile illness episodes, measured using a 2-week recall at household level, has reduced from 21.7% pre-intervention (April 2005) to 12.2% post-intervention started by the end of the year. Malaria prevalence has equally been reduced from a figure of 9.8% in 2005 to 0%. The long spell of drought in 2005 could have contributed substantially to the reduction in malaria prevalence rates. People's knowledge and participation in malaria control actions has been substantially enhanced through school and community education programmes as assessed by the household and school questionnaires. Bednet coverage has increased from 27% in 2004 to 67.3% in 2005 while the rate of bednet use (no. of people who slept under a net last night) had increased from 47 to 69.7% by the end of 2005. There has been 2-fold increase in household involvement in environmental management (8.9% pre-intervention to 15.2% post-intervention). The project has further initiated a process of consultation and cooperation among stakeholders through the Ministry of Health, an initiative that has improved communication between the Ministry and other stakeholders working on malaria in Mwea division.

The project has the following five specific objectives:

- To strengthen cooperation between community, government departments and international and non-governmental organisations towards malaria control;
- To evaluate the impact of integrated anti-malarial interventions on malaria vector populations and prevalence of malaria parasites among the community;
- To assess people's behavioural change towards malaria control actions when interventions are integrated and conveniently phased in the context of an ecosystem approach to human health;
- To conduct further research on the feasibility of seasonally rotating the cultivation of rice and soy bean as an agroecosystem strategy for simultaneously enhancing household incomes, improving nutrition and reducing malaria-vector breeding habitats;
- To disseminate information across all levels.

Participating scientists and students: *J. Githure, J. Shililu, V. Kimani, C. Kabutha, L. Kabuage (University of Nairobi), C. Mutero (SIMA), G. Jayasinghe (IWMI), P. Ng'ang'a (MPH student), R. Wanjogu (PhD student)*

Assisted by: *J. Wauna, E. Mpanga, P. Barasa*

Donor: *International Development Research Centre, Canada*

Collaborators: *University of Nairobi, JKUAT, KEMRI, International Water Management Institute*

Work in progress

1. Strengthening cooperation between community, government departments and international and non-governmental organisations towards malaria control

Enhancing cooperation and coordination is a long-term goal and as a contribution to this process, the project launched a process of consultation and collaboration through the Ministry of Health, the logical home for this process. As part of the process, the project supported the Ministry of Health (October 2005) to convene a district-wide forum for stakeholders working in the health sector. The meeting was attended by 23 local, national and international organisations. The purpose of the meeting was to:

- (i) share and exchange information on health and malaria control programmes currently being implemented in Kirinyaga district, with emphasis on Mwea division;
- (ii) establish gaps and overlaps between different organisations as a basis for possible collaboration;
- (iii) develop a strategy for effective sharing of information between different actors, including the Ministry of Health.

The meetings identified areas that needed strengthening, including overall coordination by the Ministry of Health, reporting of project activities to Ministry of Health and cooperation between organisations working on health in Mwea.

The project approach was characterised by high level consultation and interaction with different stakeholders. This resulted in a broad-base of stakeholders and a high level of awareness at all levels. Tools such as focus group discussions (FGDs), key informants (KIn) and group discussions were widely employed during workshops and meetings. The process was interactive and incremental, with every step providing a link to others.

As recommended by the stakeholder workshop, the project held two meetings in each of the four study villages. The first meeting discussed the details of the project, comparing the activities with community action plans (CAPS) developed during the first phase of the project. A second meeting developed a framework for implementation of project activities (Table 1). Through this process, communities became aware of the project and defined ways in which they would be involved. In total, 165 community representatives from the four villages were reached through this process. To effectively work with schools, consultations with the Ministry of Education were held early in the project. Following these consultations, the project got clearance to work with 8 schools.

Table 1. Summary of achievements: Stakeholder and community consultation

Activity and timing	Participants	Number reached	Areas discussed
April–May 2004: Establishment of stakeholder database	• Project team • Field assistants in four villages		
July 2004: Area-wide stakeholder workshop	• Community • Government departments • Church-based organisations • Community-based org.	48	• Awareness on the project • Areas of possible collaboration with partners • How to enhance participation
August 2004: Village level awareness and planning	• Community • Chiefs • Ministry of Health	165	• Awareness on the project • Establishment of community structures for implementation
October 2005: Health stakeholders meeting	• Health stakeholders • Ministry of Health	23 Organisations	• How to improve coordination • How to improve reporting

2. *Evaluating impact of integrated anti-malarial interventions on malaria vector populations and prevalence of malaria parasites*

The impact of integrated anti-malarial interventions on malaria vector populations and prevalence of malaria parasites and other disease outcome indicators was studied in Mwea division, Central Kenya. It was envisaged that improved community access to knowledge and the development of a strategy for phased application of integrated vector-management (IVM) would greatly impact the burden of disease. The key interventions applied included: knowledge dissemination/awareness creation through school and community-based programmes, distribution and use of long lasting insecticide-treated bednets (LLNs), and environmental management.

Malaria prevalence

Prevalence was used as a measure for assessing changes in malaria presentation following the implementation of the IVM package. A pre-intervention measure of malaria prevalence was conducted in April 2005 while the post-intervention measures were done in December 2005 to capture changes in disease burden following distribution of LLNs and the continuous knowledge dissemination for community involvement in vector interventions. Apparently healthy children (≈100 children per village) under 9 years of age were recruited into the study following consent by parents or guardians. The surveys were then conducted by Ministry of Health staff from Kimbimbi sub-district hospital following a written consent by the Medical Officer of Health (MoH) Kirinyaga District and ethical clearance by the Ethical Review Board of the Kenya Medical Research Institute (KEMRI). Thin and thick blood smears were prepared from finger prick blood samples. After Giemsa staining, parasitaemia was estimated by counting the number of malaria parasites against 200 white blood cells. Two independent slide readings were done to accurately assess parasitaemia and gametocyte levels. Positive cases were treated with standard malaria drugs as recommended by the MoH, Kenya. The data generated indicated very low levels of malaria infection among the children sampled in the 4 study sites over the 2 sampling periods. In the pre-intervention sampling phase (April 2005) no infections were recorded in Mbuinjeru ($n = 53$) and Ciagi-ini ($n = 29$), the two rice growing villages. The highest prevalence of malaria was recorded in Murinduko (38%, $n = 63$), a village 15 km away from the rice growing area of the tenant scheme. The malaria prevalence rate in Kagio, a non-tenant rice growing village was equally low (1%, $n = 85$). No malaria infections were recorded in the post-intervention survey. This result may suggest a likely effect of the interventions and to some extent the effect of the long spell of drought experienced in the area in 2005.

Febrile illness (fever) episodes

Data on malaria/fever episodes was collected at 3 time points, pre-intervention (April 2005), mid-term (November 2005) and post-intervention by the end of the year based on 2-week recall of fever cases among respondents in selected households. Interviews using structured questionnaires were administered to heads of households (or spouses) from the four study villages and records of febrile history among household members, symptoms and action taken were recorded. It was observed that of the total febrile cases reported ($n = 264$), 90.9% ($n = 240$) actually thought the cause was malaria and 99% of those parasitologically diagnosed tested positive for malaria parasites, an indication that febrile history would measure the burden of disease with up to a 40% precision. Comparisons between the pre-intervention and mid-term surveys indicated a slight drop in number of febrile episodes reported (from 15.3 to 13.8%) and a significant decrease in households reporting cases of fever during the mid-term survey (42%) compared to the pre-intervention phase (48.2%) based on a 2-week recall period.

Vector surveillance

Adult mosquitoes were sampled once fortnightly in 10 randomly selected houses in each of the four villages from January 2005 (and will be sampled to April 2006) using pyrethrum spray collection (PSC) method. All collected mosquitoes were identified morphologically to species. A total of 22,666 adult female mosquitoes representing 7 species were collected over the period of study. *Anopheles arabiensis* was the predominant species comprising 98.8% of the total *Anopheles* collection. Other species collected in only low densities included: *A. funestus, A. pharoensis, A. coustani, A. maculipalpis, A. pretoriensis* and *A. rufipes*. The density of *A. arabiensis*, expressed as number of female mosquitoes per house varied significantly among the 4 study sites (F = 17.314, df = 3, 1089, $P < 0.001$) with high densities being recorded in the Mbuinjeru (12.3 *Anopheles*/house) followed by Ciagi-ini (8.7 *Anopheles*/house) and Kiamaciri (7.5 *Anopheles*/house). The lowest density of *A. arabiensis* was recorded in Murinduko (1.9 *Anopheles*/house). The data showed a general decline in vector densities following implementation of the IVM package. Overall, pre-intervention records of anopheline densities (9.5 *Anopheles*/house) were significantly higher (F = 42.78, df = 1, 1089, $P < 0.001$) compared to the mid-term collections (4.2 *Anopheles*/house) in the 4 sites (range: pre-intervention 3.03–14.4 and mid-term phase 0.75–9.5). The trends in vector densities over the 9-months study period is shown in Figure 1. Biting rates expressed as number of bites per person per night was significantly higher during the pre-intervention phase (mean: 7.28 bites/person/night) compared to the post-intervention phase (3.1 bites/person/night). Site-specific data showed similar declining trend for biting rates in the 4 villages over the 2 sampling phases.

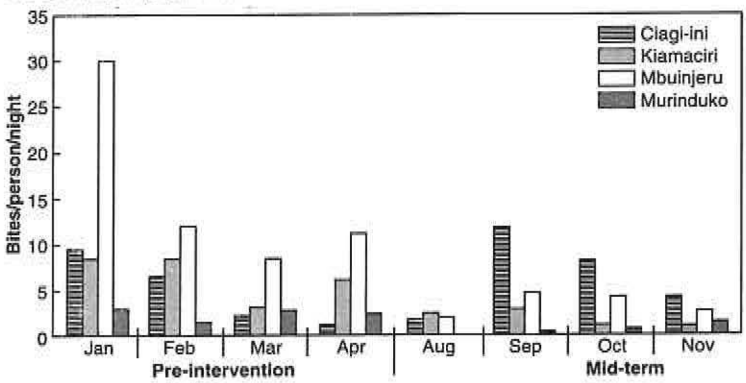


Figure 1. Temporal distribution of *Anopheles arabiensis* during the pre-intervention and mid-term phases in Mwea, Kenya

Vector abundance and associated house and ecological factors

Assessment of factors associated with vector abundance revealed that densities of anopheline mosquitoes in the houses were significantly associated with wall type. Significantly higher numbers of *Anopheles* were collected in mud walled houses compared to houses with stone walls, wooden walls and tin walls. Size of eaves and distance of house to nearest larval habitat did not significantly affect *Anopheles* abundance and distribution. Two-way interactions based on GLM ANOVA model examining the effect of wall type, eave size and distance of house to nearest larval habitat showed significant interactions at four levels (Table 2). The interaction between site and distance to nearest larval habitat, site and size of eaves, site and wall type, and wall type and distance to nearest larval habitat were significant.

Table 2. Analysis of variance examining the effects of site, wall type, size of eaves, distance of house to nearest larval habitat and their interactions on vector densities

Factors	df	F	P values
Village/site	3	17.31	< 0.001
Intercept	1	286.31	< 0.001
Size of eaves	3	1.577	0.193
Distance to nearest larval habitat	2	0.020	0.980
Wall type	3	3.413	0.017*
Site x eaves	6	2.032	0.059
Site x distance to larval site	4	6.291	0.000*
Eaves x distance to larval site	5	.208	0.959
Site x wall type	5	7.545	< 0.001*
Eaves x wall type	6	1.943	0.071
Distance to larval site x wall type	5	2.709	0.019*
Error	1032		
Corrected total	1089		

The model accounted for 48.4% in the variation in *Anopheles* densities in the study site.
Adjusted R^2 = 0.456.
*Significant interactions.

Bednet use, coverage and environmental management

A total of 2629 long lasting insecticide-treated nets (LLNs) were distributed to the 4 villages by teams of community health workers (CHWs). The distribution plan aimed at covering all children and adults at a rate of one net per two people and with regard to sleeping houses. Baseline data from the pre-intervention survey phase indicated a generally low level of bednet coverage in the 4 study villages with an average of 1 net per sleeping house except in Murinduko where a figure of 0.2 nets per sleeping house was recorded (range: 0.1–0.5). The proportion of nets per person in Murinduko was equally low (0.1 nets per person or 16.4 persons per net) while in the other 3 villages an average of 3 persons per net was reported, an indication that use of ITNs was generally low in the study villages (range: 2.3–16.4 persons per net). The rate of net use which was expressed as the proportion of number of persons who slept under a net to the number of persons who had access to a net was high (range: 94–100%) showing that there is a high likelihood of net use (range: 94–100%) based on the household questionnaire administered pre-intervention. A similar trend was evident during the post-intervention phase (range: 89–99%). Overall, the number of respondents who reported having slept under a bednet the previous night was high during the post-intervention assessment (69.7%) compared to both the mid term (57.2%) and pre-intervention phase (47.0%) giving at least a 32% increase in bednet use in the study villages following implementation of the IVM strategies.

Bednet coverage was generally low in the study sites, with Murinduko showing the lowest coverage with 1 net for about 16.4 during the pre-intervention while net coverage in the other villages was at least 1 net for 3 persons (Table 3). Overall the pre-intervention assessment gave an average of 1 net for 6 persons compared to 1 net for 2 persons at the post-intervention assessment period. Net coverage therefore increased from 27 to 67.3%.

Table 3. Bednet coverage and use pre- and post-intervention in Mwea, Kenya

	No. HH	No. Sleeping houses	No. People	No. Children	No. Bednets	Nets/ person	Persons/ net
				Pre-intervention			
Ciagi-ini	107	141	444	112	109	0.25	4.07
Kagio	106	162	482	117	169	0.35	2.85
Mbuinjeru	101	136	390	103	176	0.45	2.22
Murinduko	108	147	460	122	28	0.06	16.43
Total/Mean	**422**	**586**	**1776**	**454**	**482**	**0.03**	**6.39**
				Post-intervention			
Ciagi-ini	107	147	479	122	326	0.69	1.47
Kagio	106	162	493	123	272	0.56	1.81
Mbuinjeru	101	136	427	116	304	0.72	1.40
Murinduko	108	147	486	133	219	0.46	2.22
Total/Mean	**422**	**592**	**1665**	**494**	**1121**	**0.75**	**2.15**

The rate of community involvement in environmental management showed a significant increase with regard to clearing vegetation in canals with 0.9 and 14.9% households having reported taking action at the pre-intervention and post-intervention survey, respectively (Table 4). The proportion of households involved in filling/levelling of breeding sites rose from 23.5% (pre-intervention) to 30.4% (post-intervention).

Table 4. Environmental management strategies employed at household level

	Ciagi-ini		Kagio		Mbuinjeru		Murinduko		Total	
	#	% HH	#	%HH	#	%HH	#	%HH	#	%HH
Pre-intervention										
Clearing HH refuse/ proper waste disposal	6	23.1	37	56.1	28	41.2	28	52.8	99	46.5
Filling/levelling breeding sites	10	38.5	19	28.8	7	10.3	14	26.4	50	23.5
Clearing vegetation in canals					2	2.9			2	0.9
Clearing bushes/ vegetation around houses	16	61.5	54	81.8	57	83.8	41	77.4	168	78.9
Others			1	1.5	1	1.5	3	5.7	5	2.3
Total Respondents/%	26	100.0	66	100.0	68	100.0	53	100.0	213	100.0
Post-intervention										
Clearing HH refuse/proper waste disposal	56	62.2	70	82.4	44	57.9	35	41.2	205	61
Filling/ levelling breeding sites	41	45.6	45	52.9	13	17.1	3	3.5	102	30.4
Clearing vegetation in canals	7	7.8	37	43.5	3	3.9	3	3.5	50	14.9
Clearing bushes/vegetation around houses	59	65.6	84	98.8	73	96.1	71	83.5	287	85.4
Others	0	0	0	0	1	1.3	0	0	1	0.3
Total respondents/%	90	100	.85	100	76	100	85	100	336	100

3. Assessing people's behavioural change towards malaria control actions when interventions are integrated and conveniently phased in the context of an ecosystems approach to human health

PRA tools were applied to assess peoples' actions and attitudes towards malaria interventions at household and community levels. These included structured questionnaires, focus group discussions and direct observations of people's behaviour. Educational activities and information dissemination were conducted through training of trainers (ToTs), both men and women comprising of primary school teachers from local primary schools and village-based community health workers (CHWs). After the training the ToTs in turn taught primary school children and the community, respectively. A total of 44 community participants were selected on the basis of their interest in community health.

Based on the results of the PRA tools, malaria was ostensibly a major public health disease in the study area. A total of 93% of successful respondents in the four-study villages rated malaria as the most frequently occurring disease. Most respondents in the irrigated villages frequently mentioned bilharzia and typhoid, while common colds and intestinal worms were perceived to be most frequent after malaria and typhoid in the non-irrigated villages. In the four study villages, there were significant variations between villages in the way respondents recognised the signs and symptoms of the disease. For example, feeling cold, fever and headache were the three most mentioned symptoms in order of frequency in Ciagi-ini while general body weakness, headache and fever, were the most mentioned symptoms in Kagio. At least 95% of all respondents cited mosquito bite as the main cause of malaria. The non-biomedical multiple causes mentioned included being caught up in rain shower, dirty home surroundings, drinking polluted water and eating raw mangoes.

Through the training of trainers (ToTs) the project has managed to initiate a malaria awareness and control curriculum through participation of primary school children. This will be sustained within the target schools and hopefully the Ministry of Education would use the same model to scale up to other schools in the district and beyond. Overall, the data obtained from the pre- and post-intervention tests shows that the project has had a notable impact on the children's and communities' knowledge-base on malaria.

4. Agronomic and socio-economic feasibility of seasonally alternating rice cultivation with soya bean as an agroecosystem strategy for enhancing household incomes and reducing malaria vector breeding habitats

Research findings during the first phase of the IDRC-funded project (Mwea phase I: 2001–2003) indicated presence of malaria risks associated with farming practices as a result of high vector population due to prolonged flooding in paddies. Other negative impacts related to agronomic practices included poor soil fertility and structure due to continuous monocropping of rice; poor nutrition (based on rice staple) and apparent lack of grain legume cultivation; idle resources (labour, land, water) during off-season for rice and finally, poverty leading to poor access in health seeking (preventive and curative). These findings pointed at the importance of investigating a suitable agricultural intervention strategy that would directly intervene on malaria through vector control and indirectly via economic empowerment of the community. Alternating rice cultivation with soya bean (a dryland legume crop) was considered as the agricultural intervention of choice for Phase 2 research since the system was likely to impact positively on the above factors. Studies were therefore designed and conducted to investigate the agronomic and socio-economic feasibility of rice–soya bean production system in Mwea. The research findings would assist in making recommendations on possible adoption of this system by the farmers.

Agronomic and economic feasibility study

The soya–rice system was found to be agronomically feasible through assessment of crop yields (soya and rice), soil fertility, soil organic matter and gross margin/ income. Results of the agronomic studies have shown positive effects on soil fertility improvement from growing of soya followed by rice crop. This was clearly demonstrated through higher yields when the soya–rice treatment in the study was compared with rice–rice and fallow–rice treatments. The fertility response trial showed that rice grown after the soya crop (EAI variety) compared with that of rice–rice treatment gave a significantly ($P < 0.05$) higher yield (5531 vs 4667 kg/ha), the difference being 884 kg/ha equivalent to 11 bags/ha. Gross margin analysis indicated multiple benefits in the annual cropping year, associated with soya cultivation which translated into considerable total profit (Kshs 53,000/ha) annually for the farmer. These are positive indications on direct effects on soil fertility and structure via increase in soil nitrogen and organic matter.

Mapping

Mapping was done to enhance interpretation and application of results on potential of the rice–soya system in the context of the entire Mwea Irrigation Scheme. It captured various features depicting the periods of necessary and unnecessary flooding in the irrigated area, hence indicating where soya cultivation could fit in within the prevailing cropping cycles. About 83% of Scheme farmers harvest their rice crop in December (the rest in January), allowing regeneration of a ratoon crop which they harvested in February–March. Water was drained around harvest time and returned for growth of the ratoon crop. This period was followed by early flooding of the land in April–May awaiting rotavation which was done anywhere between this time and August–September when the rice crop (seedlings) was transplanted. This unnecessary flooding for about 4 months could be avoided if soya was grown to fill the gap, utilise the prevailing long rains, dry up the land and yield the benefits stated earlier. This would extensively reduce the vector breeding habitats scheme-wide.

Outgrowers in the irrigated area adjacent to but outside the official Scheme boundaries occupied an equivalent of 25% of the total Scheme area, planted their rice in December and harvested in March. This group could also grow soya after this main crop in a similar pattern to scheme farmers. This could further widen the dryland area during the stated long rains season increasing the scope for vector control.

Information and dissemination

Village sensitisation meetings on the project were well attended and the general response to proposed soya cultivation was positive as farmers lauded the soil fertility benefits which were manifested through exceptionally high yields when a rice crop followed a soya bean crop. The training and dissemination day at the end of the project became the highlight of the soya studies among the local communities and was attended by many farmers. Those attending included the Training of Trainers (ToTs) group from the study area (previously trained by the project as community health workers), village elders, local farmers, representatives of organised farmer groups, local stakeholder institutions, field technicians and the project research team. The ToTs were both teachers in local primary schools and trainers from the study villages. Action plans for soya field trials were also presented in this forum mainly to solicit technical and financial support from stakeholders that would facilitate implementation of these plans by farmers.

Output

Journal articles

Mutero C. M., *Kabutha C.*, Kimani V., Kabuage L., Gitau G., *Ssennyonga J., Githure J.*, Muthami L., Kaida A., Musyoka L., Kiarie E. and Oganda M. (2004) A transdisciplinary perspective on the links between malaria and agroecosystems in Kenya. *Acta Tropica* 89, 171–186.

Mutero C. M., *Ng'ang'a P. N., Wekoyela P., Githure J.* and Konradsen F. (2004) Ammonium sulphate fertiliser increases larval populations of *Anopheles arabiensis* and culicine mosquitoes in rice fields. *Acta Tropica* 89, 187–192.

Shililu J., Grueber W. B., *Mbogo C. M., Githure J. I.*, Riddiford L. and *Beier J. C.* (2004) Development and survival of *Anopheles gambiae* eggs in drying soil: Influence of the rate of drying, egg age, and soil type. *Journal of the American Mosquito Control Association* 20, 243–247.

Conferences attended

53rd Annual Meeting of the American Society of Tropical Medicine and Hygiene, 7–11 November 2004. Miami Beach, Florida, USA.

54th Annual Meeting of the American Society of Tropical Medicine and Hygiene, 11–15 December 2005. Washington DC, USA.

The Fourth Pan-African MIM meeting, 13–18 November 2005. Yaounde, Cameroon.

Working Group on Strategic Plan to Bridge Laboratory and Field Research in Disease Vector Control, 14–16 July 2004, Nairobi, Kenya.

WHO Study Group on Malaria Vector Control and Personal Protection, 10–12 March 2004. Geneva, Switzerland.

WHO Second Meeting of the Partnership for Integrated Vector Management in Africa, 22–23 April 2004. Doaula, Cameroon.

UNEP First Conference of Parties of the Stockholm Convention on Persistent Organic Pollutants, 2–5 May 2005. Punta del Este, Uruguay.

NIH meeting on Malaria in Urban Areas—Interdisciplinary Approach, 18–25 May 2005. Miami, USA.

SIMA Capacity Building Programme in Resource Mobilization Workshop, 24–26 November 2005. Dar es Salaam, Tanzania.

26th African Health Sciences Congress, 28 November to 1 December 2005. Ain Soukhna, Egypt.

Research proposals

NIH, Microbial control of immature *Anopheles* mosquitoes funded for five years (2003–2008).

NIH, Exploratory Centres. Urban malaria in Kisumu and Malindi. Funded for 3 years (September 2004–August 2007).

RTI-USAID, Community-based malaria vector control in Malindi District funded for one year (January–December 2005).

SIMA–IDRC, Agro-ecosystem management of malaria in the Mwea Rice Scheme funded for 2 years (May 2004–April 2006)

Global Fund, Control of malaria vectors in Kenya approved for 2 years, funded by Ministry of Health, Kenya.

Capacity building

PhD student

R. Wanjogu (Kenya) Alternating cultivation of rice and soybean as an agro-ecosystem strategy for enhancing household incomes and reducing malaria–vector breeding habitat. University of Nairobi, Kenya. 2004 (ongoing).

MPHE student

P. Ng'ang'a (Kenya) A study of factors affecting the implementation of malaria vector control measures in Mwea division, Kirinyaga district. Kenyatta University, Kenya. 2004 (ongoing).

MPH students

M. Oganda (Kenya) Determination of malaria in irrigated and non-irrigated villages of Mwea: A comparative assessment. University of Nairobi. 2003–2005 (completed).

L. W. Musyoka (Kenya) Treatment seeking for malaria in Mwea Division, Kirinyaga District. University of Nairobi. 2003–2004 (completed).

MSc student

J. N. Kuria (Kenya) An economic analysis of rice production in Mwea Irrigation Scheme. University of Nairobi (completed).

Malaria Control and Prevention in the Highlands of Western Kenya

Background, approach and objectives

Tropical Africa's ecosystems are in a critical state of permanent conversion as a result of human activities, like land-use. One consequence is the potential risks to human health. In addition, any ecosystem can also be disrupted by the reduction of native species populations and by the introduction of foreign species. Invasive species can be deliberately or unintentionally introduced, with potentially profound effects on humans. In particular, invasive mosquito species have aided in the spread of diseases. For instance, the *Aedes* mosquitoes from Africa and Asia have spread yellow fever and dengue worldwide.

Eighty (80) years ago, the highlands of western Kenya were malaria free. Since the end of the Second World War, this area shows epidemic malaria transmission pattern with the last outbreak occurring in 2002 when over 400 people died within 3 months. A range of etiological factors have been attributed to triggering these outbreaks, like climate change favouring vector and parasite survival, development of resistance against medications and insecticides, lack of community awareness and preparedness, to mention a few. In addition, *icipe*'s studies conducted in various sites of Nyando, Kisii Central, Gucha and Nyamira districts of Nyanza province over the last 2–5 years have revealed striking changes of land-use. These modifications are partly associated with a continued encroachment of human settlements and farming activities into the wetlands due to a variety of socioeconomic pressures like high population density and alternative income-generating activities like brick-making. The anthropogenic environmental interferences have also contributed to countless new larval habitats for malaria vectors of the species *Anopheles gambiae*, *A. arabiensis* and *A. funestus*. The most abundant types of man-made larval habitats are brick-makers pits, fishponds, community water-points and trenches around sugar-cane fields, which all show a high degree of aggregation of the mentioned anopheline species. In addition we have found numerous *Anopheles gambiae* s.s. larvae in tree holes.

The project comprises three ongoing activities with 4 specific aims: (i) to determine the dry and wet season relative population densities of immature and adult malaria vectors in various habitat types for both targeted control interventions and malaria early warning; (ii) to utilise these data for water-management, e.g. source reduction, larviciding and introduction of larvivorous fingerlings; (iii) to provide sustainable intervention tools for malaria control and prevention through community training and participation in interventions and (iv) to conserve the ecology and functions of wetlands and avoid the formation of new man-made larval habitats. The strategic approach includes the following components of integrated vector management (IVM) for reducing malaria transmission:

- spatial and temporal assessments of malaria mosquito species diversity and relative population density in natural (swamps, marshes) and man-made habitats during dry and wet seasons: immature stages in larval habitats and adult stages in houses (indoor spray catches) or caught in the field using CDC light traps;
- spatial and temporal parasitometric surveys in Kisii district in collaboration with the Ministry of Health (MoH);
- validation of a malaria early warning system (MEWS) aimed at correct and timely prediction of malaria outbreaks in the highlands (Kisii, Gucha and Nyamira districts);
- field interventions for reducing vector populations through: (1) large-scale water management, (2) large-scale larviciding with Bti and/or neem *(Azadirachta indica)* raw materials, (3) reactivation of abandoned fishponds and (4) large-scale distribution of ITNs;
- community training for malaria awareness creation and technology transfer; community participation in interventions; community wetland groups (CWGs) and eco-schools involved in wetland conservation with special emphasis on reforestation and avoidance of man-made larval habitats;
- local malaria task force groups and stakeholders meetings for information flow, planning of activities and coordination of interventions conducted by community-based organisations (CBOs).

Participating scientists: *F. Omlin, A. Howard, S. Gichia, A. Hassanali, I. Gordon, J. Carlson, J. Vulule*

Assisted by: *E. Nyarangi, E. Odhiambo, R. Osano, E. Adongo, E. Onganyi and field assistants and trainees*

Donors: *Government of Finland, Toyota Environmental Education Foundation, Biovision, UNICEF*

Collaborators: *National Malaria Control Programme, Kenya; Kenya Ministries of Health; Environment and Natural Resources and Wildlife; Education, Science and Technology; Livestock and Fisheries Development at provincial, district and local levels; provincial, district and local government administration; local community groups like CBOs (including women and youth groups), KEMRI Kisumu, Kenya; Merlin Kisii, Kenya; Tulane University, USA; Population Services International Kisumu/Nairobi, Kenya*

Work in progress

1. Brick-making sites and abandoned fishponds as most productive larval habitats for malaria vectors

Our previous work has shown that one of the most abundant habitat types in the highlands of western Kenya containing *Anopheles* larvae are brick-making pits. Considering other important ecological variables like habitat age, vegetation and predator species diversity of those pits, we affirmed that vegetation and habitat age were positively associated with predator diversity and negatively associated with malaria mosquito density. Since brick-making became the main income-generating activity in the area within the last 2 decades, it was appropriate to target these abundant larval habitats in collaboration with the Ministry of Health and local community groups. Indoor spray catches revealed that houses situated near brick-making sites or other man-made habitats had more vectors than houses which are near to natural larval habitats, like swamps or marshes. These data have been used by the district public health officer (DPHO) to establish a selection plan of targeting houses for indoor residual spraying (IRS) as well as for the distribution of ITNs.

In Kisii district, a fishpond census conducted in collaboration with the Fisheries Department, revealed a total of 262 fishponds in March 2004. From each pond the following variables were assessed and recorded: location/division, pond size, maintenance status, presence/absence of fish, and presence and number of mosquito larvae (Table 1). Of the 186 active (with fish) ponds found, 148 (80%) were well maintained whereas only 13 (17%) of the abandoned ponds (no fish) were well maintained (χ^2 = 88.87, P < 0.0001). The mean number of *A. gambiae* s.l. found in the abandoned fishponds was higher than the mean number in active fishponds and there were four times the number of *A. funestus* and culicines in abandoned ponds compared with active fishponds (Table 1). These data reveal that fish-farming in the district is not properly conducted and high

Table 1. Kisii districtwide fishpond census data and mean larval mosquito counts

	Condition of fishpond	n	Area [m²] (± SE)	*A. gambiae* s.l. Mean (± SE)	%	*A. funestus* Mean (± SE)	%	*A. pretoriensis* Mean (± SE)	%	Culicine Mean (± SE)	%	Total Mean (± SE)
Active	WM	148	130.0 (± 7.58)	1.68 (± 0.21)	54.4	0.88 (± 0.13)	28.5	0.02 (± 0.02)	0.7	0.51 (± 0.10)	16.4	3.08 (± 0.28)
	NWM	38	148.9 (± 16.78)	1.66 (± 0.47)	32.6	2.16 (± 0.64)	42.5	0.00	0.0	1.26 (± 0.59)	24.9	5.08 (± 0.94)
	Total	186	133.9 (± 6.94)	1.67 (± 0.19) a	47.9	1.14 (± 0.17) b	32.6	0.02 (± 0.01) c	0.5	0.66 (± 0.14) d	19.0	3.49 (± 0.30)
Abandoned	WM	13	118.2 (± 22.64)	11.38 (± 3.12)	63.8	4.15 (± 1.66)	23.3	0	0	2.31 (± 0.89)	12.9	17.85 (± 2.79)
	NWM	63	143.2 (± 11.03)	11.97 (± 3.69)	61.1	4.62 (± 1.02)	23.6	0.02 (± 0.02)	0.1	2.98 (± 0.91)	15.2	19.59 (± 3.97)
	Total	76	138.9 (± 9.93)	11.87 (± 3.1) e	65.6	4.54 (±0.89) f	25.1	0.01 (±0.01) c	0.1	2.87 (± 0.77) f	9.3	19.29 (± 3.32)

WM, well maintained, NWM, not well maintained, %, reflects the relative abundance of each mosquito type within the different pond types.
The same letters in a column indicate no significant difference between the pond types within the mosquito types.
The same letters in a row indicate no significant difference between the mosquito types within the pond types.

risk for malaria transmission emerges from the numerous abandoned fishponds, which are in close proximity to homesteads. The fish-farming community of Kisii district was made aware of the health risk and as a result, the supply of fingerlings has been taken up by the district fisheries officers. In addition, ongoing community training sessions were extended into locally organised 'Malaria and Environment' community workshops.

In the western Kenya highlands, the larvivorous fish *Oreochromis niloticus* L. (Perciformes: Cichlidae) (formerly *Tilapia nilotica*) is commonly farmed and eaten. We introduced this fish into abandoned fishponds and measured the effect on the numbers of mosquito larvae against untreated controls for six months. During this time all ponds were regularly cleared of emergent vegetation and fish re-stocking was not needed. After *O. niloticus* introduction, mosquito numbers dropped in the treated ponds and, after 15 weeks, there was more than 94% reduction in all *Anopheles* (Diptera: Culicidae) species, with culicines reduced by over 75% (Table 2). The numbers of mosquitoes in the control pond increased during this time due to climate reasons and after 15 weeks there were significantly higher numbers of all mosquito species in the control when compared to the treated ponds. This study reports the first field intervention data of *O. niloticus* and shows that this species, already a popular fish in western Kenya, is highly effective in larval control and may become sustainable by also offering a source of protein and income to people in rural areas.

Table 2. Introduction of larvivorous fish fingerlings into fishponds in Kisii district

	Mean (± SE)	*Anopheles gambiae* s.l.	*A. funestus*	*A. pretoriensis*	Culicine
Pond A	Before	4.50 (± 0.56) a	0.06 (± 0.04) a	0.05 (± 0.03) a	2.34 (± 0.38) a
	After	14.08 (± 0.93) c	2.45 (± 0.47) c	0.17 (± 0.04) c	4.51 (± 0.44) c
Pond C	Before	11.38 (± 0.67) b	0.57 (± 0.19) b	0.44 (± 0.07) b	2.81 (± 0.47) a
	After	1.53 (± 0.28) d	0.43 (± 0.14) b	0.03 (± 0.02) d	0.72 (± 0.18) d
	% reduction	95.8	98.3	98.1	86.7
Pond D	Before	5.40 (± 0.34) a	0.61 (± 0.14) b	0.51 (± 0.10) b	1.29 (± 0.21) b
	After	1.00 (± 0.15) d	0.56 (± 0.10) b	0.01 (± 0.01) d	0.63 (± 0.13) d
	% reduction	94.1	97.5	99.5	75.4

'Before' and 'after' relates to the 15 weeks before and 15 weeks after *Oreochromis niloticus* introduction. Percent reduction was calculated using Mulla's formula. The same letters in a column indicate no significant difference; there is no relationship between the letters within the different rows.

2. *Spatial and temporal distribution of anopheline mosquitoes in tree holes*

Preliminary investigations revealed high larval densities of *Anopheles gambiae* in the phytotelemata of introduced tree species in both the Lake Victoria basin and the highlands of western Kenya. This study was conducted to explore the presence of *Anopheles* larvae in tree holes. At five study sites in western Kenya, trees were examined for presence of tree holes and mosquito larvae. In Kisumu on the shores of Lake Victoria, 14 tree holes from 10 flamboyant trees were evaluated when containing water and when dry. Correlations were made between larval densities, habitat potential volume and height above ground.

Oviposition choice experiments were conducted in the laboratory using gravid *A. gambiae* placed into cages with water from tree holes and alternative source (Table 3). Nineteen (19) species of trees were found with *Anopheles gambiae* larvae. Habitat height was negatively correlated with *Anopheles* density (Figure 1). In cage experiments, ovipositing *A. gambiae* preferred water from tree holes over distilled or lake water.

Table 3. Oviposition choice experiments comparing preference of gravid *Anopheles gambiae* for water from trees vs control sources

Water sources	Category	N	Observed prop.	Test prop.	P-value (2-tailed)
Flamboyant tree	Tree	8	0.89		
vs	Control	1	0.11	0.50	0.039
distilled water	Total	9	1.00		
Flamboyant tree	Tree	20	0.71		
vs	Control	8	0.29	0.50	0.038
lake water	Total	28	1.00		
Leucaena tree	Tree	8	0.80		
vs	Control	2	0.20	0.50	0.109
distilled water	Total	10	1.00		
Leucaena tree	Tree	16	0.76		
vs	Control	5	0.24	0.50	0.027
lake water	Total	21	1.00		

Mosquitoes oviposited on only one of the two substrates offered. N refers to number of times a mosquito oviposited on a given substrate type (tree vs control). A binomial test for significance was performed to generate a P-value.

In conclusion, cultivating exotic tree species has changed the habitats available to mosquitoes. The large flamboyant tree holes are similar in size to ground pools traditionally used by *A. gambiae* larvae. Affinity of *A. gambiae* in flamboyant trees to holes closer to the ground suggests a connection between tree holes and ground pools. Recoveries of *Anopheles* from dry and humid tree holes suggests desiccation-resistant eggs similar to *Aedes* species. These results provide sufficient evidence that *A. gambiae* is well adapted for exploiting tree holes as larval habitat in the absence of ground pools or polluted habitats. As such, tree holes should be incorporated into malaria surveillance and control strategies in Africa, with particular emphasis on urban settlements, where ornamental trees are planted and continue to be planted.

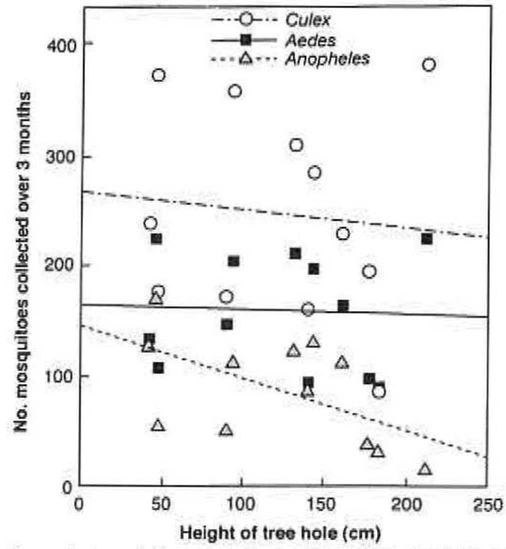


Figure 1. Association of mosquito population densities in 14 tree-holes with height over ground

3. *Adaptive management for health improvement in Nyabondo, western Kenya*

The adaptive management approach was applied in a 30 km² area in Nyabondo (Nyando district) to improve the malaria situation of the communities. Brick-making is the main income-generating activity and shows a comparable pattern to the Kisii highlands. Following baseline investigations, the main interventions were water management for vector source reduction, larviciding using *Bti* and neem raw materials and distribution of ITNs. In addition, monitoring of both vector densities and malaria infection rates were supported by the application of GIS/GPS technologies. Many of the activities on the ground have been implemented through community interest groups and the coordination was established through a local malaria task force group representing administrative and health sectors and other stakeholders.

A comparison of GIS data obtained during both dry and wet seasons in 2005 shows an increase of stagnant water during the rainy season in areas where intense brick-making activities were carried out. From a total of 15 km², the water-surface increase during the wet season was plotted against the respective estimated brick-making surface in the dry season (Figure 2). The paired sample analysis reveals a positive linear regression with the equation $y = 937.45x - 2690.6$ ($R^2 = 0.3279$). By comparing the increased size of the water-body per km² with the number of *A. gambiae* s.l. caught in nearby houses, a positive linear regression ($y = 0.7252x + 1.4106$; $R^2 = 0.3423$) was demonstrated (Figure 3). In contrast, t-tests did not show a positive regression for both *A. funestus* and *Culex* mosquitoes when their absolute numbers in each one km² was compared with the respective water-surface increase.

These data exhibit 'hot spots' where high numbers of resting *A. gambiae* s.l. are found in houses surrounded by stagnant water within the brick-making sites. Obviously, the gradual degradation of the swampy area and its continued substitution by brick-making in Nyabondo lead to flood-like situations occurring after heavy rains. As a result, we observed countless pits in which malaria vector immature stages were found in high densities. The well-known association between larval habitats and homesteads as focal places for malaria transmission constitutes a strategic element for properly conducted IVM taking into consideration that all houses (N > 5080) within the study area were situated close to larval habitats.

Water-drainage canals were built over a total length of over 16 km, about 11,000 ITNs were distributed to the communities and 3 large-scale applications of larvicides was done. Comparing the monthly malaria prevalence rates of 2002–2004 with those of 2005, there was a clear trend of reduced malaria transmission within the Nyabondo communities.

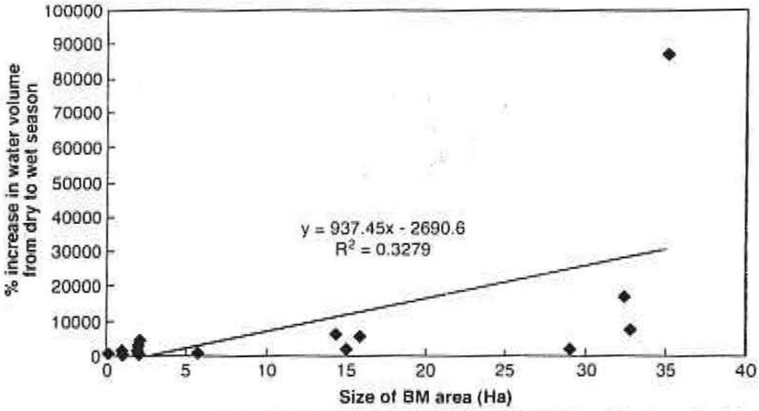


Figure 2. Association of increased water surface in the rainy season with size of brick-making (BM) estimated in the dry season

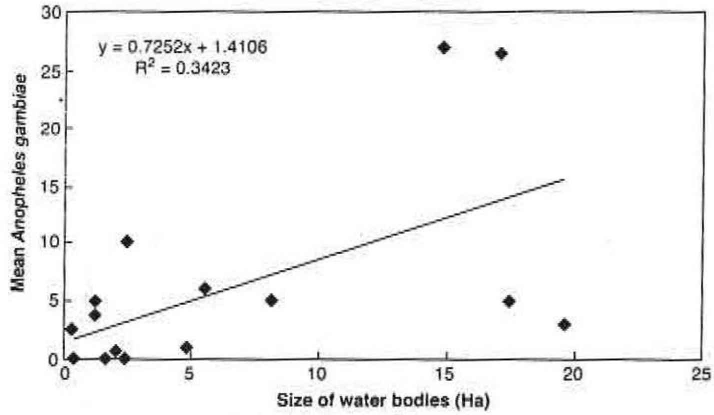


Figure 3. Association of *Anopheles gambiae* s.l. immature stages (relative population densities) and size of water bodies

Output

Journal article

Carlson J. C., Byrd B. D. and *Omlin F. X.* (2004) Field assessments in western Kenya link malaria vectors to environmentally disturbed habitats during the dry season. *BMC Public Health* (electronic resource) 4, 33–39.

Reports

Quarterly reports to Government of Finland.
Quarterly reports and end of year report to Biovision.
Progress report to Toyota Foundation.
Progress and project end reports to UNICEF.
Internal report: Highlights of the Environmental Management Programme.

Conferences attended

African Health Science Conference (Nairobi, 2004). Attended by: F. X. Omlin, S. K. Gichia, J. Vulule.

19th Research-in-Progress Meeting of the Royal Society of Tropical Medicine (London, 2005) Attended by: A. Howard and F. X. Omlin.

Research proposal

Toyota Environmental Education (Toyota Environmental Activities Grant, Tokyo, 2004) "A novel education program in environmental health and conservation for wetland communities in western Kenya: Sustainable rural development programme through synergistic integration of environmental education into human health and better livelihood" (funded, October 2004–September 2007).

Capacity building

Training of 1904 community members on malaria vector source reduction in Kisii and Gucha districts.

Impact

- Community members understand the inter-relationship between malaria and the environment.
- Community members are making use of that newly gained knowledge by reducing the numbers of mosquito larval habitats and applying botanical larvicides.
- Changed land-use patterns lead to increased numbers of malaria vector larval habitats.
- The governmental public health sector are aware of the importance of integrated vector control in the fight against malaria.
- In some intervention areas, there is a decrease in malaria mortality and morbidity.

The Applicability of Available Technologies for Adaptive Integrated Malaria Vector and Environmental Management at Malindi

Background, approach and objectives

Human health improvement through integrated malaria vectors control at Malindi will be achieved by the development and implementation of adaptive integrated mosquito population management for human health improvement. The operations are guided by decision-support tools that make efficient use of monitoring information on adult abundance, breeding site presence and larval abundance.

The objectives are to:

- develop and implement adaptive mosquito population management for human health improvement.
- determine the feasibility and sustainabililty of a malaria control programme based on insecticide-treated nets, Bti, information, education and communication and environmentally friendly tools.
- develop decision-support tools that make efficient use of monitoring information on adult abundance, breeding sites presence and larval abundance.
- develop integrated vector management approaches for controlling mosquitoes in urban environments, e.g. use of bednets, Bti and EM.
- build the capacity of the community for malaria vector control.

Participating scientists: *C. Mbogo, J. Githure, P. Luethy, J. Baumgärtner, G. Gilioli[1], L. Kibe[2], E. Mushinzimana, J. Beier[3], B. Jacob[4], J. Keating[5]*

Assisted by: *J. Nzovu, S. Kahindi, C. Nyundo (KEMRI)*

Donors: *Biovision Foundation, NIH and RTI/USAID*

Collaborators: *Ministry of Health, Municipal Council of Malindi, Population Services International, KEMRI; [1]Dipartimento di Agrochimica e Agrobiologia, Università di Reggio Calabria, Italy; [2]Kenya Medical Research Institute, Centre for Geographic Medicine Research, Kilifi, Kenya; [3]Department of Epidemiology and Public Health, Miami University, FL, USA; [4]Illinois Natural History Survey, Centre for Ecological Entomology, Champaign, IL, USA; [5]Department of International Health and Development, Tulane University, New Orleans, LA, USA*

Collaborating department: *Population Ecology and Ecosystems Science Department*

Work in progress

1. Larval surveys and malaria prevalence studies in Malindi

Entomological investigations based on adult and larval collections, habitat characterisation and clinical malaria prevalence surveys were carried out in urban Malindi on the coast of Kenya since May 2005. Larval surveys indicate that more than 90% of the larval habitats are man-made and the predominant immature mosquitoes were culicines while only a few of the habitats contained *Anopheles* larvae. Majority of the *Anopheles* were observed in unused swimming pools. An examination of 600 schoolgoing children aged between 6–12 years in June and September 2005 revealed surprisingly low malaria prevalence. Overall, *Plasmodium falciparum* parasite prevalence in June was 22.5 and 12.2% in September with the majority of the cases coming from peri-urban and rural areas. No gametocytes or mixed infections were recorded. The low number of malaria cases and abundance of man-made breeding sites in urban centres suggests that prevention strategies based on vector control, with emphasis on environmental management, should be a central feature of urban malaria control programme.

2. Training activities for community-based vector control

Involvement with local community groups has provided a wealth of background information on the measures the people are taking to prevent mosquito biting—bednets, burning traditional herbs, aerosol sprays and coils. We have selected and trained mosquito scouts in consultations with the community groups, hoteliers and other stakeholders. A training programme tailored to the needs of the community was executed. The aims are to create a cadre of individuals from the community groups and hotels, who are equipped with the basic knowledge and skills necessary for mosquito control. Topics include mosquito biology, sampling and monitoring techniques for both larvae and adult mosquitoes and mosquito control options and use of mosquito information generated from the field in decision-making. The practical demonstrations involve 3 teams each comprising of: (1) field research assistants and (2) mosquito scouts. The aim is to allow mosquito scouts gain field experiences in adult mosquito collections inside houses by pyrethrum spraying and outdoor collections using light traps. The exercise also gives the mosquito scouts an opportunity to learn aspects of consenting in research activities from household owners. Training was also conducted on larviciding using Bti.

Mosquito scouts are now able to collate data on mosquito occurrence and utilise this information to make informed decisions on mosquito control. All community groups formed one umbrella body known as Malindi Mosquito and Malaria Control Association (PUMMA) mandated to coordinate all mosquito activities and liaise with stakeholders on the best methods of control. PUMMA has developed a massive programme of community mobilisation which involves the creation of community groups and observance of Malaria Mosquito Day.

Community mobilisation, which is an important part of overall malaria control activities in Malindi, is apparently not given much investment after initial training and distribution of materials. Major challenges facing these groups include sustainability, low levels of volunteerism, monitoring and supervision, and maintaining and supporting the activities. As part of a Biovision project, we begun training community group members in larval control and environmental management techniques in August 2005. Application of *Bacillus thuringiensis* var. *israelensis* (Bti) and *B. sphaericus* (Bs) larvicides that are highly effective, selective in action and environmentally safe to non-target organisms, was extended. We are now developing locally appropriate educational materials and assessing the impact of our training programme on mosquito control. Training materials, source reduction techniques, and application of Bti and Bs guidelines developed as part of the project, will also be used to train community members in the use of mosquito reduction techniques.

The project relies on community participation and support. The site manager has already worked with the respective communities and the budget allows activities in community participation. The study sites are subdivided into cells of equal size; the cells are the units for monitoring and intervention. Monitoring and vectors control is carried out by mosquito scouts selected by the community, who are expected to make informed decisions based on the monitoring information. In general, weekly visits and discussions by the site managers should further strengthen community engagement.

Output

Journal articles

Carlson J., Keating J., *Mbogo C. M.*, Kahindi S. and *Beier J. C.* (2004) Ecological limitations on aquatic mosquito predator colonization in the urban environment. *Journal of Vector Ecology* 29, 331–339.

Depinay J. M. O., *Mbogo C. M.*, Killeen G., Knols B., Beier J., Carlson J., Dushoff J., Billingsley P., Mwambi H., *Githure J.*, Toure A. M. and McKenzie F. E. (2004) A simulation model of African *Anopheles* ecology and population dynamics for the analysis of malaria transmission. *Malaria Journal* 3, 29–49.

Jacob B. G., Arheart K. L., Griffith D. A., *Mbogo C. M.*, Githeko A. K., Regens J. L., *Githure J. I.*, Novak R. and Beier J. C. (2005) Evaluation of environmental data for identification of *Anopheles* (Diptera: Culicidae) aquatic larval habitats in Kisumu and Malindi, Kenya. *Journal of Medical Entomology* 42, 751–755.

Jacob B. G., Regens J. L., *Mbogo C. M.*, Githeko A. K., Swalm C. M., *Githure J. I.* and *Beier J. C.* (2005) Capabilities of multispectral thermal data for identification of *Anopheles gambiae* mosquito larval habitats in African urban environments. *International Journal of Remote Sensing* 26, 523–534.

Keating J., Macintyre K., *Mbogo C. M., Githure J. I.* and Beier J. C. (2004) Characterization of potential larval habitats for *Anopheles* mosquitoes in relation to urban land-use in Malindi, Kenya. *International Journal of Health Geographics* 3, 9–21.

Keating J., Macintyre K., *Mbogo C. M., Githure J. I.* and *Beier J. C.* (2005) Self-reported malaria and mosquito avoidance in relation to household risk factors in a Kenyan coastal city. *Journal of Biosocial Science* 37, 761–771.

Keating J., *Mbogo C. M.*, Mwangangi J., Nzovu J. G., Gu W., Regens J. L., Yan G., *Githure J. I.* and Beier J. C. (2005) *Anopheles gambiae* s.l. and *Anopheles funestus* mosquito distributions at 30 villages along the Kenyan coast. *Journal of Medical Entomology* 42, 241–246.

Mwangangi J. M., *Mbogo C. M.*, Nzovu J. G., Kabiru E. W., Mwambi H., *Githure J. I.* and *Beier J. C.* (2004) Relationships between body size of *Anopheles* mosquitoes and *Plasmodium falciparum* sporozoite rates along the Kenya coast. *Journal of the American Mosquito Control Association* 20, 390–394.

Conferences attended

53rd Annual Meeting of the American Society of Tropical Medicine and Hygiene, Miami Beach, Florida, USA, 7–11 November, 2004. Attended by Charles Mbogo.

25th Africa Health Sciences Congress, 4–8 October 2004, Nairobi, Kenya. Attended by Charles Mbogo and Lydiah Kibe.

Medicine and Health in the Tropics, Marseilles, France, 11–15 September 2005. Attended by Charles Mbogo.

The Fourth Pan-African MIM meeting, Yaounde, Cameroon, 13–18 November 2005. Attended by Lydiah Kibe, Janet Midega and Charles Mbogo.

26th Africa Health Sciences Congress, Ain Soukhna, Egypt, 28 November–1 December 2005. Attended by Charles Mbogo and Lydiah Kibe.

Working group on strategic plan to bridge laboratory and field research in disease vector control, 14–16 July 2004, Nairobi, Kenya.

Technical consultation on the strategy for assessment and control of urban malaria, Pretoria, South Africa, 1–5 December 2004.

Workshop on Management of Intellectual Property in Health Research and Development, Nairobi, 17 March 2005.

Workshop on Project Management System, Nairobi, 1–3 November 2005.

Research proposals

Reducing mosquitoes and malaria through environmental management in urban Malindi, Kenya. Funded by RTI/USAID.

The applicability of available technologies for adaptive integrated malaria vector management at Malindi, Kenya. Funded by Biovision Foundation.

Capacity building

PhD students

J. T. Midega (Kenya) Distribution patterns, gene flow and dispersal of *Anopheles* mosquitoes along the Kenya coast. University of Ghana (ongoing).

P. O. Mireji (Kenya) Responses of mosquitoes to heavy metals. Kenyatta University, Kenya (ongoing).

MSc and MA students

L. W. Kibe (Kenya) Community participation in malaria control: A case study in Malindi District. Kenyatta University (ongoing).

S. Muiruri (Kenya) Determination of predator feeding preference on immature stages of *Anopheles* mosquitoes. Kenyatta University (completed and graduated).

S. C. Kahindi (Kenya) Mechanisms of resistance and susceptibility to organophosphates, carbamates, and pyrethroids in *Anopheles gambiae* in Hohe District, Ghana. University of Ghana (completed and graduated).

Vector Competence in the Anopheles gambiae–Plasmodium falciparum System

Background, approach and objectives

This project focuses on the environmental and genetic factors that critically influence sporogonic development and mosquito susceptibility to *Plasmodium falciparum* parasites. This research is based on the general hypothesis that the vector competence of *Anopheles gambiae* is determined by the genetic conditions of mosquitoes and parasites, and mediated by environmental conditions. The specific aims of this project were to evaluate the effects of abiotic environmental factors (ambient temperature) and biotic factors (size, age of mosquitoes and life history parameters such as blood-feeding and sugar-feeding) on *P. falciparum* sporogonic development in African malaria vectors, and determine the genetic mechanisms of vector competence in the *Anopheles gambiae/Plasmodium falciparum* system.

Participating scientists and student: *H. Manda (PhD student), L. Gouagna, J. Githure, A. Hassanali, J. Beier[1], G. Yan*

Assisted by: *J. Arija, T. Guda*

Donors: *NIH, WHO-TDR*

Collaborators: *[1]Miami University (USA); Kenyatta University (Kenya), [2]New York State University (USA)*

Collaborating department: *Behavioural and Chemical Ecology Department*

Work in progress

1. *Plant-feeding behaviour of* Anopheles gambiae

Sugar is the basic food of adult mosquitoes. All mosquito species examined so far, both females and males, feed on plant sugar in nature. It is the only source of nutrition for males and the most important in building energy reserves in females. In the laboratory, sugar-feeding increases survival in both sexes, increases mating capacity in males, reduces biting frequency in females and increases egg production per gonotrophic cycle in females. In nature, *Anopheles* mosquitoes acquire sugar principally from floral nectars and extrafloral plant juices. However, the subject of plant-sugar feeding in *A. gambiae* and other malaria vectors is virtually untouched and unknown. It is important to identify plant species that are commonly fed on by malaria vectors in endemic areas, because they may play an important role in their fitness and vectorial capacity. This study aimed to determine plant-feeding practices of wild malaria vectors in Suba district (a malaria endemic area of western Kenya) and assess the behavioural responses of *A. gambiae* to common plants growing around human dwellings and mosquito larval habitats.

2. *Plant-feeding practices of field collected female* Anopheles *mosquitoes in relation to their dispersal, gonotrophic status, parity and seasons in Suba district, western Kenya*

The plant-feeding practices of wild female *Anopheles* mosquitoes in relation to their dispersal, seasons, gonotrophic status and parity were evaluated in Lwanda village of Suba district, western Kenya. Indoor-resting *Anopheles* females were sampled during the January to March dry season and April to May wet season, from two groups of houses, located near (< 200 m) and far (> 200 m) from larval habitats. Females collected were individually tested for the presence of fructose (the main monosaccharide unique to plant sugar) in their crop. A total of 1549 female *Anopheles* were collected including *A. gambiae* s.s. (19.81%), *A. arabiensis* (36.34%) and *A. funestus* (43.83%). Out of the number of mosquitoes sampled, 12.33% had fructose in their crop at the time of collection, indicating recent plant-feeding. The percentage of fructose-positive females was similar in all the three *Anopheles* species ($P = 0.95$), suggesting parallel evolution of the sugar-feeding strategies, given the 3 species are sympatric in the area. For each *Anopheles* species, the percentage of females positive for fructose was also insignificantly different, during both dry and wet seasons ($P = 0.8, 0.16, 0.17$), in the 4 gonotrophic status (empty, blood-fed, half-gravid and gravid) ($P = 0.96, 0.74, 0.6$) and physiological age (parous and nulliparous) ($P = 0.4, 0.9, 0.7$) for *A. gambiae* s.s., *A. arabiensis* and *A. funestus* respectively. However, the rate of fructose-positive females was significantly higher in mosquitoes collected far from larval habitats compared to those collected near ($P = 0.02, 0.005, < 0.001$) for *A. gambiae* s.s., *A. arabiensis* and *A. funestus* respectively. These preliminary field results suggest that plant sugar-feeding may be an important aspect of the biology of malaria vectors, because female *Anopheles* feed on plants even when the human host is readily available, during both seasons and any time of their physiological status and age. However, the frequency of plant-feeding by malaria vectors in nature is still being investigated.

3. *Feeding responses of* Anopheles gambiae *to common plants growing around human dwellings and mosquito larval habitats in western Kenya*

A study to determine the behavioural responses of *Anopheles gambiae* to common plants growing in western Kenya was carried out in a semi-field setup (greenhouse) with laboratory reared mosquitoes, to identify possible sources of mosquito sugar meals in the area. Thirteen candidate plant species were selected for testing on the basis of (1) their local availability around human dwellings and mosquito aquatic habitats where *A. gambiae* lives and breeds, (2) their distribution over a wide ecological range, and (3) all of them being present in the habitats year round. Feeding responses of mosquitoes to those candidate plants were recorded, each plant being presented to mosquitoes singly, and concurrently with other plant species in no-choice and choice bioassays respectively, coupled with gas chromatography analysis for mosquito and plant sugar signatures. There were significant variations in the feeding responses of mosquitoes toward the different plants in the choice arena ($P < 0.001$), and these were consistent with numbers ingesting sugar in no-choice arrangement, showing a preference ranking for the plant species by mosquitoes. In both choice and no-choice situations, five plant species were most preferred by *A. gambiae*, namely: *Hamelia patens* J., *Ricinus communis* L., *Senna didymobotrya* F., *Pathernium hysterophorus* L. and *Tecoma stans* L. GC analysis of mosquito and plant sugar profiles confirmed the same trend. In 10 out of the 13 candidate plant species tested, gas chromatography profiles indicated that mosquitoes obtained sugars primarily from flowers ($P < 0.001$). However, more mosquitoes fed on the leaves of *P. hysterophorus* L. ($P < 0.001$), *Lantana camara* L. ($P = 0.02$) and leaves and stems of *R. communis* L ($P = 0.01$) than on the flowers of these plants, indicating that floral nectar is not the exclusive source of sugar for these insects. In all the plant species tested, more feeding occurred earlier in the night 2000–2200 h. The results suggest a preferential feeding pattern of *A. gambiae* on plants and plant parts.

4. *Fitness and vector competence of* Anopheles gambiae *feeding on preferred plant species in western Kenya*

The scope of these studies is built around the following evolving hypotheses.

- Preferential feeding on host plants is related to potential fitness advantage to mosquitoes (better survival and reproduction output)
- When mosquitoes feed on floral or extrafloral nectars, it is assumed that they do not ingest sugars only, but other secondary compounds of the plants as well. Due to the well-known antiplasmodial activities of certain plant species in nature, some may affect *P. falciparum* sporogonic development in the midgut of *A. gambiae*, and thus reduce the transmission of malaria.

5. *Effect of preferred plants of* Anopheles gambiae *on its survival and fecundity*

To clarify the adaptive significance of plant preference by mosquitoes, survival and fecundity of *A. gambiae* were assessed on plant species that varied in attractiveness. In a semi-field setup, the survival of *A. gambiae* was monitored when allowed to feed exclusively on each of the 5 preferred plants: *Hamelia patens* J., *Ricinus communis* L., *Senna didymobotrya* F., *Pathernium hysterophorus* L. and *Tecoma stans* L., and one of the less preferred plants (*Lantana camara* L.). Their fecundity (number of eggs developed, laid, retained, proportion of mosquitoes ovipositing and viability of the eggs) on those plants was also assessed when given (1) three consecutive blood meals, and (2) only one blood meal. The effect of diet was significant on survival ($P < 0.001$). With the exception of *P. hysterophorus* and *H. patens*, survival was significantly high in mosquitoes fed on most preferred plants (Table 1), with a decrease in the odds of mortality by approximately 40–50% as compared to those fed on the less preferred plant *L. camara*. When given only one blood meal, mosquitoes fed on *P. hysterophorus* and on *L. camara* and laid a significantly lower number of eggs ($P = 0.01$) (Table 1). However, when given three consecutive blood meals, there was no significant difference on the number of eggs developed ($P = 0.06$), retained ($P = 0.07$), laid ($P = 0.29$), and their viability ($P = 0.14$) per female fed on each plant species, suggesting that *A. gambiae* can replace sugar with increased blood-feeding without suppressing their reproductive fitness. The proportion of mosquitoes ovipositing was also significantly low in the 2 plant species (*P. hysterophorus* and *L. camara*) (Table 1). The mean concentration of sugar (in flower + leaf) varied in plant species tested (Table 1). There was a positive correlation between sugar concentration in preferred plants and (1) median survival of mosquitoes ($r = 0.98$, $P < 0.001$), (2) proportion of mosquitoes ovipositing ($r = 0.82$, $P = 0.04$), and (3) number of eggs oviposited when given only one blood meal ($r = 0.87$, $P = 0.04$) in those plants, justifying why survival and fecundity was poor in preferred plants less concentrated in sugar. Our results suggest that plants preferred by *A. gambiae* and rich in sugars enhance their fitness (survival and reproduction). Low energy reserve in mosquitoes as a result of being exposed to less preferred plants will lead to more blood meals to compensate for the energy shortage, therefore increasing the mosquito–human contact (biting frequency). Survival and biting rate of mosquitoes being important factors on the vectorial capacity equation, these results suggest that malaria transmission can be substantially enhanced or reduced by the availability of some plant species to wild vector populations in endemic areas.

Table 1. Average sugar concentration (in flower + leaf) in each plant species tested and mean (± SE) survival, number of eggs laid when given either one or three blood meals, proportion of females ovipositing fed on each plant species and controls (glucose 6% and water)

Variables	Diets							
	Glucose 6%	*T. stans*	*S. didymobotrya*	*R. communis*	*H. patens*	*L. camara*	*P. hysterophorus*	Water
Average sugar (flower + leaf) µg/mg dry extract		254.10	136.7	23.5	11	112.3	1	
Mean survival ± SE (days)	17.1 ± 0.4 a	13.4 ± 0.5 b	11.6 ± 0.3 c	11.4 ± 0.4 c	7.7 ± 0.3 d	7.2 ± 0.2 d	4.7 ± 0.2 e	3.8 ± 0.1 e
Mean number of eggs laid per female ± SE (one blood meal)	35.7 ± 2.1 a	34.8 ± 2.0 a	33.1 ± 1.9 a	33.0 ± 2.3 a	39.1 ± 2.6 a	21.2 ± 2.5 b	15.1 ± 2.0 b	15.5 ± 3.2 cb
Mean number of eggs laid per female ± SE (three blood meals)	77.0 ± 4.6 ab	67.4 ± 3.9 ab	68.0 ± 4.2 ab	79.3 ± 4.7 a	67.7 ± 5.8 ab	75.6 ± 5.1 ab	57.8 ± 4.1 b	58.5 ± 6.1 b
Proportion females ovipositing ± SE	71.2 ± 6.7 a	69.2 ± 6.7 a	64.5 ± 6.8 a	60.5 ± 7.3 a	46.8 ± 8.0 ab	40.2 ± 7.6 b	39.1 ±10.7 b	27.5 ± 6.8 b

6. *Effects of preferred plant species on the vector competence of laboratory population of* Anopheles gambiae *for* Plasmodium falciparum

The effects of the preferred plants of *A. gambiae* were assessed on their vector competence (*P. falciparum* development in their midgut). Laboratory-reared female *A. gambiae* mosquitoes adapted on membrane feeding were fed on each of these plant species: *H. patens* J., *R. communis* L., *S. didymobotrya* F., *P. hysterophorus* L., *T. stans* L. and *L. camara* L. and experimentally infected with blood obtained from gametocyte-positive human volunteers. *Lantana camara* was included for testing because, although not attractive to mosquitoes in choice situation, it is abundant in western Kenya and mosquitoes significantly fed on it in no-choice situation.

Significantly low infection prevalences were observed on mosquitoes fed on *R. communis* (7.18%) and *P. hysterophorus* (0%), as compared to other plant species ($P < 0.01$), with a magnitude of 53 and 100% respectively below the control (glucose) (15.21%). There was a drastic decrease on the parasite load (mean oocyts per infected midgut) in the midguts of infected mosquitoes fed on 3 plant species: *L. camara* (1.6 oocysts per midgut), *S. didymobotrya* (1.3 oocysts per midgut) and *P. hysterophorus* (0 oocyst per midgut) as compared to those fed on other plant species and on the control (glucose) (9.01 oocysts per midgut) ($P < 0.0001$). The decreases in infection rates and parasite intensities were due to *A. gambiae* ingestion of these plant diets because mosquitoes fed on each plant species and the control (glucose) were reared in the same manner, infected with blood from the same *P. falciparum* gametocyte carriers and held in the same conditions. We found a positive correlation between gametocyte densities and mosquito infection rates ($r = 0.77$, $P < 0.01$) and oocyst intensities per midgut ($r = 0.71$, $P < 0.01$). The inhibitory effect of *P. hysterophorus* on *P. falciparum* development was consistent in both the infection rate of mosquitoes and parasite intensity; total knockout was only observed when mosquitoes were infected with less than 200 gametocytes/µl of blood. However, with higher gametocyte densities (mean 566.57 gametocytes/µl of blood), the mean infection rate and oocyst intensity of mosquitoes fed on *P. hysterophorus* were still significantly lower than the mean infection rate and oocyst intensity of mosquitoes fed on glucose ($P < 0.001$ in both cases). The inhibitory effects of the plants on either infection prevalence or parasite load varied according to the time mosquitoes fed on plants. High effect occurring when mosquitoes fed on plants both pre- and post-infection, followed by plant-feeding post infection only. This study suggests that the availability of some plant species to local vector population in endemic area may reduce the infectivity of mosquitoes, and to a large extent malaria transmission. However, since the inhibitory effects of plants on the parasite are greater when mosquitoes plant-feed throughout, continual feeding on the same plants being rare in nature, these results probably explain what happens in nature and call for the propagation of such plants in the hope of higher effects on the malaria transmission.

7. *Stage-specific targets of plant substrates on the early* Plasmodium falciparum *sporogonic development in* A. gambiae

To determine where the greatest impacts of plants occur during parasite development, the midgut stages of *P. falciparum* sporogonic development in the mosquito were assessed. Overall, the greatest impact of plants (*L. camara, S. didymobotrya* and *P. hysterophorus*) was found at the transition from macrogamete-to-ookinete (low parasite yield of 46.0% on average on plants compared to 72.0% on glucose), and at the transition from ookinete-to-oocyst (low parasite yield of 44.6% on average on plants compared to 81.3% on glucose), whereas in the transitions from macrogametocyte-to-macrogamete, parasite yield was comparable on mosquitoes fed on plants (9.0%) and those fed on the control (glucose) (11.8%). Specifically, parasite loss was significantly high in the transition from macrogamete-to-ookinete when mosquitoes fed on plants only pre-infection, with 30- to 35-fold parasite loss in mosquitoes when they fed on plant species pre-infection compared to 0 to 10-fold reductions when they fed on these plants post-infection. In the transition from ookinete-to-oocyst, significant loss was obtained when mosquitoes fed on plants after infection, with a 35- to 50-fold parasite loss when they fed on plants post-infection, compared to 0 to 10-fold reductions when they fed pre-infection. But the greatest overall loss (macrogametocyte-to-oocyst) was obtained when mosquitoes fed on plants throughout (70 to 80% reductions in parasite yield attributed to plants) as compared to those fed on plants pre-infection only (55 to 60% reductions) and post-infection only (55 to 60% reduction). For plants inhibiting *P. falciparum* development, the outcome or yield in oocyst numbers observed in the mosquito midgut when feeding on them was less than 2.5%. These results suggest the importance of having plant species with known effects on the mosquito vector competence close to human dwellings and larval habitats to target the most vulnerable transitions of *P. falciparum* sporogonic cycle in the mosquitoes, which is only possible if mosquitoes plant-feed before an infectious blood meal or immediately after.

These semi-field studies on the behaviour and vector competence of *A. gambiae* in relation to plant-feeding have provided some knowledge on the potential effects of some plant species on the fitness and vector competence of *A. gambiae*. Longitudinal field studies on different ecological situations are being undertaken to assess the frequency of plant-feeding by female *Anopheles* mosquitoes in nature and therefore establish the true role of this behaviour in their biology.

8. Fitness consequences of *Anopheles gambiae* population hybridisation

The use of transgenic mosquitoes with parasite-inhibiting genes to control malaria transmission will bring along novel alleles with unknown effects on native mosquito populations, hence the need to study the response of fitness traits to the introduction of novel alleles. Fitness and feeding behaviours of hybrids between the introduced and native mosquitoes should be evaluated since these hybrids may increasingly become a nuisance if they bite vigorously and survive longer than native mosquitoes.

Two *Anopheles gambiae* strains, Mbita from Kenya and Ifakara from Tanzania were cross-bred and monitored for 20 generations. We measured fitness of mosquitoes sampled from cage populations of the parent strains and hybrids between the two at F_1, F_5, F_{10}, F_{15} and F_{20} generations for fecundity, body size, blood meal size, larval survival and adult longevity in two replicate experiments (n = 50). Reciprocal crosses of either Mbita male and Ifakara female and vice versa were done to confirm the direction and effect of heterosis and to control any assortative mating of mixed populations. Their F_1 and F_5 generations were also subjected to fitness measurements. The populations and filial generations used in this study were reared in the same manner.

There was significant difference in fecundity ($P < 0.001$) between the Mbita and Ifakara strain, and between the parents and their progenies ($P < 0.001$). Inter-progeny significant difference was only found between F_1 and F_{10} ($P < 0.005$). The mean wing size of Mbita (2.86 mm) and Ifakara (2.89 mm) was not significantly different, but was consistently different between either parent and their filial generations ($P < 0.05$). Inter-progeny difference was not significant except for between F_1 and F_5 ($P < 0.05$). The mean blood meal size was significantly higher ($P < 0.001$) in Mbita (3.15) than Ifakara (2.54) and also between the parents and F_1 (3.96) ($P < 0.05$), with all the filial generations having significantly higher means than Ifakara ($P < 0.001$). Inter-progeny significant difference was observed except for between F_1 and F_5. The mean longevity of Mbita strain (22.31 days) was significantly higher than Ifakara (14.52 days). Progeny showed increased longevity from F_1, F_5, and F_{10}, and a decline at F_{15} and F_{20}. Hybrids showed higher values of fitness traits, with reciprocal crosses also showing significantly higher mean body size, fecundity and blood meal size both at F_1 and F_5 generations than either founder strain. These results suggest that if exotic genetically modified mosquitoes are introduced, hybrids may live longer, with high fecundity, large body size and will engorge more; which calls for need to release transgenes of same or very similar background to the native population.

Output

Journal articles

Bousema T. J., *Gouagna L. C.*, Drakeley C. J., Meutstege A. M., Okech B. A., Akim I. N. J., Beier J. C., *Githure J. I.* and Sauerwein R. W. (2004) *Plasmodium falciparum* gametocyte carriage in asymptomatic children in western Kenya. *Malaria Journal* 3, 18–28.

Ferguson H., *Gouagna L. C.*, *Obare P.*, Read A., Babiker H., *Githure J.* and *Beier J.* (2005) The presence of *Plasmodium falciparum* gametocytes in human blood increases the gravidity of *Anopheles gambiae* mosquitoes. *American Journal of Tropical Medicine and Hygiene* 73, 312–320.

Gouagna L. C., Ferguson H. M., *Okech B. A.*, *Killeen G. F.*, Kabiru E. W., *Beier J. C.*, *Githure J. I.* and *Yan G.* (2004) *Plasmodium falciparum* malaria disease manifestations in humans and transmission to *Anopheles gambiae*: A field study in western Kenya. *Parasitology* 128, 235–243.

Gouagna L. C., *Okech B. A.*, *Obare P.*, Miyare P., Ombonya S., Kabiru E. W., *Beier J. C.*, *Yan G.*, Knols B. G. J., *Githure J. I.* and *Killeen G. F.* (2004) Seasonality of *Plasmodium falciparum* infection and risk factors for gametocyte carriage in patients attending a rural health centre in western Kenya. *East African Medical Journal* 80, 627–634.

Impoinvil D. E., Kongere J. O., Foster W. A., *Njiru B. N., Killeen G. F., Githure J. I.,* Beier J. C., *Hassanali A.* and *Knols B. G. J.* (2004) Feeding and survival of the malaria vector *Anopheles gambiae* on plants growing in Kenya. *Medical and Veterinary Entomology* 18, 108–115.

Menge D. M., *Guda T.,* Zhong D., Pai A., Zhou G., *Beier J. C., Gouagna L.* and Yan G. (2005) Fitness consequences of *Anopheles gambiae* population hybridization. *Malaria Journal* 4, 44–50.

Okech B. A., Gouagna L. C., Kabiru E. W., *Walczak E., Beier J. C., Yan G.* and *Githure J. I.* (2004) Resistance of early midgut stages of natural *Plasmodium falciparum* parasites to high temperatures in experimentally infected *Anopheles gambiae* (Diptera: Culicidae). *The Journal of Parasitology* 90, 764–768.

Okech B. A., Gouagna L. C., Knols B. G. J., Kabiru E. W., *Killeen G. F., Beier J. C.,* Yan G. and *Githure J. I.* (2004) Influence of indoor microclimate and diet on survival of *Anopheles gambiae* s.s. (Diptera: Culicidae) in village house conditions in western Kenya. *International Journal of Tropical Insect Science* 24, 207–212.

Okech B. A., Gouagna L. C., Walczak E., Kabiru E. W., *Beier J. C., Yan G.* and *Githure J. I.* (2004) The development of *Plasmodium falciparum* in experimentally infected *Anopheles gambiae* (Diptera: Culicidae) under ambient microhabitat temperature in western Kenya. *Acta Tropica* 92, 99–108.

Abstract published in journal supplement

Manda H., Gouagna L. C., Kabiru E. W., *Hassanali A.,* Yan G., *Beier J.* and *Githure J.* (2005) *Plasmodium falciparum* development in the midgut of *Anopheles gambiae s.s.* feeding on some predominant plants in western Kenya. *Acta Tropica* 95S, 17–18.

Conferences attended

Fourth Pan-African Malaria Conference MIM, 13–18 November 2005 and Roll Back Malaria Partnership Forum V, 18–19 November 2005 Yaounde, Cameroon. Attended by H. Manda and T. Guda.

Workshops attended

Workshop on "Beyond Hunger: Communities and scientists working to implement the Millennium Development Goals (MDGs)". Kenya, Mbita 15–16 April 2005. Attended by H. Manda and B. Njiru.

Workshop on "Statistical analysis of GIS data applied to public health", 6–11 June 2005, Nairobi, Kenya. Attended by H. Manda.

Symposium for the Enhancement of Scientific Collaboration in Africa, 7–8 August 2005, Nairobi, Kenya. Attended by H. Manda.

Capacity building

PhD students

B. A. Okech (Kenya) Factors affecting the infectivity and early sporogonic development of *Plasmodium falciparum* in the malaria vectors, *Anopheles gambiae*. Kenyatta University (completed).

H. Manda (Cameroon) Plant-feeding behaviour and its effects on the fitness and vector competence of the malaria vector *Anopheles gambiae*. Kenyatta University, Kenya (due to complete in 2006).

MSc students

J. M. Mutunga (Kenya) Molecular analysis of the knockdown resistance (Kdr) gene in *Anopheles gambiae* and *A. funestus* populations in Kenya. Jomo Kenyatta University of Agriculture and Technology, Kenya (2005 completed).

T. Guda (Kenya) Vector competence in malaria vectors. Kenyatta University, Kenya (ongoing).

P. Seda (Kenya) Molecular entomology. Jomo Kenyatta University of Agriculture and Technology, Kenya (ongoing).

Short-term training

Entomological training for four undergraduate students from Egerton University (May–August 2004) and six students from Mawego Technical College and Kisumu Polytechnic (January–March 2004) was conducted.

Impact

- At our *icipe*-Mbita Point field station, in western Kenya, we have established an effective laboratory and semi-field operation that allows us to experimentally infect mosquitoes and study malaria parasite development under different experimental conditions.
- Information on the biotic and abiotic factors (temperature, locations of houses used for indoor-resting, number of previous bloodmeals, plant diets and even the origin of mosquitoes from larval habitats) that regulate malaria parasite growth and development in anopheline mosquitoes in western Kenya is now available.

Mosquito Chemical Ecology and Natural Products Potentially Useful for Malaria Vector Control

Background

Our limited knowledge of the mechanisms that underlie key behaviours in the life history of malaria-transmitting mosquitoes and of the mediating signals represents a major handicap in our ability to develop a comprehensive, bio-rational control system for these vectors. Work in the Behavioural and Chemical Ecology Department at *icipe* seeks to contribute to integrated malaria vector management by developing and testing devices and intervention tactics based on comprehensively characterised behaviour-controlling chemical signals (semiochemicals) that regulate three key behaviours of Afro-tropical mosquitoes: (1) blood-seeking from humans by female anthropophilic mosquitoes and from animals by female zoophilic mosquitoes; (2) oviposition selection pattern of gravid female mosquitoes; and (3) plant-seeking male and female mosquitoes for sugar feeding.

The major goal of the bioprospecting project in Behavioural and Chemical Ecology Department is to identify mosquito repellent and plant-derived products that can provide household or personal protection against mosquito bites, and natural products that can form the basis for community-based mosquito control operations integrated, where appropriate, with income generation activities. Significant progress has been made on each front *(see separate report under Environmental Health division.)*

Participating scientists: *A. Hassanali, P. G. N. Njagi*

Visiting scientists: *I. Ndiege (Kenyatta University), M. Ndung'u (Jomo Kenyatta University of Agriculture and Technology)*

Assisted by: *B. Njiru, E. Nyandat, P. N. Mbogo, J. Anjira, M. Omollo, B. O. K. Wanyama, M. W. Gitau*

Donors: *United Nations Development Programme/World Bank/World Health Organization Programme for Research and Training in Tropical Diseases; World Health Organization Multilateral Initiative on Malaria Research in Africa; National Institutes of Health, International Collaboration in Infectious Diseases Research*

Collaborators: *Miami University, USA; World Health Organization/Regional Office for Africa; University of Nairobi, Kenyatta University, Jomo Kenyatta University of Agriculture and Technology, Egerton University, Kenya; Addis Ababa University, Ethiopia; University of Dar es Salaam, Tanzania; Ohio State University, USA*

Work in progress

The following highlights the major foci of the studies undertaken and results obtained.

1. Semiochemicals mediating mammalian hosts finding

Although human volatile odours other than carbon dioxide contribute substantially in the host location behaviour of anthropophilic mosquitoes, despite many efforts, no synthetic baits have been identified that are effective for routine monitoring and/or mass trapping of the mosquitoes in the field. A number of electro-physiologically (EAG) active compounds associated with human odour (including indole, branched ketones and carboxylic acids) have been found to elicit behavioural responses in laboratory assays (wind tunnel). However, neither the individual components nor blends of these are effective in the field, which is indicative of inadequate characterisation of the active blend. This is attributed to a number of factors. First, adsorption techniques and specific adsorbents used may not comprehensively trap all constituents contributing to the active blend. Second, laboratory assays used to identify behaviourally active candidates and their blends do not adequately reflect host-location mechanism of mosquitoes. Third, to date, the procedure adopted to locate potential constituents of the attractive kairomone blend in a complex profile of irrelevant components that make up the human odour, has been largely opportunistic, based as they were on assays of either components (rather than blends) specific to human odour or those common to odours collected from a number of human subjects. Additionally, no suitably designed trap has been available that could be reliably used under semi-field conditions to verify results from laboratory assays.

Our studies are built around the hypothesis that host location by a malaria vector involves two overlapping steps (analogous to tsetse flies with which the *icipe* team has a lot of experience): an upwind anemotactic flight from some distance to hosts/host dwellings guided by plumes of very volatile, predominantly breath odour chemicals (including carbon dioxide); and chemotactic responses closer to hosts up concentration (convective) gradient of odour emanating from preferred feeding sites (e.g. human feet).

We have sought to converge on the blend of active constituents associated with foot and breath odours through the following succession of steps: (1) grading the attractiveness of foot odours from 16 different individuals under semi-field conditions using Counter Flow Geometry (CFG) traps (American Biophysics), and comparing the chemical compositions (GC-MS) of the most and least attractive odours; (2) similarly, precise grading of breath collections was replicated from 28 different individuals in a 2-choice wind-tunnel that compared these collections with clean medical air; (3) selection of appropriate adsorbents and (for foot odours) use of static adsorption procedure developed at *icipe* (Gikonyo *et al.* 2002: *Journal of Chemical Ecology*, pp. 961–973), and characterisation of constituents unique to or present in higher relative amounts in the collections from the most attractive individuals; (4) careful optimisation of coupled gas chromatography-electroantennographic detection (GC-EAD) technique and its deployment in the location of candidate components of the active blend in the more attractive foot and breath odours; and (5) subtraction assays in the laboratory and semi-field arena to identify the attractive blend (all constituents that contribute additively or synergistically).

Progress made in the last 3 years

- Demonstration that bulk foot odour collections from 16 different human beings (each on different occasions, under standard conditions [CFG traps in a screen house]) differ reproducibly and significantly in attractiveness to *A. gambiae* s.s., with collections from the most attractive subject being about 8-fold more attractive than the least (Table 1). Gas chromatographic profiles of odour collections of individuals with more and less attractive foot odours differed both quantitatively and qualitatively, with those with comparable attractiveness demonstrating similar profiles.

Table 1. Mean catches* of CFG traps baited with foot odour collections from 16 human subjects

Person	Mean catches identity (± SE)	Person	Mean catches identity (± SE)
1	12.50 ± 8.92 e,f	9	6.75 ± 2.19 f
2	12.63 ± 14.08 e,f	10	15.88 ± 5.28 e,f,d
3	20.38 ± 14.96 e,c,d	11	42.50 ± 7.91 a
4	12.38 ± 12.38 e,f	12	37.00 ± 17.13 a,b
5	18.63 ± 15.17 e,f,c,d	13	14.88 ± 7.14 e,f
6	28.88 ± 14.41 b,c	14	21.50 ± 19.85 e,c,d
7	28.13 ± 18.39 b,c,d	15	21.63 ± 17.96 e,c,d
8	23.13 ± 6.64 e,c,d	16	15.25 ± 10.98 e,f,d

*Based on 8 replicate collections from the feet of each human subject.
Means with the same letter are not significantly different (LSD test, $P < 0.0001$).

- Comparison of foot odour profiles and GC-MS identification of potential kairomones/ allomones. Six commercial adsorbents placed concurrently on the feet of each individual were originally compared: Porapak Q (80–100 mesh), activated charcoal (80–100 mesh), octadecyl-silica and octyl-silica (both 40 μm), tenax and chromosorb (both 80–100 mesh). Odours trapped on Porapak Q and C-18 silica were quantitatively and qualitatively the richest and these were used concurrently to trap from individuals with most and least attractive odours (see Figure 1 for Porapak collections). Comparison of GC-MS profiles of odour collections showed clear quantitative and qualitative differences. Mass spectral identification of most of the components has been completed. Compounds present in the most attractive person, but absent in the least attractive, and those present in larger relative amounts in the former make up about 1/6th of over 300 constituents. These comprise carbonyl compounds, akylated benzenes, alcohol derivatives and a number of halobenzenoids (suggestive of bacterial origin). Some of the compounds have never been reported before as constituents of human odours.

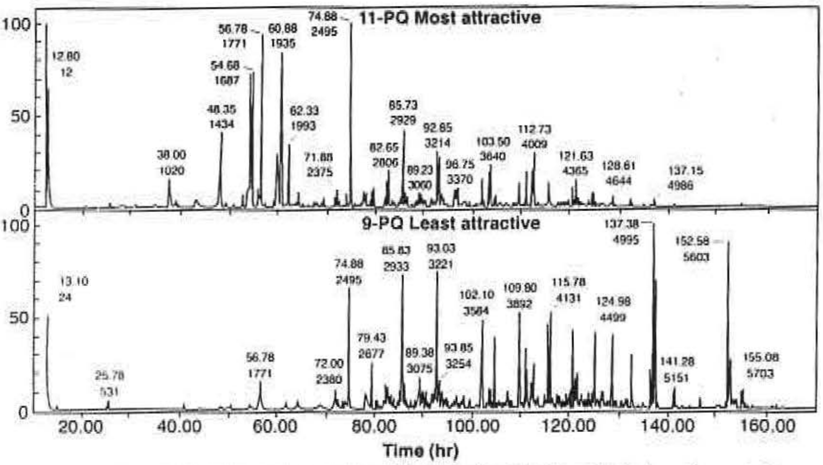


Figure 1. The GC profile of the most (top) and least (bottom) attractive odours collected on Porapak Q

- A procedure that ensures optimal and sustained sensitivity of coupled gas chromatography-electroantennographic detection (GC-EAD) and off-line electroantennogram (EAG) recording from the antennae of hungry *Anopheles gambiae* has been developed. This has involved careful experimentation with the different electrodes, physiological saline, antennal preparations, lab-reared and freshly field-collected insects, handling of the insects, and ambient conditions. Using this procedure, up to 11 compounds in the foot volatiles of the most attractive person have been shown consistently to be EAG-active in GC-EAD runs. These represent about 1/30th of over 300 constituents of the foot odour. Both prominent and minor components are represented. As far as we are aware, the procedure represents the first successful deployment of on-line GC-EAD detection of electrophysiologically active constituents in a complex blend with *A. gambiae* antennal preparations. Detailed comparisons of GC-EAD and GC-MS profiles of odours and candidate constituents have been carried out to confirm the chemical identity of the EAG-active constituents for behavioural studies.

- Screenhouse comparisons of CFG traps baited with the crude odour collections from the human subject with the most attractive feet and a synthetic blend of EAG-active constituents have given comparable levels of *A. gambiae* s.s. catches. Assays involving comparison of the 11-constituent blend and this blend but with one constituent missing (subtraction assays) have demonstrated that blends with one of 8 of the constituents missing gave significantly reduced catches, and on the other hand, blends with one or all of the 3 other constituents missing resulted in impressive enhancements of the catches. The 8-constituents blend then represents the kairomone associated with the foot odour and the three components represent the repellent fraction. The relative proportions of the two sets of constituents may largely determine the short-range attractivity of the feet of a given human subject. IPR protection of both blends (i.e. attractive and repellent) is being undertaken. Significantly, in screenhouse experiments, the performance of CFG traps baited with the foot odour kairomone blend was far better than that of CDC light trap and significantly better than bednet trap (with human subjects).

- Detailed comparison of air enriched with different concentrations of CO_2 with/without minor breath constituents from the most attractive and repellent breath has been completed. The results indicate that both CO_2 (~5% in medical air) and minor breath constituents are involved in upwind flight behaviour of *A. gambiae* s.s. and that whereas minor constituents of the most attractive breath enhance upward flight activity, those of the least attractive breath have the opposite effect.

- Comparison of upwind flight choices of individual *A. gambiae* s.s. to breath collections in a 2-choice wind tunnel has also shown large variations in the responses of mosquitoes, with collections from some individuals being less preferred (repellent) relative to medical air. Gas chromatographic profiles of minor breath constituents show a richer composition in the most attractive breath compared to the least.

- Initial GC-EAD studies with minor constituents indicate the presence of ~15 electrophysiologically-active constituents. Identification of these and behavioural assays of different blends are in hand.

2. Oviposition selection behaviour

The scope of studies on *A. gambiae* oviposition behaviour is built around the following evolving set of hypotheses:

- Oviposition selection behaviour is related to potential fitness and chances of survival of the progeny in different pools associated with biotic and abiotic factors. The biotic microenvironment is shaped, on one hand, by organic matter arising from habitat vegetation and the microbial population structure it sustains, and, on the other, by the presence of competing species or potential predators in these environments. Gravid females use the chemical characteristics resulting from microbial activity and/or those associated with competitors as interspecific cues to select suitable habitats for oviposition.

- *Anopheles gambiae*'s characteristic tendency to spread egg laying spatially may be regulated by both the interspecific signals referred to above and intraspecific signals associated with eggs or larvae. We hypothesised that at low egg/larval densities, the signal may reinforce/synergise the interspecific signals, but that at high densities, it may function as a deterrent.

The following highlight the major foci of the studies and results obtained.

Role of semiochemicals resulting from microbial activities

Laboratory studies were carried out to investigate the role of larval habitat-derived microorganisms in the production of semiochemicals for oviposition site selection by *A. gambiae* s.s. mosquitoes. Dual-choice bioassays with gravid females were conducted in standard mosquito cages equipped with 'double-cup' set ups that allowed only olfactory contact by gravid females. Field-collected or laboratory-reared mosquitoes, individually or in groups, were offered a choice between unmodified (water or soil from a natural breeding site) or modified substrates (sterile-filtered water, autoclaved solid or sterile media to which bacterial suspensions had been added). Egg counts were used to assess oviposition preferences. Mosquitoes preferred to oviposit on unmodified substrates from natural larval habitats containing live microorganisms rather than on sterilised ones (Table 2).

Table 2. Mean number of eggs oviposited by groups (n = 10) of laboratory-reared (Ifakara strain) *Anopheles gambiae* s.s. and wild *A. gambiae* s.l. females or by individual laboratory-reared (Mbita strain) *A. gambiae* s.s. and wild *A. gambiae* s.l. females that were offered a choice between sterile and non-sterile substrates

		Individual mosquito			Group of mosquitoes		
Mosquito	Substrate	Mean ± SE[1]	N[2]	P[3]	Mean ± SE[1]	N[2]	P[3]
Laboratory	Fresh soil	60.6 ± 10.1			91.3 ± 12.8		
	Autoclaved soil	15.5 ± 8.6	12	0.03	25.7 ± 7.6	30	< 0.001
	Non-filtered water	47.5 ± 7.4			78.5 ± 16.1		
	Filter-sterilised water	18.4 ± 5.1	24	0.01	17.1 ± 5.4	10	0.03
	Autoclaved soil	39.5 ± 7.3			85.2 ± 16.6		
	Distilled water	22.6 ± 5.5	33	0.18	98.9 ± 16.1	32	0.59
Wild	Fresh soil	84.8 ± 15.0			182.2 ± 25.6		
	Autoclaved soil	18.3 ± 12.5	16	0.03	45.9 ± 14.9	13	0.002
	Non-filtered water	65.5 ± 17.2			147.2 ± 34.9		
	Filter-sterilised water	6.4 ± 6.4	10	0.02	5.6 ± 3.1	11	0.03

[1]Standard error.
[2]Number of paired replicates.
[3]Values represent results of Wilcoxon signed rank test for paired replicates.

Since ovipositing females had no direct contact with test substrates in the oviposition cups, selection was based on volatiles associated with microbial activity in preferred anopheline pools.

Daily oviposition patterns on preferred and unpreferred substrates

Anopheles gambiae is known to prefer to lay eggs on certain pools and to avoid others (preferred by culicines). A laboratory study was carried out to determine if the presence or absence of a preferred substrate affects its diel oviposition pattern.

Greenhouse-reared gravid and hypergravid (delayed oviposition onset) *A. gambiae* s.s. and wild-caught *A. gambiae* s.l. were exposed to three types of substrates in choice and no-choice cage bioassays: water from a predominantly anopheline colonised pool (anopheline habitat water), swamp water mainly colonised by culicine larvae (culicine habitat water) and distilled water. The daily oviposition pattern and the number of eggs oviposited on each substrate during the entire egg-laying period were determined. The results were subjected to analysis of variance using the General Linear Model (GLM) procedure. The main oviposition time for greenhouse-reared *A. gambiae* s.s. was between 1900 and 2000 hrs, approximately one hour after sunset (Figure 2). Wild-caught gravid *A. gambiae* s.l. displayed two distinct peak oviposition times between 1900 and 2000 hrs and between 2200 and 2300 hrs, respectively. During these times, both greenhouse-reared and wild-caught mosquitoes significantly ($P < 0.05$) preferred anopheline habitat water to the culicine one. Peak oviposition activity was not delayed when the mosquitoes were exposed to the less preferred oviposition substrate (culicine habitat water). However, culicine water influenced negatively ($P < 0.05$) not only the number of eggs oviposited by the mosquitoes during peak oviposition time but also the overall number of gravid mosquitoes that laid their eggs on it. The differences in mosquito feeding times did not affect the daily oviposition patterns displayed. The study shows that the peak oviposition time of *A. gambiae* s.l. may be regulated by the light-dark cycle rather than oviposition habitat characteristics or feeding times. However, the number of eggs laid by the female mosquito during the peak oviposition time is affected by the suitability of the habitat.

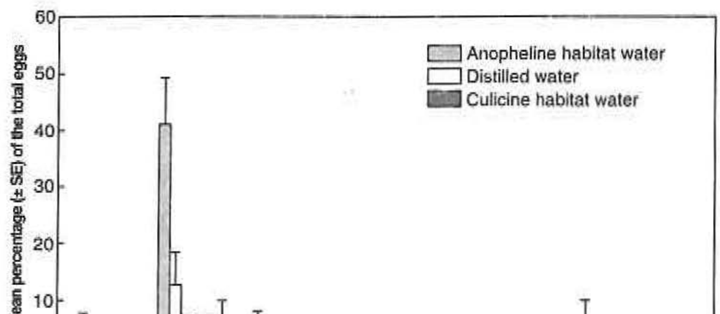


Figure 2. Daily oviposition patterns of *Anopheles gambiae* on different oviposition substrates in a choice bioassay. Mean percentage (± SE) of the total eggs laid on each of the three different oviposition substrates during 1-h time intervals n = 20 cages containing five females each. Mosquitoes could choose from different substrates placed in the same cage under a natural LD cycle (sunset at 1800 h)

Conspecific effects in oviposition

Oviposition choices of *A. gambiae* to aqueous substrates preferred and unpreferred by gravid females in the presence of varying density of conspecific eggs and larvae were investigated in the laboratory. In one set of experiments, the number of eggs laid in a choice of: (1) water collected from preferred anopheline pools with/without varying density of eggs or larvae, and (2) distilled water also with/without varying density of eggs or larvae, were noted. In another experiment, the insect was exposed to a 4-choice of pond water and distilled water, each with/without a selected density of larvae.

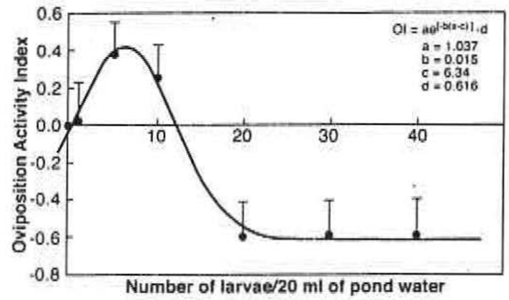


Figure 3a. Oviposition activity in a choice of two artificial 'ponds' containing water from natural anopheline ponds with one containing increasing number of larvae

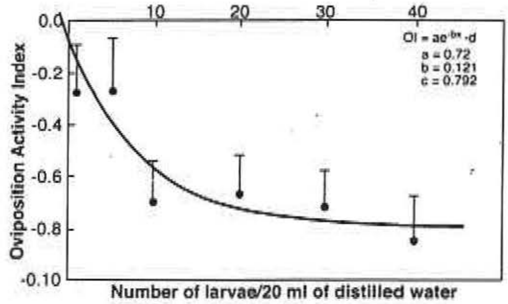


Figure 3b. Oviposition activity in a choice of two artificial 'ponds' containing distilled water with increasing numbers of larvae in one

Eggs had no significant effect in oviposition choices by gravid females. Figure 3a gives the oviposition index in a choice between two artificial oviposition 'ponds' with one containing increasing numbers of larvae (2nd instar). Figure 3b gives the results obtained when distilled water was used instead of anopheline pool water. The results show that low density of larvae in a preferred pool enhances its attraction, high density deters oviposition. However, in an unpreferred pool (illustrated by distilled water), the presence of any number of larvae reduces egg-laying. The results confirm that *A. gambiae* is very selective in its oviposition behaviour and that it uses conspecific larval density to regulate its egg laying activity, which accounts for the spatial spread of oviposition in large number of pools during the rainy season.

Table 3 summarises the results obtained in the 4-choice experiments. These confirm that anopheline pool water with low density larvae are most preferred and show that the larvae are perceived even when they are not visible. This indicates that an intra-specific olfactory signal (a pheromone) associated with larvae is responsible for incremental attraction of anopheline pool to the gravid female.

Table 3. Number of eggs (mean ± SE) laid by gravid *Anopheles gambiae* s.s. exposed concurrently to various oviposition waters. The waters were either visible or not visible to the ovipositing females

	Early stages (10 larvae)	
Oviposition water type	Visible (N = 16)	Not visible (N = 22)
Distilled water + larvae	22.8 ± 13.7 a	21.4 ± 8.8 a
Distilled water only	30.3 ± 13.9 a	36.1 ± 11.5 a
Pond water + larvae	197.9 ± 23.9 b	198.2 ± 21.7 b
Pond water only	96.3 ± 19.8 c	93.2 ± 15.1 c

Any two means in the same column sharing a common letter are not significantly different at 5% level (LSD test).

3. *Plant feeding*

Plant sugar feeding by female mosquitoes is important in their survival and vectorial capacity. Males rely wholly on plant sugar, and their performance and female insemination rate may be directly related to sugar intake. However, very little is known about feeding preferences of male and female Afro-tropical malaria vectors on plants available in different ecologies and the relation between plant phytochemistries and mosquito performance.

As a step toward filling this knowledge gap, the responses of *Anopheles gambiae* Giles (Diptera: Culicidae) to 13 plant species, selected on the basis of their local availability around human dwellings and mosquito aquatic habitats in Suba District, western Kenya, were studied. The feeding preferences of male and female mosquitoes toward these plant species were compared in a choice arena bioassay (competitive) with all plants present, and in a no-choice (non-competitive) bioassay involving individual plants. In the choice arena, several behaviours of the mosquito, including perching and intermittent/sustained ingestion, were monitored by direct observation. Cold-anthrone tests were carried out on individual mosquito homogenates to detect fructose intake. Samples of these homogenates, as well as relevant parts of each plant, were subsequently derivatised and analysed by gas chromatography. In the no-choice bioassay, the cold-anthrone test was carried out to assess the number of mosquitoes feeding on each plant. There were significant variations in the behavioural responses of mosquitoes toward the different plants in the choice arena (Figure 4), and these were consistent with numbers ingesting sugar in both choice and no-choice arrangements, showing a preference ranking for the plant species by mosquitoes

(Table 4). In both competitive and non-competitive situations, females fed significantly more than males, except on *Pathernium hysterophorus* L. in the no-choice arrangement. In 10 out of the 13 candidate plant species tested, gas chromatography profiles indicated that mosquitoes obtained sugars primarily from flowers. However, more mosquitoes fed on the leaves and stems of *Pathernium hysterophorus* L., *Lantana camara* L. and *Ricinus communis* L. than on the flowers of these plants, indicating that floral nectar is not the exclusive source of sugars for these insects.

The study of the volatile emissions from some of these plants, male and female *A. gambiae* responses to them, and identification of behaviourally active blends have been initiated.

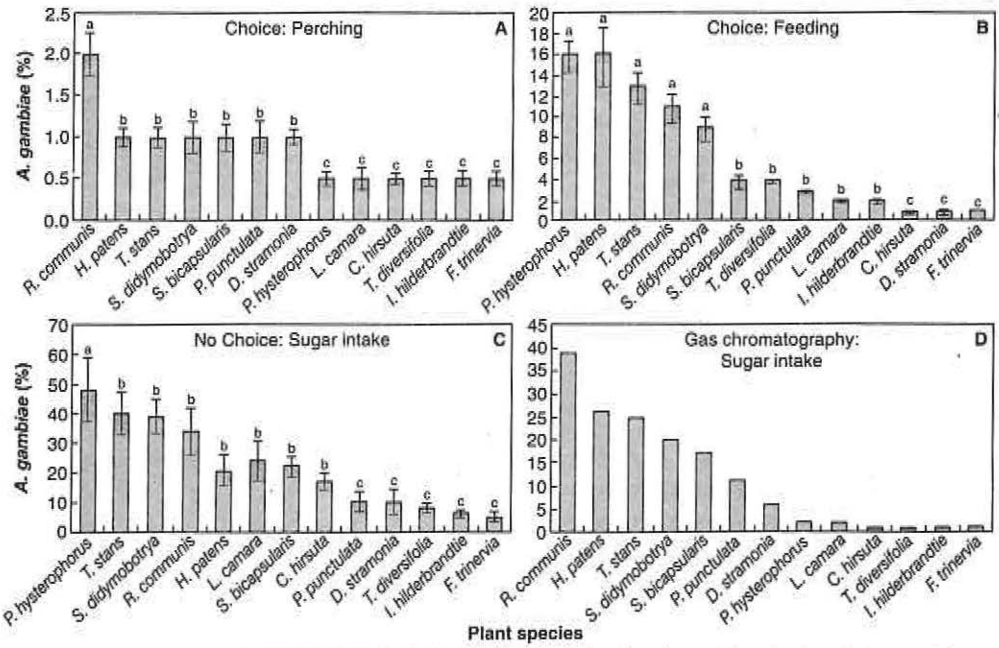


Figure 4. Percentage (mean ± standard error) of sampled individuals of male and female *Anopheles gambiae* that were (A) perching (resting on plant); (B) feeding (includes both probing and ingesting); (C) positive for fructose; and (D) contained sugar that matched sugar profiles of plants. Different letters: significantly different, same letters: non-significant (SNK multi-range comparison, α = 0.05). The number of replicates were 39 (A, B), and 3 (C). Eighty (40 males and 40 females) mosquitoes were tested in (D)

Table 4. Percentage of *Anopheles gambiae* (pooled males and females) with sugar profiles matching the sugar profiles of the plant parts of each candidate plant by gas chromatography analysis. N = 80 (40 males + 40 females), the total number of mosquitoes tested

	Percentage matching			Statistics	
Plant candidates	Leaf	Flower	Stem	P value	Chi square
Pathernium hysterophorus	17.5	0.0	NA	< 0.001*	15.34
Psiadia punctulata	1.25	0.0	NA	0.31	1.0
Senna bicapsularis	0.0	1.25	NA	0.31	1.0
Tecoma stans	2.5	22.5	NA	< 0.001*	14.62
Ricinus communis	21.25	26.5	35	0.14	3.88
Datura stramonia	0.0	1.25	NA	0.31	1.0
Cassia hirsuta	1.25	1.25	NA	1.0	0.0
Lantana camara	11.25	2.50	NA	0.02*	4.78
Senna didymobotrya	2.5	17.5	NA	< 0.001*	10.0
Tithonia diversifolia	0.0	2.5	NA	0.15	2.02
Ipomoea hildebrandti	3.75	6.25	NA	< 0.001*	15.3
Hamelia patens	0.0	26.2	NA	0.31	1.0
Flaveria trinervia	0.0	1.25	NA	0.31	1.0

NA = Not applicable.
*Significant difference among the different plant-part categories.

4. *Bioprospecting for antimalarial natural products*

(See also separate report under Environmental Health)

Participating staff: *A. Hassanali, W. Lwande*

Visiting scientists: *J. Ndiege (Kenyatta University), M. Ndung'u (Jomo Kenyatta University of Agriculture and Technology)*

Assisted by: *E. Nyandat, B. O. K. Wanyama, B. N. Njiru, P. N. Mbogo, J. Anjira*

Donors: *UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases, Geneva, Switzerland; World Health Organization/Multilateral Initiative on Malaria Research in Africa; National Institutes of Health*

Collaborators: *World Health Organization/Regional Office for Africa; Addis Ababa University, Ethiopia; University of Dar es Salaam, Tanzania; Kenyatta University, Nairobi, Kenya; Egerton University, Njoro, Kenya; Ohio State University, USA*

The following highlights the major foci of the studies undertaken and results obtained.

- Setting up of a collaborative network comprising *icipe*, Kenyatta University, University of Dar es Salaam, Jomo Kenyatta University of Agriculture and Technology, Makerere University and Addis Ababa University to undertake bioprospecting (mainly through postgraduate research) of plants in eastern Africa.
- Evaluation of a series of plants selected from ethnobotanical uses in a screenhouse as sources of repellent fumigants (burning, thermal expulsion, potted plants) and identification of several good sources of repellents, including *Conyza newii, Ocimum kilimandscharicum, O. suave* and *Corymbia citriodora*. Thermal expulsion (placement of foliage material on a hot surface, rather than direct burning) is the most effective method and represents a major improvement over the traditional burning on charcoal.
- Demonstration in an operational field study (funded by WHO/AFRO) that periodic thermal fumigation with *O. kilimandscharicum* resulted in 55–62% reduction in *Anopheles gambiae* s.l. in treated homes relative to untreated ones with corresponding reduction of malaria parasites in the human subjects.
- Identification of about six essential oils from different plants that are more repellent than DEET [RC_{50} range = 0.67–9.21 x 10^{-5} mg/cm^2 compared to RC_{50} of 33 x 10^{-5} mg/cm^2 of DEET in human-bait technique (WHO, 1996: Report of the WHO Informal Consultation on Evaluation and Testing of Insecticides, pp. 32–36, 50–52)]. Key constituents of the repellent blend have been identified. The potential of these oils in household fumigation and protection against mosquitoes is being explored.
- Demonstration of the high potency of a formulation of menthane diol (Mozigone) in long-lasting personal protection and potential sources of the repellent from precursors available in large amounts from certain grasses.
- Demonstration of the potential of tetranortriterpenoids from plant species belonging to the families Meliaceae and Verbenaceae as agents for controlling mosquito larvae. The compounds appear to function as ecdysteroid agonists or antagonists and disrupt the normal growth and development of the larvae.

Output

Journal articles

Impoinvil D. E., Kongere J. O., Foster W. A., *Njiru B. N., Killeen G. F., Githure J. I., Beier J. C., Hassanali A.* and *Knols B. G. J.* (2004) Feeding and survival of the malaria vector *Anopheles gambiae* on plants growing in Kenya. *Medical and Veterinary Entomology* 18, 108–115.

Ndung'u M. W., Kaoneka B., *Hassanali A., Lwande W.,* M. Hooper A., Tayman F., Zerbe O. and Torto B. (2004) New mosquito larvicidal tetranortriterpenoids from *Turraea wakefieldii* and *Turraea floribunda*. *Journal of Agricultural and Food Chemistry* 52, 5027–5031.

Ndung'u M., Torto B., Knols B. G. J. and *Hassanali A.* (2004) Laboratory evaluation of some East African Meliaceae as sources of larvicidal botanicals for *Anopheles gambiae*. *International Journal of Tropical Insect Science* 24, 311–318.

Odalo B. J. O., *Omolo M. O.*, Malebo H., Angira J., Njeru P. M., *Ndiege I. O.* and *Hassanali A.* (2005) Repellency of essential oils of some plants from the Kenyan coast against *Anopheles gambiae*. *Acta Tropica* 95, 210–218.

Omolo M. O., Okinyo D., Ndiege I. O., Lwande W. and *Hassanali A.* (2004) Repellency of essential oils of some Kenyan plants against *Anopheles gambiae*. *Phytochemistry* 65, 2797–2802.

Omolo M. O., Okinyo D., Ndiege I. O., Lwande W. and *Hassanali A.* (2005) Fumigant toxicity of the essential oils of some African plants against *Anopheles gambiae sensu stricto*. *Phytomedicine* 12, 241–246.

Sumba L. A., Guda T. O., Deng A. L., *Hassanali A., Beier J. C.* and Knols B. G. J. (2004) (Short Communication) Mediation of oviposition site selection in the African malaria mosquito *Anopheles gambiae* (Diptera: Culicidae) by semiochemicals of microbial origin. *International Journal of Tropical Insect Science* 24, 260–265.

Sumba L. A., Okoth K., Deng A. L., *Githure J.*, Knols B. G. J., *Beier J. C.* and *Hassanali A.* (2004) Daily oviposition patterns of the African malaria mosquito *Anopheles gambiae* Giles (Diptera: Culicidae) on different types of aqueous substrates. *Journal of Circadian Rhythms* 2, 6.

Conferences attended

Fifth European Conference on Ecological Modelling ECEM, 19–23 September 2005, Pushchino, Russia. Attended by: L. V. Nedorezov, A. Hassanali, A. M. Sadykov.

Fourth MIM Pan-African Malaria Conference, 13–18 November 2005, Yaounde, Cameroon. Attended by: A. Hassanali.

MIM Funders Forum, 31 March to 2 April 2004, Stockholm, Sweden. Attended by: A. Hassanali.

The joint WHO/TDR, NIAID, IAEA and Frontis Workshop on Bridging Laboratory and Field Research for Genetic Control of Disease Vectors, 14–16 July 2004, Nairobi, Kenya. Attended by: W. Takken, C. Costantini, G. Dolo, A. Hassanali, N'F. Sagnon and E. Osir.

Capacity building

PhD students

L. Sumba (Kenya) Oviposition behaviour of the African malaria mosquito *Anopheles gambiae* Giles (Diptera: Culicidae): Influence of external factors on oviposition site selection. Egerton University, Kenya (completed in 2004).

M. Omollo (Kenya) Isolation, identification and synthesis of behaviourally active semiochemicals from human foot odour. Kenyatta University, Kenya (completed in 2005).

H. Manda (Cameroon) Plant-feeding behaviour and effects of plant diets on the African malaria vector *Anopheles gambiae* fitness. Kenyatta University, Kenya (ongoing).

E. Innocent (Tanzania) Bioprospecting for botanical larvicides and repellents for the control of malaria (ongoing).

S. Wachira (Kenya) Identification of oviposition semiochemicals of *Anopheles gambiae* and exploration of their potential in control. Jomo Kenyatta University of Agriculture and Technology, Kenya (ongoing).

MSc students

S. M. Karenga (Kenya) Phytochemical investigation of the anti-larval compounds and blend(s) from *Melia volkensii* (Gürke) against *Anopheles gambiae* s.s. (completed 2004).

J. O. Odero (Kenya) Phytochemical investigation of anti-larval activity of genus *Vitex* (*V. payos* and *V. schiliebenii*) against *Anopheles gambiae* (completed 2005).

G. M. Nyamoita (Kenya) Phytochemical investigation of anti-larval activity of genus *Vitex* (*V. payos* and *V. schiliebenii*) against *Anopheles gambiae* (ongoing).

T. Rimu (Kenya) Isolation and characterisation of anti-mosquito compounds from *Turraea nilotica* and *Turraea holstii* (ongoing).

Individual-Based Model of Mosquito Choices Up Odour Plumes to Alternative Hosts

Participating scientists: *L. Nedorezov, A. Hassanali*

Collaborating department: *Behavioural and Chemical Ecology Department*

Collaborating unit: *Biostatistics Unit*

An individual-based simulation model of zoophilic mosquitoes is presented with a choice of two odour plumes at varying distance from each other. The simulation is based on the following assumptions:

(i) Every mosquito appears on a plane 'downwind' and flies up odour plumes originating from two points 'upwind', $C_1 = (x_1, y_1)$ and $C_2 = (x_2, y_2)$, which correspond to odour sources from N_1 human subjects and N_2 mammalian hosts, respectively (Figure 1);

(ii) A mosquito may locate an odour source if it comes under the influence of either plume; the probability of its flight up one or the other is described by fractional-linear functions dependent on a set of values of model parameters that reflect the number of individuals from each source and relative attractiveness of human and mammalian hosts: An insect that is outside the zone of behavioural influence of the plumes, has zero probability of locating the source;

(iii) The insect's movement under the influence of a plume is a stochastic process with exponential distribution, each step being dependent on the perception of the odour signal: The flight of an insect that loses the signal is considered equivalent to movement parallel to and away from the zone of influence $[A,B]$.

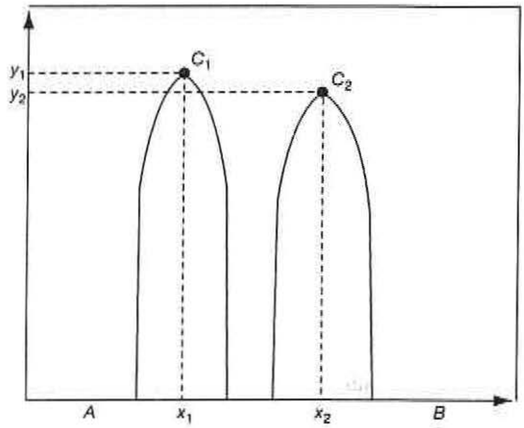


Figure 1. Plume structures from two alternative sources $C_1 = (x_1, y_1)$ and $C_2 = (x_2, y_2)$; interval $[A,B]$ represents the limit of significant behavioural influence on mosquitoes

Within this set of assumptions, we modelled the relationship between the number of mosquitoes that arrive at odour sources C_1 and C_2 with varying number of hosts (human or animal) and the relative distance between these sources. Computer experiments, each involving a large number of insects comprising 10^5–10^6 individuals, were carried out. The results are summarised below.

The most interesting result was the finding that the number of mosquitoes that arrive at the source of human odour is dependent on its distance from animal odour source; that is, it has a non-linear and non-monotonous pattern (Figure 2). This confirms our expectation that, at a given mosquito population density, significant diversion of insects between alternative hosts occurs at certain spatial relationships between competing plumes. A smaller or greater gap than a certain optimum does not facilitate net diversion of incoming insects from one to the other.

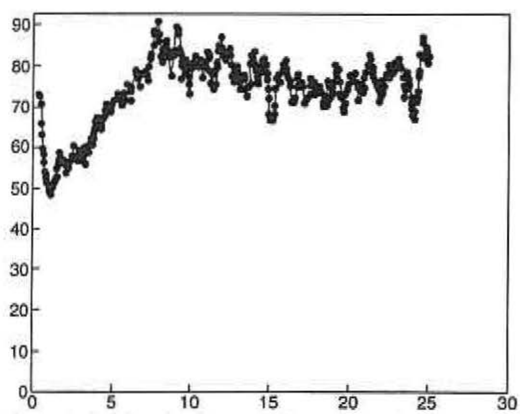


Figure 2. Relationship between the number of mosquitoes attracted to humans and the distance from animal odour source (data based on moving average with n = 7)

We also analysed the relationship between the number of attracted mosquitoes per person on the number of human subjects and animals at the respective odour sources. We found that, at any given human host number, this parameter decreased monotonously with increasing number of animals. However, at a given animal host number, the effect of increase of the number of human subjects appears to have a non-monotonous effect (Figure 3).

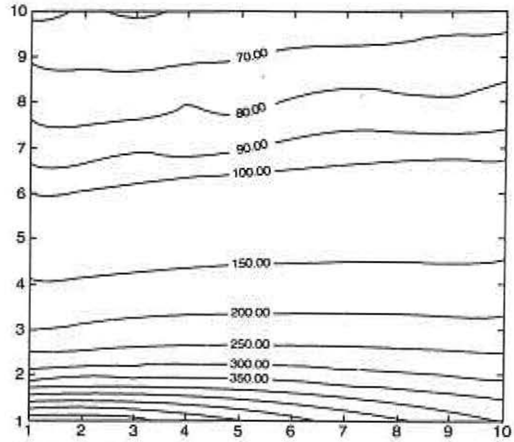


Figure 3. Intersection of surface of the function which describes the dependence of the number of mosquitoes per unit source of human odour on the number of human subjects and animals at C_1 and C.

Output

Abstracts in proceedings

Nedorezov L. V., Hassanali A. and Sadykov A. M. (2005) Individual-based model of mosquito choices up odour plumes to alternative hosts, pp. 136–137. In *Proceedings of the Fifth European Conference on Ecological Modelling-ECEM 2005* (Edited by A. S. Komarov). Pushchino, Russia, 19–23 September 2005.

Conferences attended

Fourth European Conference on Ecological Modelling (ECEM 2004), Bled, Slovenia, 27 September–1 October, 2004. Attended by: L. Nedorezov.

B. Tsetse/Human African Trypanosomosis

Developing a Diagnostic Test for Sleeping Sickness Caused by Trypanosoma brucei rhodesiense

Background, approach and objectives

Human African trypanosomosis, commonly called sleeping sickness, is caused by two protozoan parasites that are morphologically similar but cause different disease presentations. In eastern and southern Africa *Trypanosoma brucei rhodesiense* causes an acute infection, while in western Africa *Trypanosoma brucei gambiense* causes a chronic infection that can last several years. Both diseases are transmitted by the bite of tsetse of the genus *Glossina*. The disease is found in 37 sub-Saharan African countries, including 32 of the 42 most heavily indebted and poor countries in the world. Sleeping sickness has a profound impact on the health of a large portion of sub-Saharan Africa.

Sleeping sickness has an incubation period of one to four weeks with an initial phase characterised by chancre, fever, enlarged lymph glands and spleen, headaches and anaemia. A second and final phase constitutes a neurological phase where the parasite crosses the blood–brain barrier and infects the central nervous system. The diagnosis of the disease is based on the detection of the parasite in the host's blood and spinal fluid, but this is dependent on the presence of large numbers of parasites in these fluids; yet microscopic examination has limited sensitivity. Improving the ability of clinicians in the most remote localities to accurately diagnose sleeping sickness would greatly improve disease management and enhance the ability of rural communities affected by trypanosomosis to contribute to poverty reduction.

The project goal of the Molecular Biology and Biotechnology Department is to develop diagnostic test for human African trypanosomosis (sleeping sickness) caused by *T. b. rhodesiense*, using a recombinant DNA approach to generate antigens that are expressed by most isolates from the eastern Uganda/western Kenya endemic focus.

Participating scientists and student: *D. Masiga, E. Matovu[1], M. Turner[2], L. Akinyi*
Assisted by: *V. Owino and V. Jepchumba*
Donors: *UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases*
Collaborators: *[1]Makerere University, Uganda and [2]Glasgow University, UK*

Work in progress

An analysis of expression profiles of four clones (2 each from Kenya and Uganda) has aided the identification of 4 surface genes with diagnostic potential. These have been cloned into the pET28α expression system. Expression will allow evaluation against documented serum samples from patients and non-immune serum samples to evaluate the specificity and sensitivity of the antigens.

Output

Conference attended

Meeting on Capacity Strengthening for Research on Human African Trypanosomiasis, 6–7 June, 2005 Geneva, Switzerland, organised by UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases (TDR). Attended by R. K. Saini.

Capacity building

MSc student

L. Akinyi (Kenya) Characterisation and expression of variant surface glycoprotein genes in *Trypanosoma brucei rhodesiense* isolates from East Africa. Kenyatta University, Kenya (2005, ongoing).

PHOTO: Santiago Escobar

ENVIRONMENTAL HEALTH

A. Biodiversity Conservation

PRELIMINARY ASSESSMENT OF CARBON STORAGE AND THE POTENTIAL FOR FORESTRY-BASED CARBON OFFSET PROJECTS IN THE ARABUKO-SOKOKE FOREST

Background, approach and objectives

Habitat conservation offers the only realistic approach to insect conservation in the tropics as no single insect species can command the kind of resources that are mobilised for charismatic vertebrates such as rhinos and elephants. *icipe*'s strategy for biodiversity conservation is therefore habitat-based, with a particular focus on tropical forests, because they harbour two-thirds of all known insect species, and on global biodiversity hotspots because these contain the most threatened forests.

Global biodiversity hotspots are defined by two major criteria: (1) loss of over 70% of the original habitat must have been lost, and (2) presence of at least 1500 plant species endemic to the hotspot (Myers et al., 2000: *Nature*, pp. 853–858). Because insect diversity is so closely tied to plant diversity, a forest hotspot strategy is particularly effective for prioritising insect conservation efforts. Such a strategy demands an eclectic approach in which all means possible are employed to protect and conserve forests. *icipe*'s strategy for insect conservation, therefore, goes beyond the boundaries of conventional insect science. One thread in this strategy is to explore the potential of carbon trading.

Emerging markets for carbon trading may offer developing nations such as Kenya with added funding sources for reforestation and forest protection efforts. Rapidly rising atmospheric carbon dioxide levels have been linked to global warming and climate change. In an effort to mitigate this, there have been a number of internationally backed projects that offset carbon dioxide emissions by increasing storage of carbon in terrestrial pools. Projects that involve reforestation, afforestation, and deforestation prevention increase terrestrial carbon stocks, decreasing atmospheric CO_2 stock.

Having ratified the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) in 2005, Kenya can now participate in the UN sponsored carbon market, as well as voluntary carbon markets.

Kenya is in need of reforestation and forest protection activities. Forest loss means loss of many valuable ecosystem services such as pollination, erosion protection, soil quality maintenance, microclimate stabilisation, water filtration, fuelwood and other forest product provision, biodiversity, etc. Much of Kenya's indigenous forest has been degraded or cleared over the past century and high rates of loss continue with 93,000 ha cut in the last decade (FAO, 2001: State of the World's Forests 2001, pp. 1–175). It has been estimated based on biophysical and climatic features, that Kenya has the potential to double its current aboveground biomass (Brown and Gaston, 1995: *Environmental Monitoring and Assessment*, pp. 157–168), meaning that Kenya could at least double its storage of carbon in vegetation and soils.

Forest carbon offset projects could, therefore, assist Kenya by supplying financial assistance and incentives to slow the rapid disappearance of its forests. Model-based assessments of vegetation carbon storage in Africa suggest great potential to increase carbon stocks: Much of the area with the biophysical capacity to support carbon rich tropical forests is currently degraded or deforested (Brown and Gaston, 1995; Zhang and Justice, 2001: *Ambio*, pp. 351–355). Based on analysis of rainfall, topography, temperature and soil, Brown and Gaston (1995) suggest that Kenya could double its aboveground biomass carbon, and the deforestation rates in Kenya clearly suggest possibilities for forest protection and reforestation projects.

A barrier to Kenya's participation in carbon trading is the large amount of information needed to initiate a carbon project. General models can identify lands that are 'technically suitable' for carbon sequestration, areas that *could* support forest cover, but there is also need to determine which areas are 'actually available' for such efforts (Iverson et al., 1993: *Climate Research*, pp. 23–38). Much of Kenya's area with the biophysical capacity to support forest is used for smallholder agriculture or is surrounded by dense populations with high resource needs. Assessment of local socioeconomic, political, tenure and cultural factors of technically suitable areas helps ensure carbon storage activities can be achieved in a sustainable manner in these areas. A carbon baseline and monitoring programme also needs to be established, requiring more detailed forest inventories than currently exist for many African forests and carbon inventories of any agricultural/agroforestry systems involved.

The Arabuko-Sokoke Forest (ASF) is one of Kenya's most biodiverse forests and one of the largest remaining fragments of East African coastal dry forest (ASFMT, 2002: Arabuko-Sokoke Strategic Forest Management Plan 2002–2027, pp. 1–56). It falls within one of the 25 global biodiversity hotpots (Eastern Arc Mountains and Coastal Forests of Kenya and Tanzania) originally recognised by Myers et al. (2000). It supports over 600 plant species, 50 of which are considered rare; 230 bird species, of which 6 are globally threatened and 52 mammal species, of which 5 are globally threatened (ASFMT, 2002). While it is now a protected area, it has been subject to significant anthropogenic disturbance from past saw-milling of commercial timber as well as continued logging and subsistence resource extraction. This study aimed to assess the current carbon stock in ASF and the potential for carbon stocks to be increased through activities that could receive funding through existing carbon markets.

Measurement methods for carbon storage in tropical forests are still evolving. Carbon storage estimates for African forests have been primarily based on extrapolation from a few forest surveys and inventory data from the United Nations Food and Agriculture Organization, the FAO (Brown and Gaston, 1995; Cao et al., 2001: *Climate Research*, pp. 183–193). Many existing forest inventories in Africa completed by government agencies have typically focused on commercially valuable trees which can underestimate carbon storage by ignoring high densities of small trees and/or noncommercial species (Cao et al., 2001).

Remote-sensing techniques can help determine the area of forest cover, but field surveys are still needed to account for the range of biomass densities in closed canopy forest. Due to the high spatial variability typically found in tree species, tree sizes and stem densities in tropical forest, it can be difficult to produce a reliable estimate of average carbon density for a forest without high sampling intensity—large numbers and/or sizes of sampled areas (Brown et al., 1995: *Forest Ecology and Management*, pp. 175–189; Hall et al., 2001: *Global Change Biology*, pp. 389–403; Chave et al., 2003: *Journal of Ecology*, pp. 240–252). For a carbon-trading project, the frequency and intensity of forest monitoring impacts the amount of carbon sequestration that can be accounted for at the necessary precision for the sale of carbon credits.

Currently funded forest protection/regeneration projects show that suitable carbon stock estimates for natural forest can be achieved at non-prohibitive cost. Economic models developed to balance monitoring costs with carbon gains suggest long-term average monitoring, in which monitoring is performed every 5–10 years until a stable long-term average has been attained is often the most economical option in modelled forestry systems (Robertson et al., 2004: *Environmental Science and Policy*, pp. 465–475). If carbon monitoring can be combined with other inventories funded by other means more frequent monitoring should be feasible.

In this project, remote sensing techniques were combined with field surveys to obtain baseline levels of carbon storage against which future monitoring will be possible. The baseline levels are essential for any subsequent attempts to obtain carbon credits for Arabuko-Sokoke Forest.

Participating scientists: *J. Glenday (icipe intern), I. Gordon*

Assisted by: *M. Nyambenge (GIS expert: ICRAF); field assistants: W. Kombe (ASF Guides Association), G. Mashauri (KEFRI), M. Kinyanjui and P. Mukirae (KEFRI)*

Donor: *Critical Ecosystem Partnership Fund of Conservation International (The CEPF is itself funded by CI, Government of Japan, Global Environment Facility, MacArthur Foundation and the World Bank)*

Collaborators: *World Agroforestry Centre, Regional Centre for Mapping of Resources for Development, Arabuko-Sokoke Forest Management Team*

Work in progress (completed 2005)

1. Assessment of carbon stock in Arabuko-Sokoke forest and the potential for increase of carbon stocks in the future

Methods used:

Inventory plots: Carbon density in ASF was estimated with data from 97 circular, 20 m-radius (0.126 ha) inventory plots sampled in November–December 2004. In each plot, six major carbon storage pools were assessed: live tree aboveground biomass, tree belowground biomass, coarse deadwood (>10 cm diameter), litter, herbaceous vegetation and soil (Brown, 1997: *Estimating Biomass and Biomass Change of Tropical Forests—A Primer*; MacDicken 1997: *A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects*).

Plots were categorised by basic forest type, *Cynometra* forest/thicket, *Brachystegia* forest and mixed forest, and randomly placed within blocks of each type. The number of plots sampled in each forest type was roughly proportional to the relative area covered by each and the predicted spatial heterogeneity (variability between different areas in the forest) of carbon density within each class. Plot positions and observed disturbances, such as timber or fuelwood cutting, were recorded using a GPS unit and geo-referenced to ASFCMP land-cover maps (ASFMT, 2002). Plots for which field assessments of forest type did not match map classifications were assigned to the cover class seen on the ground. Plots located in known areas cleared in the 1930s to 1960s and subsequently abandoned, were classed as regenerating. Attempts were made to further classify plots within broad forest types on the basis of canopy height, size distribution and species composition to determine if sub-classes, such as *Cynometra* forest vs. thicket, had significant differences in carbon densities.

Vegetative biomass carbon: Carbon densities (Mg C/ha) in each plot were calculated from biomass densities, assuming 50% of vegetative biomass is carbon (MacDicken, 1997). To quantify aboveground biomass, tree and liana diameters were recorded at 1.3 m from the ground (diameter at breast height or dbh), in 97 inventory plots using a nested sampling design:

- Within a 4 m radius of the plot centre, all trees with dbh ≥ 5 cm were measured.
- Within a 14 m radius of the plot centre, all trees with dbh ≥ 20 cm were measured.
- Within a 20 m radius of the plot centre, all trees with dbh ≥ 40 cm were measured.

The species of each measured tree was recorded and an importance value of each species observed in a forest type was calculated as described by Brower et al. (1998: *Field and Laboratory Methods for General Ecology*, 4th Edition).

Aboveground biomass (AGB) of each tree was calculated based on diameter using a generalised tropical dry forest equation recommended for rainfall > 900 mm/year (Brown,1997). Belowground tree biomass (BGB) was calculated for each tree using a regression equation relating aboveground biomass density (AGB) to root biomass density (RBD) derived for tropical trees (Cairns et al.,1997: *Oceologia*, pp. 1–11).

Coarse deadwood biomass was estimated in each plot using the transect method described by Harmon and Sexton (1996: US LTER Publication No. 20), using tropical dry forest deadwood densities for the three decomposition classes reported by Jaramillo et al. (2004: *Ecosystems*, pp. 609–629). Standing dead trees were measured with the live trees, but given decomposition rankings with which to scale down biomass.

Clip plots were used to measure understorey vegetation and litter (MacDicken, 1997). The wet to dry weight ratio of sub-samples was used to estimate total dry weight for herbaceous vegetation. This same procedure was followed for litter collected in each clip plot after herbaceous vegetation removal.

Soil carbon: After clearing vegetation and litter from the clip-plots, three soil samples were collected per plot from the bare ground. Soil cores were taken with a tube corer to a depth of 30 cm and separated into 10 cm depth intervals. Samples were air-dried, passed through a 2 mm sieve and subsequently weighed. Bulk density was calculated using the measured weight of each dried, sieved sample divided by the core volume. Soil cores in which considerable compaction was observed were not included.

Sample carbon concentrations were predicted using the spectral library approach described by Shepherd and Walsh (2002: *Soil Science Society of America Journal*, pp. 988–998). All samples were analysed by diffuse reflectance spectroscopy, using a FieldSpec FR spectroradiometer (Analytical Spectral Devices Inc., Boulder, Colorado) at wavelengths from 0.35 to 2.5 μm with a spectral sampling interval of 1 nm using the optical setup described in Shepherd et al. (2003: *Agronomy Journal*, pp. 1314–1322). Soil carbon was measured on a random selection of 15% of the samples by acid oxidation. Measured concentrations for this subset were used to calibrate the reflectance spectra using partial least squares regression with Unscrambler 7.5® software (CAMO Inc., Corvallis, OR., USA). The regression models were used to predict C concentrations for all samples. The average carbon concentration at each depth was found for each sampled strata and multiplied by the bulk density to estimate soil carbon density (Mg C/ha).

Main findings:
Carbon densities in ASF's indigenous forest types (*Brachystegia* forest, *Cynometra* forest, 'mixed forest') ranged from 53–80 Mg C/ha (Figure 1). The total estimated carbon stock for ASF in 2004 was 3.0 Tg ± 0.2 Tg C. Evidence of recent illegal logging of trees of all sizes was observed throughout the forest (Figure 2), although more frequent near forest edges, roads and guardposts. Areas with tree stumps were found to have lower carbon densities on average than those areas without. Improved forest management techniques that prevent continued anthropogenic disturbance and allow natural regeneration could increase carbon stocks in ASF by as much as 0.40 ± 0.2 Tg C. A carbon emission offset this size could be worth roughly US$1.6 million. However, the slow growing nature of indigenous dry forests and the current lack of Kyoto Protocol sanction for improved forest management as a carbon offset mechanism are barriers to attracting a carbon driven investor.

The recently gazetted Madunguni Forest, which abuts ASF to the north, was seen to have lost 86% of its closed forest and 20,000 Mg C between 1992–2004. Reforesting this area and facilitating

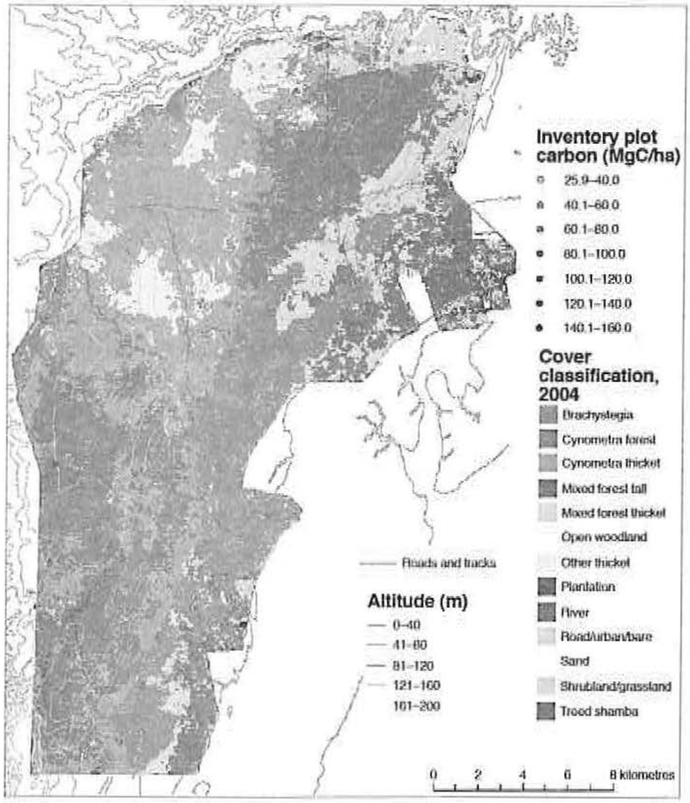


Figure 1. Land cover classification for Arabuko-Sokoke Forest and inventory plot carbon density, 2004

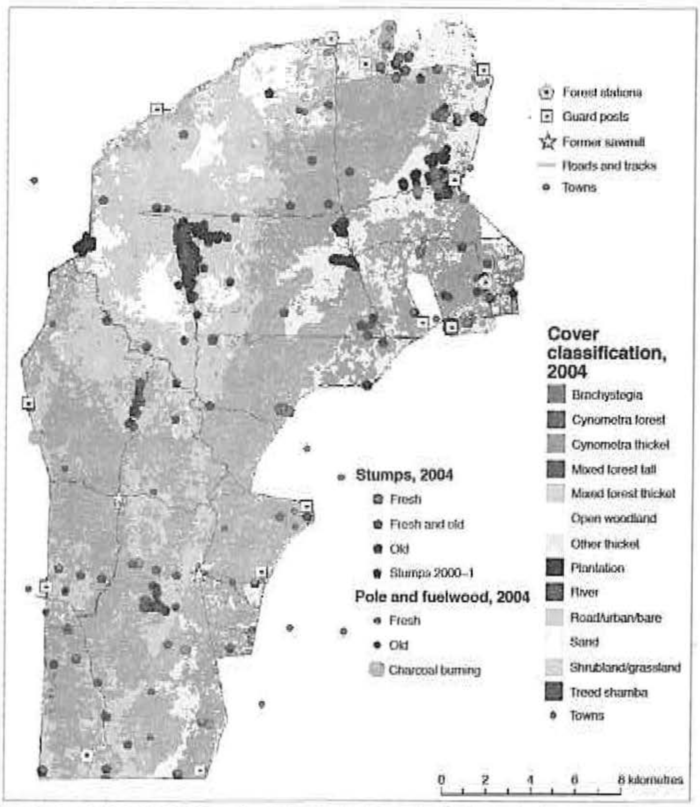


Figure 2. Anthropogenic disturbances observed in Arabuko-Sokoke Forest, 2004

tree planting on communal or individually owned land would provide carbon stock increases in a shorter time scale. Planting of agroforestry and fuelwood species would also provide resource and income alternatives to local communities, create carbon stores and potentially carbon sinks, while removing some pressure on the indigenous forest.

Ouput

Donor report

Glenday J. (2005) Preliminary Assessment of Carbon Storage and the Potential for Forestry Based Carbon Offset Projects in the Arabuko-Sokoke Forest. Critical Ecosystem Partnership Fund.

Conferences attended

Climate Change Workshop, 26–29 April 2005, Mombasa, Kenya. Attended by: J. Glenday.

Capacity building

Training workshop in carbon storage assessment organised for members of the Arabuko-Sokoke Forest-Adjacent Dwellers Association (ASFADA), Kenya Forestry Research Institute (KEFRI) scientists, Forest Department (FD) officers, National Museums of Kenya staff and Kenya Wildlife Service (KWS) wardens and rangers. 25 participants. Gede Forest Station, March 2005.

Impact

The study demonstrated a correlation between freshly cut stumps and proximity to forest guard stations. As a result there were transfers of senior staff in both KWS and FD.

Preliminary Assessment of Carbon Storage and the Potential for Forestry-Based Carbon Offset Projects in the Lower Tana River Forests: The Tana Delta Irrigation Project and the Tana River National Primate Reserve

Background, approach and objectives

(The general background and approach to this project is as described above for the Arabuko-Sokoke forest carbon storage project.)

The Lower Tana River forests are scattered floodplain forest fragments growing in semi-arid conditions, supported by groundwater and flooding from Kenya's Tana River. These forests have existed in a cycle of senescence through desiccation in some areas and forest growth in others as the meandering river channel migrates. This has made these forests particularly vulnerable and forest cover has been lost due to changed flooding patterns from upstream dams and irrigation projects, intense flooding from 1997 El Niño events, forest clearing to meet local agricultural needs and loss of new forest growth sites to riverine agriculture. These forests control erosion and water quality in the Tana, provide local communities with fuel, building materials, medicine, and foods and provide one of the last habitat areas for endangered primates, the red colobus and crested mangabey. This study aimed to assess the carbon storage value of these forests and the potential for carbon emission offset trading to help fund protection and rehabilitation of these forests in two sample sites: the Tana River National Primate Reserve (TRNPR) and the Tana Delta Irrigation Project (TDIP).

Participating scientists: *J. Glenday (icipe intern), I. Gordon*

Assisted by: *M. Nyambenge (GIS expert: ICRAF); D. Garisse, S. Jilloh, W. Kilimu (TARDA Forestry Officer), Mzee Dismus, A. Gafo (Mchelelo Camp) (field assistants)*

Donors: *Critical Ecosystem Partnership Fund of Conservation International. The CEPF is itself funded by CI, Government of Japan, Global Environment Facility, MacArthur Foundation and the World Bank*

Collaborators: *World Agroforestry Centre, Regional Centre for Mapping of Resources for Development, Kenya Wildlife Service, Tana River National Primate Reserve, Tana Delta Irrigation Project*

Work in progress (completed 2005)

1. Assessment of the carbon storage value of the Tana River Delta Irrigation Project and the Tana River National Primate Reserve sample sites and their potential for tradeable carbon

Methods used:
Inventory plots: Carbon density in riverine forests in TRNPR and TDIP was estimated with data from 148 circular, 20 m-radius (0.126 ha) inventory plots sampled in February–March 2005. In each plot, six major carbon storage pools were assessed: live tree aboveground biomass, tree belowground biomass, coarse deadwood (>10 cm diameter), litter, herbaceous vegetation and soil (Brown, 1997: *Estimating Biomass and Biomass Change of Tropical Forest—A Primer*; MacDicken 1997: *A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects*).

Plots were randomly placed both within forest patches and on patch edges with the number of plots sampled in each fragment roughly proportional to the fragment size. Plot positions and observed timber or fuelwood cutting were recorded using a GPS unit and geo-referenced to land-cover maps. An additional 8 sample plots were measured in the small planted exotic woodlots in the TDIP area.

All plots were classified on the basis of species composition (from importance values) and soil type into the following discernible forest classes: levee evergreen forest, clay evergreen forest; clay/levee evergreen forest; and transitional vegetation/woodland. Plots were also given an observed canopy closure ranking (open, medium, closed or low thicket). Mean carbon densities were estimated for each forest class.

Vegetative biomass carbon: This was estimated using the methods described for the Arabuko-Sokoke Forest carbon storage project.

Soil carbon: Soil was sampled in half of all inventory plots as soil carbon content was predicted to be low. Otherwise procedures were the same as described for the Arabuko-Sokoke Forest carbon storage project.

Main findings:

It was found that carbon densities in forest fragments in TRNPR and TDIP had values ranging from 160 to 260 Mg C/ha (Figure 1), intermediate values between those typically found in tropical dry and moist forests. 'Levee' forests which occur close to the river channel and are well fed by river groundwater and alluvial nutrient deposits had the highest carbon densities, while drier areas further from the river had significantly lower carbon densities and may have been undergoing a transition to woodland savanna or shrubland cover types.

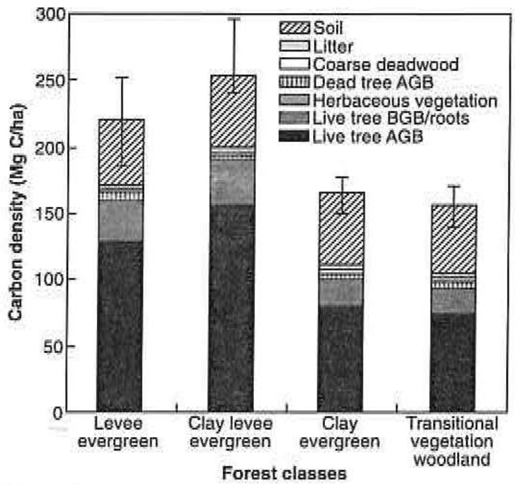


Figure 1. Mean carbon densities of forest types in Lower Tana River forests

Total carbon stock for the TRNPR was estimated to be 1.4 ± 0.1 Tg C, but has decreased by at least 50,000 Mg C since 1992. Total carbon stock for the TDIP area was estimated to be 0.55 ± 0.05 Tg C, having decreased by roughly 29,000 Mg C since 1992. It is possible that carbon stocks lost since 1992, if not more, could be regained through reforestation, agroforestry and forest protection strategies. Such projects could be tailored to both address local community resource and employment needs as well as produce tradeable carbon credits. Proposed reforestation corridors for the TDIP area could increase the area's carbon stocks by 100,000 Mg C (0.1 Tg C), a project scale that has received carbon offset funding in the past and would qualify as a small-scale afforestation and reforestation project under the CDM.

Output

Donor report

Glenday J. (2005) Preliminary Assessment of Carbon Storage and the Potential for Forestry Based Carbon Offset Projects in the Lower Tana River Forests. Critical Ecosystem Partnership Fund.

Conferences attended

Climate Change Workshop, 26–29 April 2005, Mombasa, Kenya. Attended by: J. Glenday.

Capacity building

Training workshop in carbon storage assessment organised for members of the Arabuko-Sokoke Forest-Adjacent Dwellers Association (ASFADA), Kenya Forestry Research Institute (KEFRI) scientists, Forest Department (FD) officers, National Museums of Kenya staff and Kenya Wildlife Service wardens and rangers. 25 participants. Gede Forest Station, March 2005.

Preliminary Assessment of Carbon Storage and the Potential for Forestry-Based Carbon Offset Projects in the Kakamega National Forest, Kenya

Background, approach and objectives

(The general background and approach to this project is as described above for the Arabuko-Sokoke forest carbon storage project.)

The Kakamega National Forest of Kenya's Western Province is a 23,700 ha area located on the edge of the Lake Victoria basin. Thirty-two percent of this area is agricultural or plantation land and only 60% (14,000 ha) contains closed indigenous forest. The remaining indigenous forest has a 30 m tree canopy dominated by evergreen hardwood species, the most common of which are *Funtumia africana*, *Ficus* spp., *Croton* spp. and *Celtis* spp. The indigenous forest area is now under multiple management strategies enforced by different institutions. The FD manages 20,000 ha of which 11,000 ha is indigenous forest. Some extractive forest uses such as cattle grazing and the collection of dead fuelwood, medicinal plants and thatching grass have always been permitted in much of the forest, but logging and charcoal burning are illegal. There are three zones in which all extractive uses are forbidden: two FD Nature Reserves (700 ha total) established in 1967 and the Kakamega National Reserve (4000 ha) established in 1985 and managed by the Kenya Wildlife Service (KWS). In comparison to FD areas, the national reserve is more heavily patrolled, has more severe penalties for offences, and, starting in 2003, requires a fee for entry.

This study aims to assess carbon storage in the Kakamega National Forest to provide a preliminary assessment of the biophysical potential for further carbon sequestration and suggest some possible management options to achieve this in light of the region's sociopolitical and economic conditions.

Participating scientists: *J. Glenday (Brown Univerity, icipe Intern), I. Gordon; L. Carlson, J. Albert, D. Murray, J. Orchardo, M. Delaney and P. Frumhoff (Brown University); K. Sheperd, A. Awiti, E. Weullow (ICRAF)*

Assisted in the field by: *L. McGeoch, M. Kapitulnik, P. Luteshi, B. Shimenga and W. Opondo*

Donor: *Watson Scholars Program and the Royce Fellowship Program*

Collaborators: *World Agroforestry Centre, Forest Department Kakamega Station, Brown University*

Work in progress (completed 2004)

1. Assessment of carbon storage in the Kakamega National Forest and the biophysical potential for further carbon sequestration

The methodology was as described in the report for Arabuko-Sokoke. Carbon density values for indigenous forest and plantations were estimated based on data collected in 95 randomised 20 x 20 m plots throughout the Kakamega National Forest from June to August of 2003. Data were analysed and an honours thesis completed in 2004. Tree biomass was estimated from diameter at breast height (dbh) measurements and allometric equations, while litter and herbaceous vegetation biomass was quantified using destructive sampling. Soils were sampled using both combustion and spectroscopy techniques. Land cover maps for 1975, 1986, and 2000 from Kenya's Department of Remote Sensing and Resource Surveys (DRSRS), were used to estimate both current carbon storage in the forest and the influence of land use change over the past 25 years on forest carbon stocks.

Figure 1 shows interpolated carbon densities for 2000. The average carbon storage density in indigenous forest is 340 ± 48 Mg C/ha (95% confidence interval), which is greater than that of the average found in the forest's hardwood plantations (280 ± 52 Mg C/ha) and significantly

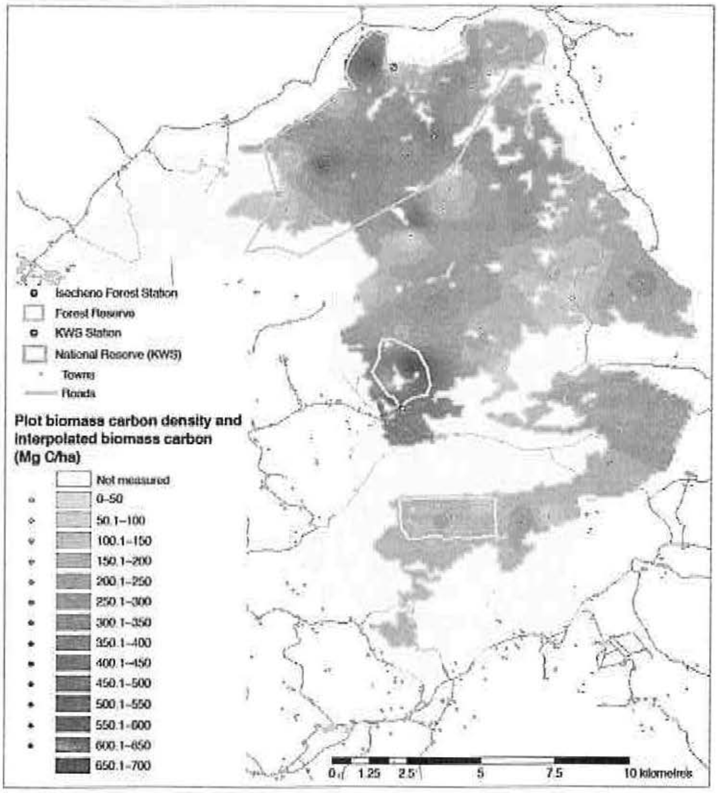


Figure 1. Kakamega Forest 2000 interpolated biomass carbon density

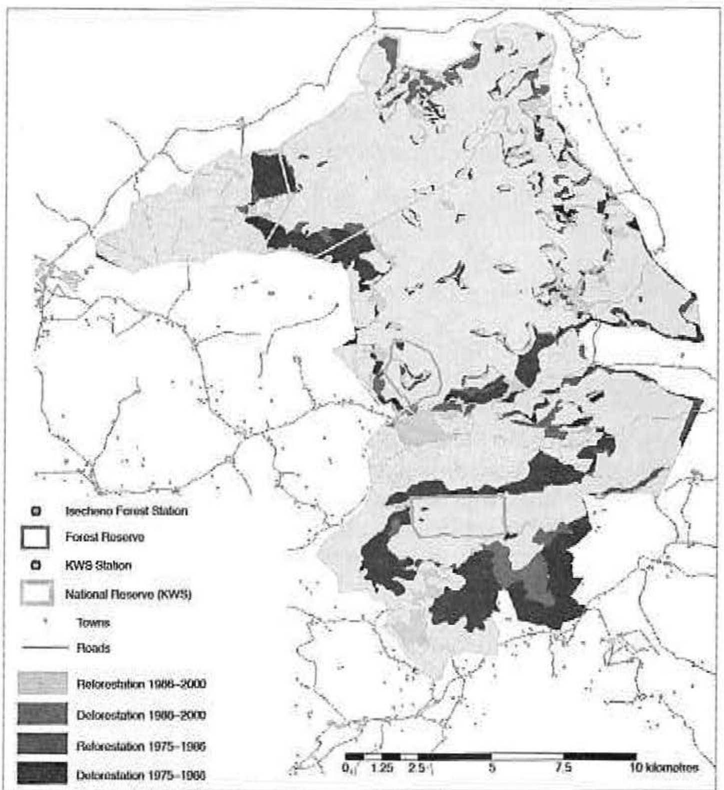


Figure 2. Kakamega Forest 1975–2000 reforestation and deforestation

greater than that of softwood plantations (210 ± 50 Mg C/ha). Deforestation between 1975 and 1986 and limited reforestation from 1986 to 2000 (Figure 2) have resulted in a net loss of 0.6 ± 0.1 Tg C. The distribution of carbon densities within the indigenous forest and variation between plantation types suggests that there are management practices that could increase Kakamega's carbon stock back to speculated 1975 levels if not higher. Even given current low carbon prices, a 0.6 Tg C increase in carbon stock could represent a $3 million value, a figure that dwarfs the operational budgets of the forest's management bodies and could begin to address the income deficit in the region.

Ouput

Thesis

Glenday J. (2005) Preliminary assessment of carbon storage and the potential for forestry based carbon offset projects in the Kakamega National Forest, Kenya. Brown Centre for Environmental Studies, Brown University Honours Thesis.

ECOSYSTEM PROFILE FOR THE EAST AFRICAN COASTAL FORESTS AND EASTERN ARC MOUNTAINS GLOBAL BIODIVERSITY HOTSPOT

(The general background and approach to this project is as described above for the Arabuko-Sokoke forest carbon storage project.)

Participating scientists: *I. Gordon, T. Butynski (CI), N. Burgess (WWF-US), D. Ocker, K. Sebunya, P. Langhammer (CEPF)*

Donor: *Critical Ecosystem Partnership Fund*

Collaborators: *N. Doggart (Tanzanian Forest Conservation Group), P. Matiku (Nature Kenya), J. Watkin (Consultant), R. Gereau (Missouri Botanical Gardens), D. Knox (Centre for Applied Biodiversity Science)*

Completed work

Hotspots cover only 1.4 percent of the planet yet contain 60% of all terrestrial species diversity. The Eastern Arc Mountains and Coastal Forests of Tanzania and Kenya Global Biodiversity Hotspot runs along the Tanzanian and Kenyan coasts and includes the islands of Zanzibar and Pemba (Figure 1). This is one of the smallest of the 25 Global Biodiversity Hotspots recognised by Conservation International (CI), and ranks first among them in the density of endemic plant and vertebrate species. (This hotspot is now split into two and the number of recognised hotspots has expanded to 34.) It is rated as the hotspot most likely to suffer the most plant and vertebrate extinction for a given loss of habitat and as one of 11 'hyperhot' priorities for conservation investment.

In 2003, *icipe* was invited by CI and the Critical Ecosystem Partnership Fund (CEPF) to lead on the compilation of an Ecosystem Profile for this East African hotspot. The purpose of such profiles is to identify key sites in which globally threatened species are found, assess previous investments and

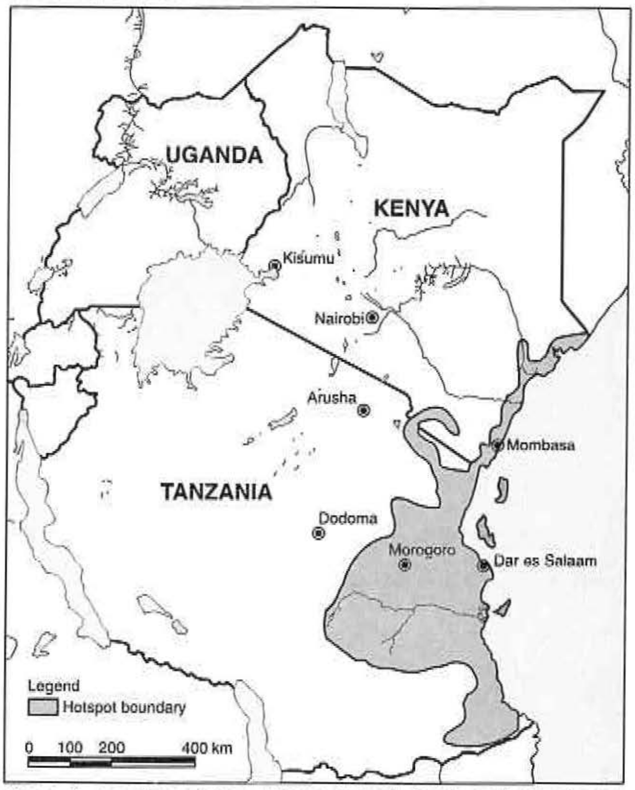


Figure 1. Location of East African coastal forests and Eastern Arc Mountains Global Biodiversity Hotspot

threats, and recommend a funding strategy for conservation action by Civil Society.

The Ecosystem Profile was completed in 2004 and approved by the CEPF Donor Council in June 2004. A database was compiled for 333 red-listed species (occurring in 160 sites, mostly but not exclusively forests) (Figure 2, Table 1).

The major threats were identified as commercial and subsistence agriculture, logging, extraction of carving wood, charcoal and fuelwood, fires, settlement, hunting, human–wildlife conflicts, mining and urbanisation. Investment in the hotspot was estimated at more than $19 million in 2003 and was analysed by sites, donors and implementers, and types of investment. Sites that had been underfunded with respect to biodiversity importance and those that had been insufficiently studied were identified. The East Usambaras, Udzungwas, Jozani, Taita Hills and Lower Tana River forests were prioritised as most in need of CEPF funding. Five Strategic Funding Directions and 21 Investment Priorities were recommended.

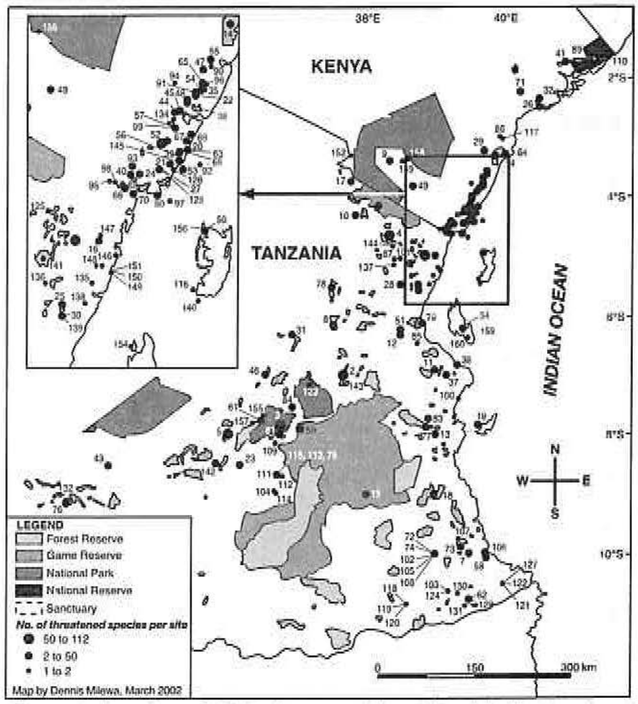


Figure 2. Location of 160 sites containing 333 globally threatened species

Table 1. Numbers of critically endangered, endangered and vulnerable species in five major taxonomic groups in the Eastern Arc Mountains and East African Coastal Forest Mosaic Biodiversity Hotspot

Taxonomic group	Degree of threat				Country	
	CR	EN	VU	Total	Tanzania	Kenya
Mammals	5	8	16	29	27	9
Birds	3	10	15	28	24	10
Amphibians	4	11	18	33	31	3
Gastropods	3	3	1	7	4	3
Plants	9	36	191	236	221	80
Total	24	68	241	333	307	105

CR, Critically endangered; EN, endangered, VU, vulnerable.

Output

CEPF (2003) Ecosystem Profile: Eastern Arc Mountains and Coastal Forests of Tanzania and Kenya Biodiversity Hotspot. Critical Ecosystem Partnership Fund. Washington DC. http// www.cepf.net/xp/cepf/where_we_work/easern_arc_mountains/full_strategy.xml.

Burgess N., Salehe J., Doggart N., Clarke G. P, *Gordon I.*, Sumbi P. and Rodgers A. (2004) Coastal forests of eastern Africa, pp. 230–239. In *Hotspots Revisited*. CEMEX, Mexico City.

Impact

On the basis of the recommendation in the Ecosystem Profile, the CEPF Donor Council authorised an investment of US$ 7 million in funding for Civil Society in the Hotspot for the period 2004–2008. CEPF subsequently gave a US$ 780,000 grant to *icipe* and its partners (BirdLife International; World Wide Fund for Nature, East African Region Programme Office and Tanzanian Forest Conservation Group) to assist in the administration of this funding.

Spatial and Temporal Dynamics of a Male-killer Endosymbiont (Spiroplasma) in the African Queen butterfly, Danaus chrysippus

Background, approach and objectives

Biodiversity studies are increasingly inclusive of microorganisms. For example, Sogin et al. (2006: *Proceedings of the National Academy of Sciences*, pp. 12115–12120) have recently drawn attention to the megadiversity of bacteria in the oceans. From the arthropod perspective, one group of microorganisms are of particular interest and have been the subject of much study by evolutionary biologists. These are cytoplasmically inherited endosymbiotic bacteria that cause reproductive disorders. They have been described in more than 30 insect species spanning six insect orders (Hurst and Jiggins, 2000: *Emerging Infectious Diseases*, Vol. 6 No. 4).

Wolbachia has been implicated in the majority of these cases, but there is increasing understanding of the importance of other bacterial clades including *Spiroplasma* and *Rickettsia*. Contrasting inheritance patterns of endosymbiotic genetic elements and their host autosomes lead to genetic conflicts. Endosymbionts are transmitted from mother to daughter through the egg cytoplasm and are therefore selected on the basis of their effects on the number and fitness of female offspring (Stouthamer et al., 1999: *Annual Review of Microbiology*, pp. 71–102). Autosomal genes are generally selected for even investment in either sex (Fisher, 1930: The genetic theory of natural selection). Opposing selective forces generate inter-genomic conflict between cytoplasmic and autosomal genes. In some cases, opposing selective forces are manifested in a distortion of sex-ratios. Endosymbiotic sex-ratio distorting bacteria are reproductive parasites, and function as 'selfish genetic elements' (Hurst and Werren, 2001: *Nature Reviews*, pp. 597–606), gaining a relative transmission advantage by means that are either neutral or detrimental to the organism's fitness. When detrimental, they offer the intriguing possibility of being used in pest control. A case in point is male-killing.

Male-killing in the African queen butterfly *Danaus chrysippus* is caused by a *Spiroplasma* bacterium (Jiggins et al., 2000: *Parasitology*, pp. 439–446). It has been noticed, however, that there is a markedly heterogeneous spatial and temporal distribution of *Spiroplasma* in *D. chrysippus* (Smith et al., 1998: *Biological Journal of the Linnean Society*, pp. 1–40; Jiggins et al., 2000). Male-killers appear to be restricted to an East and Central African hybrid zone between different races (incipient species) of *D. chrysippus* (Gordon, 1984: *Heredity*, pp. 583–593). At certain times of the year they infect as many as 80% of female butterflies. Male killing in this species is also of particular interest since it lays its eggs singly and scatters them widely. Most male-killers are found in insects which are batch layers, a situation in which infected females suffer less sibling competition (since their brothers die in the egg stage) and gain a nutritional advantage by eating the dead eggs. It is not at all clear what advantage infected females (and their endosymbionts) would gain when eggs are scattered.

In this study, spatial and temporal variation in the incidence of *Spiroplasma* infection in *D. chrysippus* was investigated by monitoring hatching rates in wild collected eggs and by screening wild adults for spiroplasma presence.

Participating scientists: *I. Gordon; J. Herren, P. Holland (Oxford University); D. Smith (retired, ex Eton College)*

Assisted by: *P. Muthoni*

Donor: *Self-funded*

Collaborators: *Zoology Department, Oxford University*

Work in progress

1. Spatial and temporal variation in the incidence of Spiroplasma *infection in* Danaus chrysippus

Wild eggs and adults were collected from several sites in Kenya (adults from Nguruman, Tsavo and Nakuru, eggs from Nairobi, Mombasa, Watamu and Muhaka). Egg hatching was monitored in the lab. Adult butterflies were dissected under sterile conditions and ovaries were stored in 95% ethanol at -20°C. DNA was extracted from the ovaries and subjected to PCR. *Spiroplasma* presence was confirmed using two primers (Spiro27f and SpiroG).

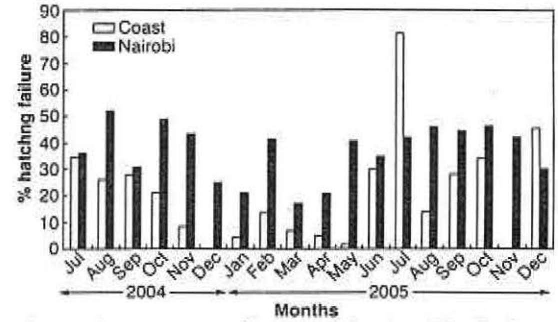


Figure 1. Percentage rate of hatching failure in wild collections of eggs from Nairobi and the coast

Figure 1 shows seasonal changes in hatching failure for eggs from Nairobi and the coast. In both locations hatching failure is more frequent during the rains, suggesting that *Spiroplasma* frequencies peak at this time.

Table 1. The frequency of *Spiroplasma* infection at each sample site

	Tsavo 2004	Tsavo 2005	Nguruman	Nakuru
N	31	15	110	37
% Infection	77.4	33.3	30.9	56.8

Infection frequency (Table 1) varied significantly between sites ($\chi^2_{[3]} = 24.9$; $P < 0.0001$). The Tsavo specimens were collected in consecutive years; in August and September 2004, the infection frequency was 77% (n = 31) whereas in August 2005 it was 33% (n = 15). The difference in *Spiroplasma* prevalence is significant ($\chi^2_{[1]} = 8.4$; $P = 0.004$). Due to the significant difference between the two Tsavo samples these are considered separately in subsequent analyses. In Nakuru, 56% (n = 37) were infected. The lowest levels of infection (31%, n = 110) were found at Nguruman. Overall, 44% (n = 193) of females were positive for *Spiroplasma*.

Host genotype at three biallelic wing pattern loci, representative of subspecific genetic divergence, was correlated to *Spiroplasma* infection (Table 2). Linkage between the recessive *a* allele and *Spiroplasma* was established. Three of four females homozygous recessive (*aa*) at the A locus were positive for *Spiroplasma*. Fifty-nine percent of identifiable heterozygotes at the A locus (n=49) were infected compared with 40.6% of butterflies with the dominant phenotype; these are significantly different ($\chi^2_{[1]} = 4.25$; $P = 0.039$). It is likely that the latter value is an overestimate as some heterozygotes (*Aa*) were undetected due to low penetrance of the *a* allele. No correlations between alleles and *Spiroplasma* infection were found at the *B* or *C* loci.

Table 2. Genotype at the A, B and C loci of *Danaus chrysippus* individuals in relation to sample site (number of butterflies)

	A-loci			B-loci		C-loci		
	A-	*Aa*	*aa*	B-	*Bb*	C-	*Cc*	*cc*
Tsavo 2004 (N = 69)	45	12	0	12	46	54	15	0
Tsavo 2005 (N = 16)	11	15	0	3	12	14	2	0
Nguruman (N = 110)	84	23	3	29	81	62	46	2
Nakuru (N = 55)	37	16	2	25	30	18	16	21

There is also spatial variation for linkage disequilibrium between *Spiroplasma* and the *A* locus. Linkage was highest at Tsavo (2004) with 100% of females with the *a* allele infected (n = 7). Tsavo (2005) was 50% (n = 4), Nguruman 51.9% (n = 27) and Nakuru 53.3% (n = 15).

In addition, a negative correlation between *D. chrysippus* forewing length and *Spiroplasma* infection was identified. Infected individuals had on average a 0.7 mm shorter forewing length (Pooled SD = 2.90). The difference between infected and uninfected individuals was found significant ($P = 0.05$, df = 192) in an unstacked t-test. The difference was consistent among samples and in the same direction. The reduction in forewing length associated with *Spiroplasma* infection was 0.59 mm (SD = 2.49) in Nakuru, 0.48 mm (SD = 3.11) in Nguruman, 1.24 mm (SD = 3.03) in Tsavo 2004 and 0.3 mm (SD = 1.07) in Tsavo 2005.

The results raise several questions regarding the origin and maintenance of *Spiroplasma* infections in *D. chrysippus*. Are the seasonal changes in infection frequency related to natural selection or migration or both? Does the reduction in body size indicate negative effects on infected female fitness? Is the correlation of infection with the *A* locus an indication of geographical origin for *Spiroplasma*? A proposal to follow up these findings was submitted to the Leverhulme Foundation in collaboration with David Smith and Michael Majerus of the Genetics Department of Cambridge University.

Output

Thesis

Herren J. (2005) The dynamics of *Spiroplasma* infection in *Danaus chrysippus*. BSc Honours Thesis, Department of Zoology, Oxford University.

B. African Stemborers Diversity

Biodiversity and Chemical Ecology of Gramineous Noctuid Stemborers in Africa

Background, approach and objectives

In Africa, the economic importance of noctuid stemborers and associated parasitoids varies according to phytogeographic characteristics and ecoregion. The reasons are not well understood in spite of extensive research over the past 50 years. Currently, the hypotheses for fluctuations of pest densities put forward centre around the existence of biogeographic races, the proximity of the natural habitats and alternate insect and plant hosts, and the inefficiency of natural enemies (mainly parasitoids) to control stemborers in crop fields.

In 2001, IRD initiated a project which focuses on assessing the genetic variation in populations of selected noctuid pest species, namely *Busseola fusca* (Fuller), *Sesamia calamistis* Hampson, *Sesamia nonagrioides* (Lefebvre), and related genera as well as of the larval parasitoid *Cotesia sesamiae*, which is one of the main antagonists of noctuid borers attacking cereals in two of Africa's regions: in West Africa, represented by Benin, Togo and Ghana, and in East Africa, represented by Kenya.

The research involves the following main activities:

- Description of the taxonomic diversity of the noctuid stemborers *Busseola* spp., *Sesamia* spp., and related genera such as *Manga, Sciomesa, Carelis, Poeonoma* and *Speia*, in different ecoregions;
- Study of the genetic diversity of *B. fusca, S. calamistis* and *S. nonagrioides* populations at the geographic and ecological level using molecular tools and characterisation of pheromonal communication systems;
- Study of coevolutionary processes between *B. fusca* and its main parasitoid *C. sesamiae;*
- Determination of the selective values (fitness) of the differences observed among populations in terms of habitat foraging capacity, reproductive (oviposition) success and development performance;
- Analysis of host plant selection mechanisms by stemborers with special reference to *B. fusca*, and the importance of physical and chemical characters of the host plant on oviposition;
- Study of the role of host plants in the adaptive radiation of *Busseola, Sesamia* and related genera in Africa;
- Study of the role of wild habitats in the colonisation of crop fields by stemborers.

In addition to a better taxonomic knowledge of African stemborers in cultivated and wild habitats. results will lead to:

- Development of evolutionary scenarios explaining the present-day interactions between host plants, herbivores and parasitoids. This will help to predict how global change (global warming) or human activities (use of GMOs, deforestation and/or displacement of wild habitats) may modify these interactions;
- A better understanding of the population dynamics and an improvement of existing strategies to manage stemborers in crops;
- A better understanding of carry-over effects of wild habitats in biological control by introduced and indigenous natural enemy species.

Participating scientists: *B. P. Le Rü, P.-A. Calatayud, S. Dupas, P. Le Gall, P. Moyal, J. F. Silvain, S. Calatayud*

Assisted by: *B. Musyoka, L. Ngala, P. Ahuya, A. N. Kibe*

Donor: *IRD (French government: Department of Education and Foreign Ministry), icipe*

Collaborators: *FRANCE: INRA St Cyr, France; CNRS, Gif/Yvette, France. KENYA: icipe, Nairobi, Kenya; Kenyatta University, Kenya; Jomo Kenyatta University of Agriculture and*

Technology, Kenya. BENIN: IITA, Cotonou, Bénin. SOUTH AFRICA: University of Natal, Scottsville, South Africa; North West University, Potchefstroom Camp, South Africa; Transvaal Museum, Pretoria, South Africa. UGANDA: National Agricultural Research Organisation, Uganda. TANZANIA: National Biological Control Programme, Kibaha Biocontrol Station, Tanzania; Ministry of Agriculture, Plant Protection Division, Zanzibar, Tanzania. MADAGASCAR: Ministère des Universités et de la Recherçhe, Madagascar. ETHIOPIA: Ethiopian Institute of Agricultural Research, Ethiopia. MOZAMBIQUE: Eduardo Mondlane University, Faculty of Agronomy and Forestry Engineering, Campus Universitario, Maputo, Mozambique. ERITREA: University of Asmara, Eritrea

Work in progress

1. *Phylogeography and population genetics of the maize stemborer* Busseola fusca *(Lepidoptera: Noctuidae) in sub-Saharan Africa*

The economic importance of *Busseola fusca* varies with region. In West Africa, it is the prevalent stemborer species on sorghum in the dry savannas but minor on cereals in the humid-hot lowlands; in Cameroon it is the predominant pest of maize across all ecozones and altitudes while in East and southern Africa it is the major pest in the mid-altitudes and highlands.

Previous studies on the genetic structure of *Busseola fusca* shows that this ecological preference is associated with major differences in partial DNA sequence of the cytochrome *b* mitochondrial gene. According to that study, *B. fusca* populations are differentiated into three major clades of mitochondrial haplotypes, one localised in the West African region (*W*), one restricted to East Africa (*KI*) and one found in Central and East Africa (*KII*). The origin of these clades is likely related to Pleistocene climate events. Partial geographic overlaps were observed only between clades *KI* and *KII* (Figure 1). Biogeographic barriers such as the Cameroon Volcanic Line region between Central and West Africa and in East Africa, the Rift Valley, which are linked to *B. fusca*'s ancient history on wild Poaceae, have been shown to be major factors of differentiation of this species. These barriers appear to be the same that shaped geographic differentiation of phytophagous mammals and rodents. However, no signature of sorghum domestication and maize introduction has been detected yet on the genetic structure of *B. fusca*, despite the expected important demographic consequences of this switch to cultivated plants. The regional evolutionary history and the centres of origin of the mitochondrial clades remain unknown. To answer these questions and to more accurately estimate geographical distribution of each clade, *B. fusca* was sampled across most of its geographic range from West, East to southern Africa (samples from Eritrea, Ethiopia, Malawi, Mozambique, Rwanda, Republic of South Africa, Uganda, Zambia and Zimbabwe).

Partial sequences of the gene coding for cytochrome *b*, informative at the intrageneric level in Lepidoptera have been used. A sequential approach combining several phylogeographic and evolutionary methods was used to analyse the molecular data to infer the demographic history of *B. fusca* populations in more detail. Such a sequential approach, from phylogeny to evolutionary history via demography and genetic structure, allows us to move from testing deeper phylogenetic splits to inferring recent patterns of population structure. This also may highlight the centres of origin of *B. fusca* populations and may elucidate the regional evolutionary history that has produced this genetic structure. Comparisons of sequences of partial mitochondrial DNA gene (cytochrome *b*) from 489 individuals of 98 localities in Southern, Central, East and West African countries confirmed the presence of the three main clades. Phylogenetic, F-statistics, demographic parameters and nested clade phylogeographic analyses confirmed that the clades experienced geographic and demographic expansion with isolation by distance after their isolation in three refuge areas. The geographic range of clade *KII*, already known from East to Central sub-Saharan Africa, was extended to Southern Africa. Mismatch distribution analysis and the negative values of Tajima D index are consistent with a demographic expansion hypothesis for these three clades. Significant genetic differentiations were revealed at various hierarchical levels by analysis of molecular variance (AMOVA).

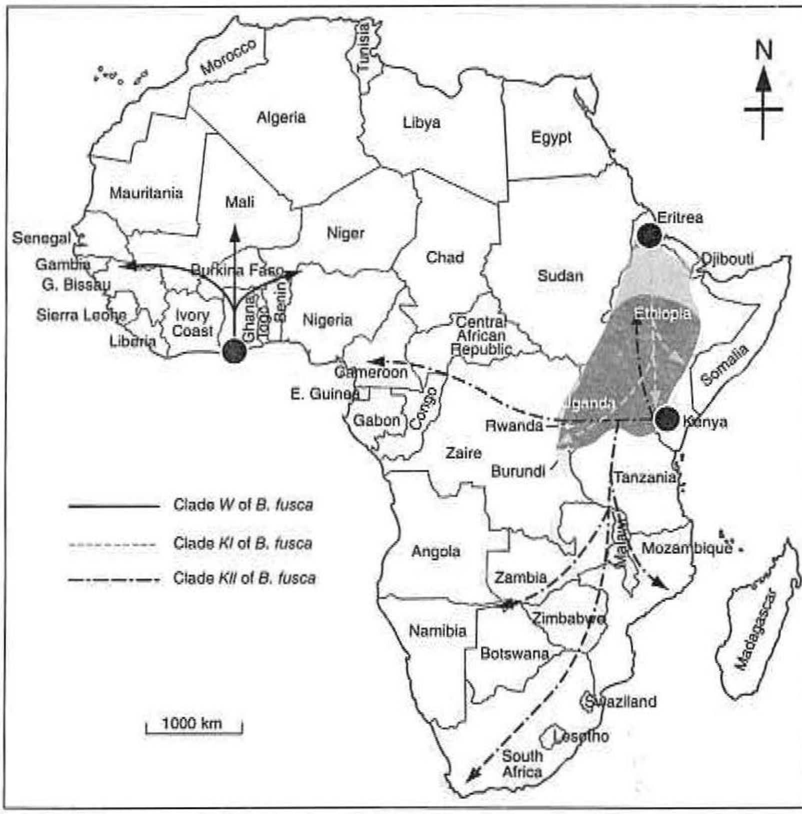


Figure 1. Current geographic distribution of *Busseola fusca* and the different centres of origin of its three main clades based on phylogenetic analyses

2. *Biodiversity of lepidopteran stemborers in East and Southern Africa*

Surveys were carried out between December 2002 and April 2005 in Eritrea, Ethiopia, Kenya, Madagascar, Mozambique, South Africa, Tanzania, Uganda and Zanzibar, to assess the lepidopteran stemborer species diversity on wild host plants. A total of 24,674 larvae belonging to 135 species have been collected from 75 species of wild host plants belonging to the Poaceae, Cyperaceae, Typhaceae and Juncaceae families. Among them were 43 noctuid species (with 17 new species) belonging to at least 9 genera (Figure 2), 33 crambids, 15 pyralids, 16 pyralid species not yet identified, 25 tortricids and 3 cossids. The noctuid larvae represented 76.6% of the total number of larvae with 68.6, 4.1, 3.8 and 0.1% found on Poaceae, Cyperaceae, Typhaceae and Juncaceae respectively. The Crambidae, Pyralidae, Tortricidae and Cossidae represented 20.0, 1.3, 2.0 and 0.1%, respectively, of the total larvae collected, with 90.4% of the Crambidae and Pyralidae collected from Poaceae and 99.7% of the Tortricidae collected from Cyperaceae (Figure 3).

Our results show that both host plant range and stemborer diversity in East and Southern Africa are much higher than reported in previous surveys. Among the 75 host plants found infested, 55 were never reported as hosts of stemborers before, thus the number of known host plants is now 92 indicating the host plant range attacked by stemborers is vast. Infested host plants were found in all vegetation mosaics whatever their ecological characteristics but no doubt stemborer larvae were found principally on host plants with robust and thick stems, growing in wetter parts of the vegetation mosaics. All Cyperaceae and Typhaceae species grow in swampy areas so it is not easy to relate any preference for a particular species with the ecology. The ecology of Poaceae is much more diverse. Almost half of the species have a high preference for wet conditions (*Echinochloa* sp., *Eriochloa* sp., *Pennisetum macrourum*, *P. purpureum*, *Panicum maximum*, *Setaria megaphylla*, *S. incrassata*) and they hosted 83% of the larvae. All localities surveyed in the current study were below 2400 m above sea level and in agroecological areas where maize is grown. However, we missed the high altitude forested areas, which reach 3000 m in tropical Africa, and the alpine areas found in all African mountains above 3000 m from where many stemborers were recorded

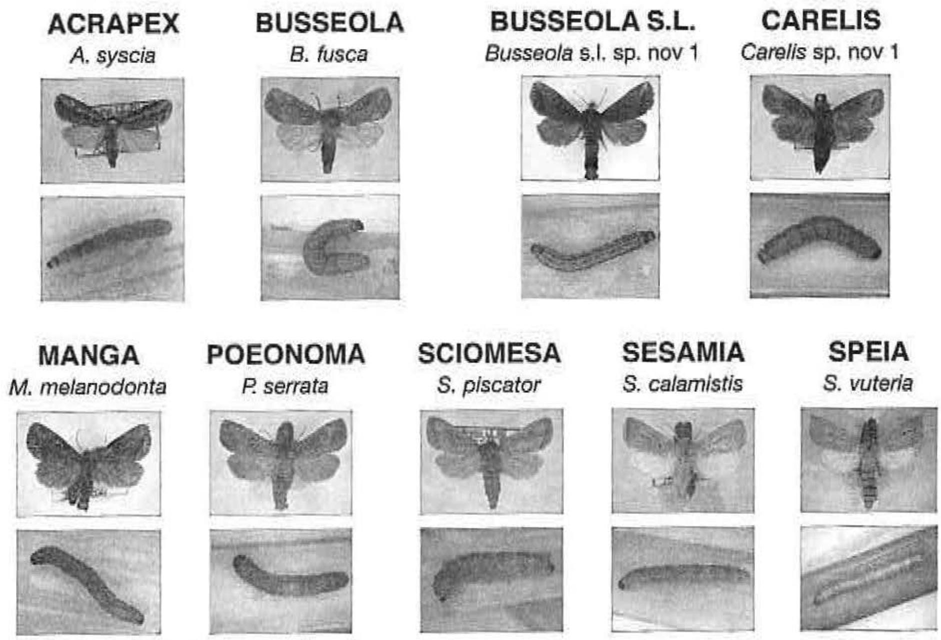


Figure 2. A glimpse on noctuid diversity

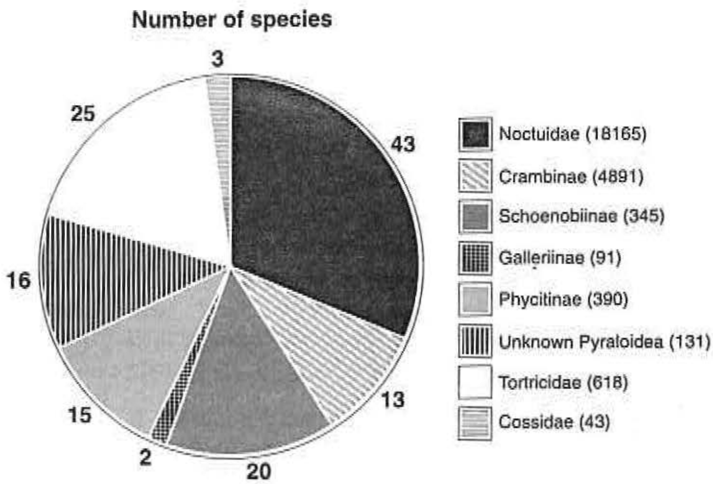


Figure 3. Abundance and relative species diversity of lepidopteran stemborers in eastern Africa

in previous faunistic studies. These high altitude areas appear particularly rich in *Acrapex* and *Sesamia* species. This could explain why our survey reported only 2 *Acrapex* and 12 *Sesamia* species, although they are known to be the most diverse noctuid stemborer genera in East and Southern Africa, with 37 and 33 known species, respectively. Our work provides for the first time a general overview on host plant range of the different lepidopteran stemborer families. With the notable exception of the *Speia* genus found on Typhaceae only, all the noctuid genera were found on Poaceae. Several genera appear specialised on this family like *Busseola*, 'new genus', *Manga* and *Poeonoma*. When they adopt other plant families, they appear more abundant and diversified on the former one, like the *Carelis*, *Sciomesa* and *Sesamia* genera. Information on host plant range for other lepidopteran stemborer families is missing completely in the literature with the exception of *Eldana saccharina* (Pyralidae). Our results confirm that *E. saccharina* is primarily an insect of the Cyperaceae (82% of the specimens on 5 species). Other families or subfamilies show a restricted host range compared to Noctuidae with Crambinae, Phycitinae and Cossidae found on Poaceae only, Schoenobiinae on Cyperaceae and Typhaceae and Tortricidae on Poaceae and

Cyperaceae. Although apparently less specialised, Schoenobiinae and Tortricidae show a marked preference for one plant family as indicated by the species diversity.

Our work confirmed that *Sesamia calamistis* and *E. saccharina* are polyphagous species found on 24 and 11 host plant species, respectively. However, they are not as common on wild host plants as reported before and they were not common or not found on some of the hosts previously described (i.e. *Echinochloa pyramidalis, Panicum maximum, Typha domingensis*). On the other hand, our work showed that *B. fusca* and *C. partellus* are oligophagous species found only on, respectively, four and eight Poaceae species. Although we were unable to separate accurately the different species of the *C. orichalcociliellus* group, *C. orichalcociliellus* is also an oligophagous species like *C. partellus*. Our results clearly showed some discrepancies with findings by previous surveys. We can assume that the main reason for these discrepancies is the misidentification of stemborer species. Our work underlines that proper identification of stemboring pests is essential to appraise accurately their host ranges and the importance of uncultivated land as a source of pests for adjacent crops. *Busseola fusca* was uncommon on wild host plants in Kenya, Mozambique, Tanzania and Uganda and very common in Northeast Africa particularly in Eritrea where it accounted for 43% of the noctuid larvae. The present results show that the host range of most insects is dynamic and often location- and time-specific.

3. *The role of wild habitats in the colonisation of stemborers of crop fields*

In an attempt to understand the role of wild host plants on pest population dynamics between natural and cultivated habitats, two representative locations, Kakamega and Muhaka, were chosen in Kenya for their diversity of habitats and farm management practices. Kakamega is dominated by *B. fusca* and Muhaka by *C. partellus*. The aim was to assess survival of stemborer pests in wild habitats during the off-season and their subsequent invasion of crop fields at onset of the rainy season. This study will also determine whether wild habitats can be used in resistance management of Bt-transgenic maize.

In Kakamega no differences in wild host plant species richness and relative abundance were found between cropping and non-cropping seasons suggesting continuous presence of host plants (Table 1). However, among the wild plant species identified only three (*Sorghum arundinaceum, Setaria megaphylla* and *Pennisetum purpureum*) were identified as hosts of *B. fusca*, covering less than 4% of the area. This suggests that in this location the natural habitat could not support high populations of *B. fusca* during the off-season. Coupled with the limited host range of this pest, dense human population is putting more pressure on the remaining land resulting in constant destruction of wild habitat, which may disrupt the plant–herbivore interaction and thus affect the pest population in the wild and cultivated habitats.

In Muhaka, wild host species richness and relative abundance varied between seasons though in general the area coverage of wild hosts was higher than that of maize (Table 2). Among the hosts recorded, only three (*Panicum maximum, S. arundinaceum* and *Rotboellia cochinchinensis*) were identified as host plants of *C. partellus*. *Panicum maximum* was the main alternate host in all vegetation structures in both seasons. The other two hosts were mainly found at the edge of cultivated fields, thus, farming practices can favour the maintenance of alternative host plants for stemborer pests during the non-cropping season. Besides the extended dry season, uncontrolled burning of wild habitats during the dry season to clear land in preparation for the cropping season probably was responsible for the low abundance of wild hosts of the pest in Muhaka.

In both localities, the total area covered by wild host plants of stemborer pests was below 5%, which may not be sufficient to play an important role in the carry-over of pests between the seasons. Interaction between vegetation structure and movement patterns of insects ultimately affects population dynamics in a heterogeneous landscape. Thus, the absence or presence of alternate hosts alone might not account for pest outbreaks in the cultivated fields, and hence, there is a need to study the movement patterns of the stemborers as well. The limited information available on movement of adult moths suggests that most of the population moves relatively short distances (less than 100 m) within the crop or the adjacent vegetation though reports indicate that *B. fusca* is likely to fly long distances under optimum conditions. However, it is worth noting that, contrary to *B. fusca* recovered from *S. arundinaceum*, *B. fusca* collected from *S. megaphylla*

Table 1. Total relative cover (%) and relative cover of each wild host plant species of lepidopteran stemborers in the four different vegetation structures in Kakamega during the cropping and non-cropping seasons. The wild host plants of *Busseola fusca* are in bold type

Plant species	FRV	BC	FG	FCV	Cover %
Cropping season					
Cyperus dives Delile	0.09	0.15	0.00	0.00	0.08
Cyperus distans L.	0.50	0.25	0.00	0.00	0.31
Cyperus dichrostachyus A. Richard	0.00	0.13	0.00	0.00	0.03
Scleria racemosa Poiret	0.30	0.90	0.00	0.00	0.38
Brachiaria brizantha (A. Richard) Stapf	1.08	1.47	42.52	1.67	6.60
Cynodon dactylon (L.) Persoon	4.94	5.65	3.53	0.80	4.41
Digitaria milanjiana (Rendle) Stapf	0.00	0.00	0.07	0.00	0.01
Hyparrhenia diplandra (Hackel) Stapf	0.67	0.00	0.00	0.00	0.32
Hyparrhenia rufa (Nees) Stapf	0.46	1.25	0.00	0.00	0.54
Panicum maximum Jacquin	0.23	0.15	4.62	2.10	1.02
Pennisetum macrourum Trinius	0.64	0.00	0.00	0.00	0.31
Pennisetum purpureum **Schumacher**	**0.58**	**2.33**	**0.00**	**0.00**	**0.88**
Pennisetum clandestimun (Chiovenda) Hochstetter	0.00	0.00	0.50	0.20	0.09
Pennisetum trachyphyllum Pilger	0.00	0.00	0.00	2.67	0.34
Setaria megaphylla **(Steudel) T. Durand & Schinz**	**0.88**	**3.08**	**0.00**	**6.30**	**2.04**
Setaria sphacelata (Schumacher) Moss	0.18	0.00	0.00	0.00	0.09
Sorghum arundinaceum **(Desvaux) Stapf**	**0.30**	**0.00**	**6.43**	**0.00**	**0.98**
Typha domingensis Persoon	0.00	0.67	0.00	0.00	0.17
Average cover in respective structures	10.84	16.03	57.67	13.73	18.60
Non-cropping season					
Cyperus dives Delile	0.00	0.09	0.00	0.00	0.03
Cyperus distans L.	0.00	0.16	0.00	0.00	0.06
Cyperus dichrostachyus A. Richard	0.00	0.27	0.00	0.00	0.10
Scleria racemosa Poiret	0.07	0.09	0.09	0.00	0.07
Brachiaria brizantha (A. Richard) Stapf	0.70	0.17	26.93	0.74	5.427
Cynodon dactylon (L.) Persoon	7.56	3.25	1.78	0.14	6.57
Cymbopogon nardus (L.) Rendle	0.41	0.30	3.47	0.00	1.01
Digitaria milanjiana (Rendle) Stapf	4.25	6.75	0.00	1.00	5.36
Echinochloa pyramidalis (Lamark) Hitchcock & Chase	0.07	0.00	0.00	0.00	0.05
Panicum maximum Jacquin	0.00	0.00	0.79	0.67	0.20
Pennisetum macrourum Trinius	0.45	0.00	0.00	0.17	0.32
Pennisetum purpureum **Schumacher**	**0.27**	**0.54**	**0.00**	**0.00**	**0.37**
Setaria megaphylla **(Steudel) T. Durand & Schinz**	**2.14**	1.33	**0.00**	**1.44**	**2.04**
Pennisetum trachyphyllum Pilger	0.00	0.00	0.00	4.05	0.36
Sorghum arundinaceum **(Desvaux) Stapf**	**0.37**	0.00	**0.85**	**0.73**	0.47
Typha domingensis Persoon	0.00	0.37	0.00	0.00	0.13
Average cover in respective structures	16.51	13.30	33.90	8.95	22.60

FRV, Forest and riverbank vegetation; BC, between cultivation; FG, forest glade; FCV, forest corridor vegetation.

in Kakamega did not develop to adult moths on the artificial diet under laboratory conditions. This could be an indication that the *B. fusca* population belonging to this location might be divided into different compartments with very low exchange between cultivated and non-cultivated habitats. The need to investigate the structure of *B. fusca* populations in Kakamega and to quantify the exchange between the different habitats are future prospects.

The presence of wild host plants of stemborers in cereal-growing areas has always been considered detrimental to cereal crop production as they serve as reservoirs for stemborer pests. Surveys to determine the role of these host plants on stemborer pest populations was carried out during the cropping and non-cropping seasons along varying altitudinal gradients in Kenya. Contrary to earlier reports only two larvae of *B. fusca* were recovered from *P. purpureum* which grew within a maize

Table 2. Area covered (km^2) and percentage surface cover by each vegetation structure in Kakamega and Muhaka. The number of sampling points per vegetation structure is in parentheses

Land cover vegetation structure	Area covered (km^2)	Cover %
Kakamega		
Maize (M)	9.16	43.13
Tea (T)	0.42	1.96
Natural forest (NF)	9.17	43.18
Between cultivated (BC)	0.60	2.83 (8)
Forest edge and riverbank vegetation (FRV)	1.38	6.48 (15)
Forest glade (FG)	0.34	1.62 (4)
Forest corridor vegetation (FCV)	0.17	0.81 (4)
Total area	21.25	100.00 (31)
Muhaka		
Mixed vegetation (MV)	9.69	44.37 (13)
Palm vegetation (PV)	3.13	16.22 (5)
Open quarry (OQ)	0.05	0.24
Buildings (B)	0.07	0.36
Roadside vegetation (RV)	0.10	0.54 (3)
Natural forest and edge (NF&E)	1.56	8.09 (4)
Open grassland (OG)	3.76	19.69 (6)
Cultivated vegetation (CV)	2.06	10.69
Total area	19.30	100.00 (31)

field. Very likely reports of *B. fusca* on *P. purpureum* in Kenya may have been a result of the larvae moving from maize or sorghum onto *P. purpureum*, or misidentification. Unlike *B. fusca*, *S. calamistis* was recovered from many plant species confirming its polyphagy also reported from West and Central Africa. *Chilo partellus* was restricted to low and mid-altitude zones with high populations in maize and low populations in wild habitats. *Chilo partellus* populations were higher than other borers supporting earlier studies which suggested that this zone is ecologically suitable for its establishment. This can explain its rapid population build up that resulted in the displacement of indigenous *C. orichalcociliellus*. However, there was evidence of variation in the niche occupied by the two species in the wild as most of the *C. partellus* larvae were found on *S. arundinaceum* while the *C. orichalcociliellus* group was found mainly on *P. maximum*. Observed richness of the non-pest species (Table 3) agrees with Polaszek and Khan (1998: *African Cereal Stemborers: Economic Importance, Taxonomy, Natural Enemies and Control*, pp. 4–10) suggesting that stemborer diversity in non-cultivated habitats has been underestimated.

Table 3. Proportions (%) of stemborer genera and families in different altitudinal zones from wild host plants (the numbers in parentheses indicate the number of species)

Super-family	Family	Genera	<1000	1000–1500	> 1500
Noctuoidea	Noctuidae	*Busseola* (1)	1.5	0.1	14.7
		Carelis (1)	0.0	0.0	4.8
		Busseola sensu lato (3)	0.0	0.0	13.3
		Manga (2)	23.4	9.7	1.9
		Poeonoma (1)	0.0	0.0	15.8
		Sciomesa (6)	4.6	0.8	38.8
		Sesamia (9)	15.8	28.7	5.8
Pyraloidea	Crambidae	*Chilo* (5)	43.4	56.8	0.1
		Other crambid species (7)	1.8	0.5	3.1
	Pyralidae	*Eldana* (1)	0.1	0.1	0.3
		Other pyralid species (8)	6.9	0.3	0.3
Tortricoidea	Tortricidae	11 species	2.5	2.6	1.1
Cossoidea	Cossidae	2 species	0.0	0.4	0.0

Similar to pest species, the distribution of some wild stemborers was found restricted to either a certain plant species or altitudinal zone. The *Manga* genus was commonly found in *P. maximum* in low altitude zone, while *Busseola* spp. were found mainly in the high altitude zones. The presence and abundance of the 'wild' stemborer species in different regions appear to be affected by the availability of suitable host plants. Borer species belonging to *Sesamia, Sciomesa, Busseola* genera as well as crambids, pyralids and tortricids constituted an important proportion of the total collections made. Most of the wild stemborer species were recovered from limited number of wild hosts. However, some of the non-pest stemborer species (*B. phaia* group and *Sciomesa piscator*) develop easily on maize stems exhibiting a potential to shift and become pests of cultivated cereals. The recent host switch of *E. saccharina* from sedges to sugar cane in South Africa where it became the key pest, confirms this assumption. *Eldana saccharina* was only found on wild plants during this study though it is an important pest of maize in West Africa. It could be a major threat to maize crops in Kenya if it eventually shifts to cultivated fields.

4. *Contact chemosensilla on the ovipositor of* Busseola fusca *(Lepidoptera: Noctuidae)*

Given the importance of the host plant selection process for the survival of offspring, females of *Busseola fusca* very likely have special organs for detection of a wide range of cues from the host plants including tactile, olfactory and gustatory chemostimuli. The role of plant volatiles as long-range chemical cues is not clearly understood in *B. fusca*. However, these chemicals may facilitate host finding by stimulating take-off and flight activity in gravid females. We observed that after landing on a host plant, *B. fusca* females extend the abdomen and touch the plant surface with the tip of the ovipositor making broad lateral movements, termed as 'ovipositor sweep' (Figure 4a). During this behavioural step, tactile and gustatory stimuli are likely to play a major role in decision-making for the acceptance of the plant for oviposition. As shown earlier, physical and chemical characteristics of the oviposition site are involved in host plant acceptance for oviposition.

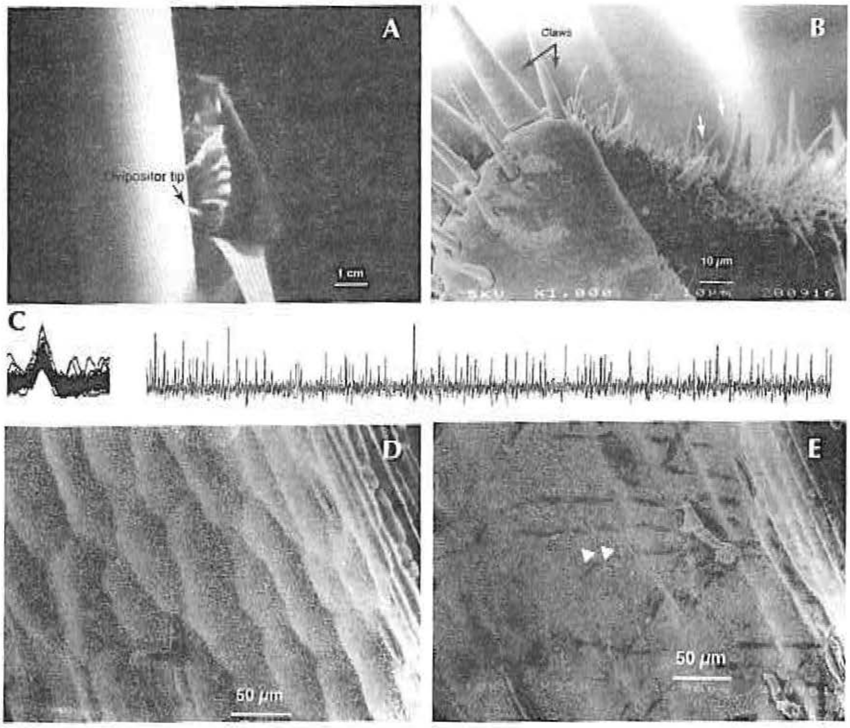


Figure 4. Typical oviposition behaviour in *Busseola fusca*: sweeping the plant surface with the tip of the ovipositor (A); distal part of the ovipositor showing contact chemoreceptive sensilla (white arrowheads) close to the claws (B); electrophysiological recordings of action potentials (spikes) obtained after contact with one of the sensilla located on the distal part of the ovipositor in response to dilute KCl solution (C); external surface of a maize leaf sheath not swept by the ovipositor (= control) (D); external surface of a maize leaf sheath after being swept by *B. fusca* ovipositor, showing several scratches (white arrowheads) left by the ovipositor (E)

In this context, we studied the distribution of chemosensory structures on the ovipositor that may be involved in oviposition site selection process by *B. fusca* females. Their physiological function has been delineated with regard to morphological characteristics observed by scanning electron microscopy and by electrophysiological tip recording.

Contact chemosensilla were found on the distal part of the ovipositor of *B. fusca* female (Figures 4b and c). These sensilla may be related to the process of probing the host plant surface for acceptance for oviposition. During the 'ovipositor sweep' behaviour, the claws at the distal part of the ovipositor left small injuries on the plant surface (Figures 4d and e).

These observations indicated that when the female walks down the stem of the host plant, with ovipositor movements probing the plant, the sensilla are exposed to chemical cues that could be involved in decision-making with regard to accepting or rejection of the plant. This is crucial for *B. fusca* and some other lepidopteran species since the neonate larvae do not have a propensity to migrate onto nearby plants as compared to winged adults. Further studies will identify the chemical cues that the sweeping ovipositor exposes when damaging the plant cuticle.

5. *How meaningful are behavioural studies with laboratory-reared insects?*

Laboratory-reared insects tend to differ from wild populations in their genetic, behavioural and physiological characteristics. Some insect species reared under laboratory conditions have been found to lose their ability to successfully grow on their original host and in some cases they may accept plants outside their natural host range. The rearing conditions can, therefore, strongly influence insect behaviour and physiology. For future studies on *B. fusca*, it was first necessary to verify if the laboratory-reared insects differed from the natural population in the oviposition response of the females.

The influence of the support on oviposition response in relation to the population origin of naive gravid *B. fusca* females was investigated in a dual choice situation using maize, the most common host plant of *Busseola fusca* in the field, and paper surrogate stems. With wild insects, the number of eggs laid was about 199 ± 49 on maize and 18 ± 9 on paper (Figure 5). Hence wild insects preferred maize over paper stem for oviposition. For laboratory-reared insects, the number of eggs laid was about 154 ± 31 on maize and 66 ± 16 (mean ± SE) on paper. Hence the laboratory-reared insects did not show a strong preference for either maize or paper stem.

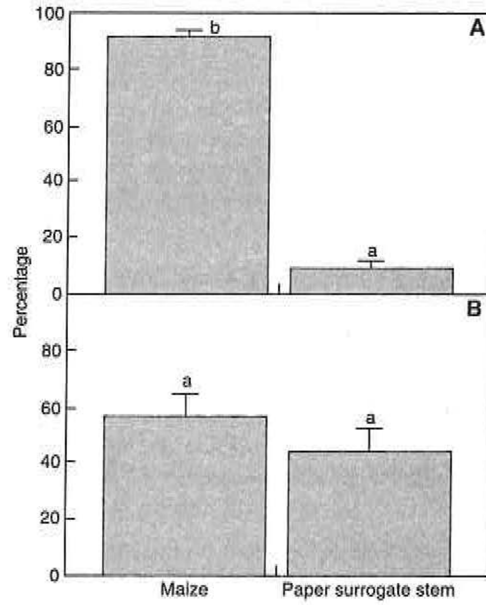


Figure 5. Relative proportions (in %, means ± SE, n = 20) of eggs laid by females from wild population (in A) or from laboratory-reared population (in B) on maize plants or paper surrogate stem in dual choice situation after 3 nights. Bars with different letters are significantly different using an experiment-wise error rate of 5% (Student's t-test)

A bioassay was used to study the role of contact host chemicals (i.e. plant surface chemicals) on oviposition response of wild and lab-reared *B. fusca*, by using two nylon surrogate stems (one imbibed with chloroform maize extract and another with chloroform alone), in a dual choice situation. The number of eggs laid per wild insect were 57 ± 16 on surrogate stem imbibed with chloroform alone and 104 ± 33 (mean ± SE) with maize extract (Figure 6). For laboratory-reared insects, the number of eggs laid was 123 ± 34 and 113 ± 26, respectively.

In addition, the rearing conditions of *B. fusca* significantly influenced the insect orientation towards the plants under wind tunnel conditions (Table 4).

The proportion of females showing an orientated flight toward maize plants was significantly lower with laboratory- than wild-reared insects. However, the females regardless of the population origin reacted similarly towards the host plant odours. This was illustrated by the EAG amplitude responses recorded for two synthetic plant volatiles (Figure 7). Although significant differences were found at one dose for each compound tested, the EAG dose-response elicited by (*Z*)-3-hexenyl acetate and (*Z*)-3-hexen-1-ol was similar among female antennae of the laboratory-reared and wild populations.

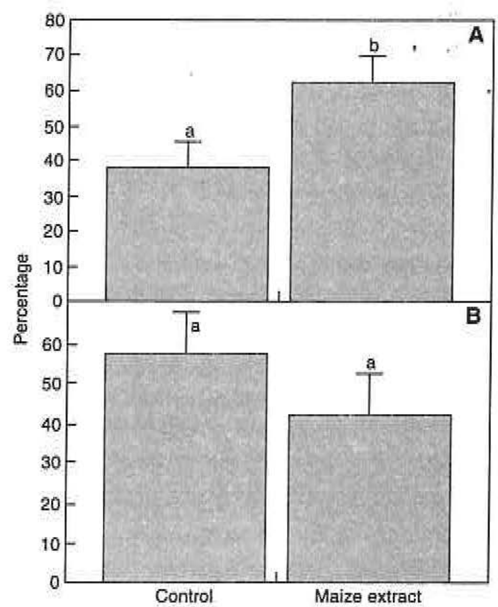


Figure 6. Percentage of eggs laid by females from wild (in A, n = 20) or from laboratory-reared populations (in B, n = 17) on nylon surrogate stem imbibed with chloroform alone (control) or with chloroform maize extracts (maize extract) in dual choice situation 8 hours after onset of scotophase. Bars with different letters are significantly different at $P < 0.05$ (Student's t-test)

In conclusion, wild insects differ from lab reared insects and their use for behavioural studies is limited and the results have to be interpreted with care. Ideally, such insects would directly come from the field.

Table 4. Proportion of *Busseola fusca* females showing orientated flight towards the maize plants in wind tunnel according to the population origin

Population origin	Orientated flight proportion (%)* [n]
Wild insects	52 [42] b
Laboratory-reared insects	31 [45] a

*Proportions followed by different letters are significantly different at $P < 0.05$ (Chi-square test).

6. *Role of plant surface metabolites in host selection for oviposition of* Busseola fusca

We studied the influence of polar and less polar plant surface compounds involved in host plant selection for oviposition of naive gravid *Busseola fusca* females coming directly from the field. Three plant species were used in this study: maize *(Zea mays)*, sorghum *(Sorghum bicolor)* and Napier grass *(Pennisetum purpureum)*. The females were placed individually in cylindrical transparent plastic jars with two nylon surrogate stems in a dual choice situation. The nylon surrogate stems were made from a rectangular piece of nylon rolled helicoidally. One surrogate stem was imbibed with plant extracts while the control with extraction solvent (water or chloroform). The solvent was allowed to evaporate before introduction into the jar. The number of eggs laid on each support was counted after the eighth hour of the night.

First, as blank experiment to check if the position of the surrogate stem had an effect, two surrogate stems of nylon without impregnation were tested. Eight hours after onset of the scotophase, the artificial stems received similar proportion of eggs, i.e. 49 and 51% respectively ($U = 196$, $P = 0.9138$ according to Mann-Whitney U test).

To further validate the role of both water and chloroform extractable chemicals on oviposition response the result was presented as oviposition stimulation index (OSI):

$$\text{OSI} = \frac{\text{No. eggs on extract (T) - No. eggs on control (C)}}{\text{No. eggs on extract (T) + No. eggs on control (C)}}$$

The oviposition index can have a positive or negative value, thus, identifying extracts that are preferred by females for oviposition (positive values) and those that are not preferred (negative values). Positive indices were obtained for all chloroform and water extracts from maize plants (Figure 8). In contrast, negative stimulation indices were observed for water extracts from sorghum and Napier grass plants. Moreover, the stimulation index was significantly higher and significantly different from the dual blank test (N vs N) for chloroform extract from sorghum plants only, suggesting that they are oviposition stimulants for *B. fusca*.

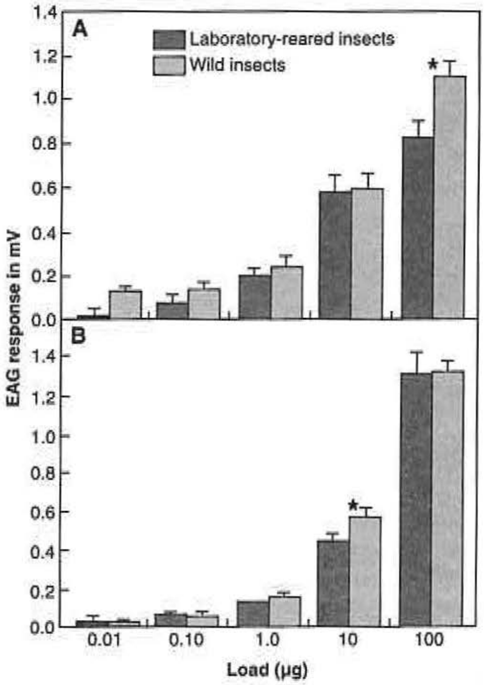


Figure 7. Mean (± SE) EAG amplitude responses of *Busseola fusca* females from laboratory-reared and wild population to different doses of two synthetic plant volatiles [A for (*Z*)-3-hexenyl acetate and B for (*Z*)-3-hexen-1-ol]. Bars with stars are significantly different at $P < 0.05$ (Mann-Whitney U test, laboratory-reared vs wild insects comparisons)

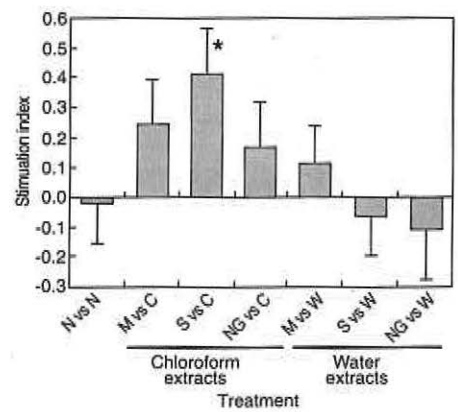


Figure 8. Oviposition stimulation index (OSI) calculated for the following dual tests: N vs N (nothing vs nothing = blank test), M vs C (maize chloroform extract vs chloroform), S vs C (sorghum chloroform extract vs chloroform), NG vs C (Napier grass chloroform extract vs chloroform), M vs W (maize water extract vs water), S vs W (sorghum water extract vs water) and NG vs W (Napier grass water extract vs water). Bar with star was significantly different at 5% level to the blank test N vs N according to Student's t-test.

Gas chromatographic analysis to identify the types of compounds present in the water extracts was performed. All extracts contained simple sugars, organic acids and free amino acids. No difference in quantity and composition was observed among the three plant species used. Thus, water extracts were not involved in host selection of *B. fusca*. Based on peak areas and regardless of the plant species, sucrose, fructose and glucose were the major sugars, while alanine, leucine and arginine were the major free amino acids detected (Figure 9).

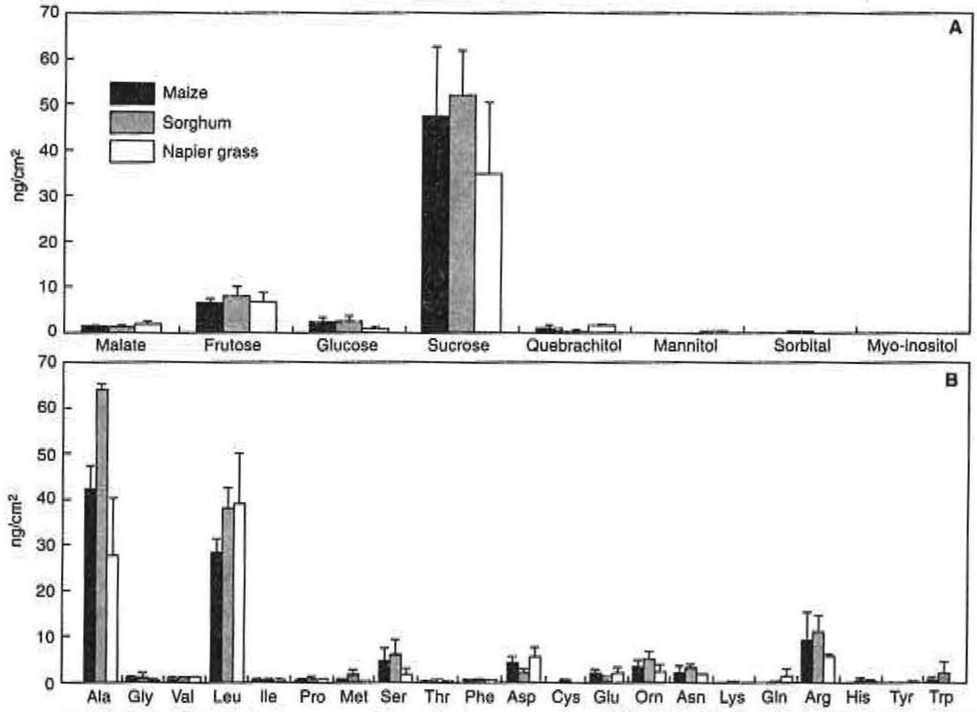


Figure 9. Concentrations (in ng/cm², mean ± SE, n=4) of sugars and organic acids (A) as well as free amino acids (B) detected in the water extracts. For each compound, no difference was found among the plant species (Kruskal-Wallis test)

HPLC analysis of the chloroform dip extracts indicated that the retention times of the maize peaks closely matched those of Napier grass (Figure 10). The chromatograms profile of maize and Napier grass were similar in composition. Sorghum chromatogram, however, had at least three additional peaks (Rt 7.17, 8.00 and 33.52 min), which were absent in maize and Napier grass. Subsequent preliminary analysis of the peak at 33.52 min by mass spectrometer showed the molecular ion at about 814 m/z and tentatively assigned the compound as a high molecular weight compound. These analyses confirmed the putative presence of compound involved in host selection of oviposition of *B. fusca*.

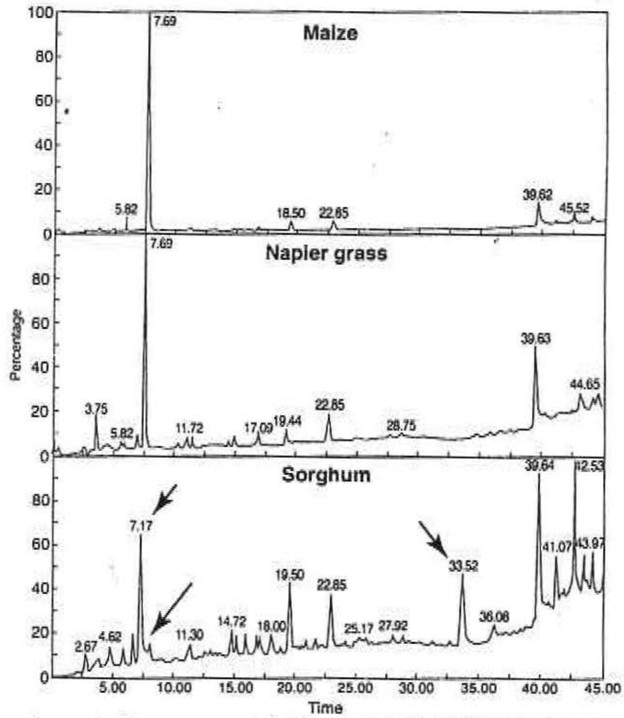


Figure 10. Chromatograms of chloroform extracts of maize, Napier grass and sorghum after HPLC analysis. The grey spots represent the common peaks found in the three plant extracts and the arrowed peaks were found only in sorghum extract

7. *Performance of* Cotesia flavipes *on cereal stemborers and wild host plants*

In Africa, maize fields are usually islands surrounded by wild graminaceous plants, many of which harbour borer species not found on crops. It is not known if the exotic parasitoid *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) follows these borers into the wild habitat, and whether they are suitable for its development. Thus, the purpose of this study was to: (1) assess the suitability of some borer species found in crops and wild host plants for the development of *C. flavipes*, (2) study the host-foraging behaviour of the parasitoid and (3) isolate and identify plant volatiles that could mediate host finding by *C. flavipes*. Six stemborer species were used: *Chilo partellus* Swinhoe, *Busseola fusca* (control species), *Sesamia calamistis, S. nonagrioides* Tams and Bowden, *B. phaia* Bowden and *Sciomesa piscator* Fletcher. *Chilo partellus, S. calamistis* and *B. fusca* are mostly found on cultivated crops whereas *S. nonagrioides, B. phaia* and *S. piscator* are mostly found on wild grasses.

All the stemborer species exposed to *C. flavipes* were equally acceptable for oviposition. However, the suitability varied with species. Parasitoid emergence occurred only on *C. partellus* and *S. calamistis* while species feeding on wild host plants were not suitable (Table 5). *Cotesia flavipes* females were significantly more attracted to volatiles from stemborer-infested plants than to volatiles from uninfested plants regardless of stemborer and the plant species used (Figure 11). This was probably due to the richer profile of chemicals of stemborer-infested plants and especially in green leaf volatiles and terpenoids compared to uninfested plants. It can be concluded that the unsuitable borer species used in the present experiment form a reproductive sink.

Table 5. Stemborer suitability for the development to *Cotesia flavipes*

Host borer	No. of emerging parasitoid progeny per female	Developmental time of progeny (in days)	No. of dying parasitoid larvae	% female progeny
Chilo partellus	21.5 ± 3.3 c	19.0 ± 0.2 b	1.0 ± 0.3 a	72.5 ± 3.1 b
Sesamia calamistis	12.0 ± 2.4 b	17.8 ± 0.1 a	3.6 ± 0.7 b	51.8 ± 7.3 a
S. nonagrioides	0.0a	-	-	-
Busseola fusca	0.0a	-	-	-
B. phaia	0.0a	-	-	-
Sciomesa piscator	0.0a	-	-	-

Means (± SE) followed by different letters are significantly different at 5% level (Turkey-Kramer test following ANOVA).

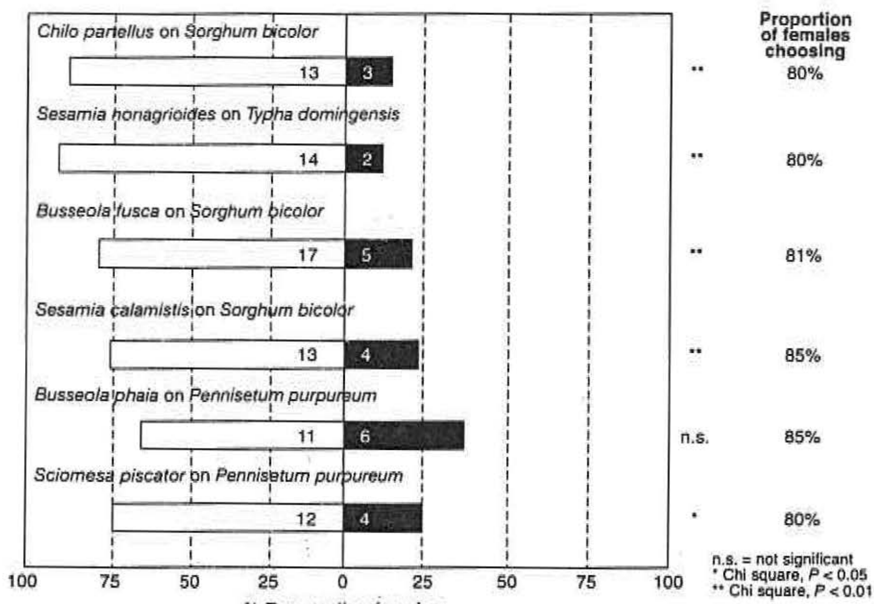


Figure 11. Response of *Cotesia flavipes* in a Y-tube olfactometer to the odours of infested (white bars) and uninfested plants (black bars). In each bar the actual number of wasps that made a particular choice is given, while the X axis indicates the percentages of choosing wasps as well as the proportion of females that made a choice n = 20 for each combination, except n = 27 for *Busseola fusca* on *Sorghum bicolor*

Output

Journal articles

Kergoat G. J., Delobel A., Fedière G., *Le Rü B.* and Silvain J. F. (2005) Both host-plant phylogeny and chemistry have shaped the African seed-beetle radiation. *Molecular Phylogenetics and Evolution* 35, 602–611.

Conferences attended

XXII International Congress of Entomology (ICE, 2004), Brisbane Convention and Exhibition Centre, Brisbane, Australia, 15–21 August 2004. Attended by: G. J. Kergoat, A. Delobel, G. Fedière, B. Le Rü and J.-F. Silvain.

XXXI Congress de Socolen, 28–30 July 2004, Bogota. Attended by: S. Dupas, C. Gitau, A. J. Ngi-Song, G. Ongamo and B. Le Rü.

International Conference on Lepidopteran Cob and Stem Borers in Africa (ICLCBA) 24–28 October 2005, *icipe*, Nairobi, Kenya. Attended by: M. Sezonlin, S. Dupas, B. Le Rü, N. Faure, P. Le Gall, J. F. Silvain, G. O. Ongamo, P. Moyal, P.-A. Calatayud, N. A. Otieno, L. Ngala, M. Makobe, J. Ochora, B. Musyoka, Z. Abdullah, D. Cugala, B. Defabachew, T. A. Haile, T. Kauma Matama, V. Y. Lada, B. Negassi, K. Pallangyo, Ravololonandrianina, A. Sidumo, C. Omwega, F. Schulthess, E. L. Muchugu, G. Juma, P. G. N. Njagi, B. Frérot, G. Mangoma, D. Tauban, F. Marion-Poll, M. Chimtawi, N. Faure, G. Gigot, S. Dupas, M. Sezonlin, C. Gitau, A. E. Félix, I. Giffard, M. Obonyo, P. Lomo, A. Branca.

Le Petit Poids Déridé, 28ème Réunion du Group de Biologie et Génétique des Populations, Bordeaux, 29 August to 1 September 2005. Attended by: N. Faure, G. Gigot, M. Sezónlin, S. Dupas, B. Le Rü and J. F. Silvian.

Conferences organised

International Conference on Lepidopteran Cob and Stem Borers in Africa (ICLCBA), 24–28 October 2005, *icipe*, Nairobi, Kenya.

Capacity building

PhD students

G. Juma (Kenya) Host plant adoption process by the African graminaceous stemborer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) larvae. Jomo Kenyatta University of Agriculture and Technology, Kenya (ongoing).

D. M. Mailafiya (Nigeria) Assessment of the diversity and ecological preference of parasitoids associated with lepidopteran stem borers in Kenya. Kenyatta University, Kenya (ongoing).

M. O. Obonyo (Kenya) Basis of host recognition by the larval endoparasitoids: *Cotesia sesamiae* Cameron and *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae). North West University (Potchefstroom campus), South Africa (ongoing).

G. Ong'amo (Kenya) Diversity and dynamics of lepidopteran stemborers in Kenya. Kenyatta University, Kenya (ongoing).

MSc students

E. Etabale (Kenya) Yield losses and comparative damage assessments by *Chilo partellus* (Lepidoptera: Pyralidae) *Busseola fusca* Fuller and *Sesamia calamistis* Hampson (Noctuidae) on maize. MSc in Environmental Science. Kenyatta University, Kenya (IRD Fellowship 2004).

E. Goux (France) Cartographie à l'aide d'images satellites des habitats cultivés et sauvages dans deux localités, du sud du Kenya, Mtito Andei et Kitale. Mémoire de stage de DESS (Gestion des systèmes agro-sylvo-pastoraux en zones tropicales), Paris XII Créteil, France (IRD Fellowship 2005).

Y. Guihéneuf (France) Cartographie à l'aide d'images satellites des habitats cultivés et sauvages dans deux localités, du sud du Kenya, Muhaka et Kakamega. Mémoire de stage de DESS (Gestion des systèmes agro-sylvo-pastoraux en zones tropicales), Paris XII Créteil, France (IRD Fellowship 2004).

G. Juma (Kenya) Role of plant volatiles and surface metabolites in mediating host selection and oviposition of *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). MSc in Biochemistry, Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya (IRD Fellowship 2005).

M. O. Obonyo (Kenya) Performance of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) on stem borers of cereals and wild crops. MSc in Biochemistry. Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya (DRIP Fellowship 2005).

G. Ong'amo (Kenya) Assessment of lepidopteran stemborer species distribution relative to diversity of wild host grasses in maize and sorghum growing zones in Kenya. MSc in Environmental Science. Kenyatta University, Kenya (IRD Fellowship 2005).

N. Otieno (Kenya) Diversity and abundance of wild host plants (Poaceae, Cyperaceae, Typhaceae) of lepidopteran stem borers in two localities from South Kenya, Kakamega and Muhaka. MSc in Environmental Science. Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya (IRD Fellowship 2005).

Impact

Results we got in the wild habitats, on diversity of stemborers, and low abundance of stemborer pests and wild host plants raise questions on the putative role of wild habitats as reservoirs for stemborer pests and their natural enemies underlined in previous studies. Further studies under different local conditions are essential for a better knowledge of the role of wild habitats as a source of pests for adjacent crops and the development of sustainable integrated management of cereal stemborers.

Basic knowledge on the host plant selection process of *Busseola fusca* as well as on the host recognition process by the larval endoparasitoids *Cotesia sesamiae* and *C. flavipes* will be given. Moreover, our studies will provide also a framework for understanding host-plant adoption process in *B. fusca*.

C. Applied Bioprospecting

BIOPROSPECTING FOR USEFUL PRODUCTS FROM BIODIVERSITY

Background, approach and objectives

Biodiversity continues to be destroyed worldwide, due to economic and population pressures, and lack of awareness about the importance of its conservation. The destruction is concentrated mainly in the developing countries. With this destruction, there is a corresponding loss of a vast wealth of useful arthropod, plant and other animal species. Bioprospecting, the systematic search, development and commercialisation of useful chemical products from natural sources provides an opportunity to rescue irreplaceable biological and associated chemical information evolved by biological species over millions of years before it is lost forever. It is also recognised as a means to promote conservation of biodiversity if benefits that arise are shared with the custodians of the biodiversity.

The Applied Bioprospecting Programme (together with the Behavioural and Chemical Ecology Department), undertakes research and capacity building in bioprosecting for useful products from insects, plants and microorganisms that includes the following:

- Discovery and development of products from biodiversity for pest, vector and disease management that are suitable for use by rural communities and for personal protection;
- Discovery, development and commercialisation of low technology natural products that provide new avenues for income generation for local communities living adjacent to biodiversity-rich areas.

In 2004 to 2005, the research work of the Applied Bioprospecting Programme focused on bioprospecting for mosquito repellent and insecticidal plants and products. The ultimate aim was to develop techniques or products that could be deployed in the control of mosquitoes by different socioeconomic strata. The work covered the following activities:

- Screening for repellent and insecticidal plants and associated products and identification of active components and blends;
- Development, evaluation and promotion of simple, effective and sustainable methods of controlling malaria vectors using selected repellent and insecticidal plants and products derived from them:

In the area of capacity building, the Programme continued to coordinate a collaborative project on R&D partnership in bioprospecting for mosquito repellent and insecticidal plants. The project was undertaken within a network of eight institutions in four East African countries: Tanzania, Uganda, Ethiopia and Kenya. The network approach allowed for pooling of facilities, expertise, experience and resources of the collaborating institutions in a complementary way.

During the period, about 300 plants from East Africa were screened for mosquito repellency and insecticidal activity and active constituents of some of them identified. The potential of using repellent plants and products in reducing human exposure to mosquitoes in rural homesteads was demonstrated, while one naturally-derived mosquito repellent product for personal protection was developed and commercialised. Three PhD and 13 MSc students drawn from the East African region were trained within the Programme. In addition, the Programme continued to build the capacity of members of the local community living adjacent to Kakamega forest to cultivate and process two indigenous medicinal plants as a means of generating alternative non-forest-derived income.

Work in progress

1. Demonstration of the potential of using mosquito repellent plants in the control of malaria vectors in rural homesteads

Participating scientists and students: *A. Seyoum[1]· K. Palsson[2], G. F. Killeen, A. Hassanali, B. G. J. Knols, W. Lwande, S. Kunga, E. W. Kabiru[3], A. Odulaja*

Donors: *UNDP/ World Bank/ WHO Special Programme for Research and Training in Tropical Diseases, grant 990056, DSO and NIH (grant numbers ICIDR-U19AI4511 and ABC-D43TW01142), Ministry of Foreign Affairs, The Netherlands, program number RF 042603/4*

Collaborators: *[1]Addis Ababa University (Ethiopia), [2]Uppsala University (Sweden), Tulane University Health Sciences Centre (USA), [3]Kenyatta University (Kenya)*

Collaborating division/department/unit: *Behavioural and Chemical Ecology Department/ Biostatistics Unit/Human Health Division*

An ethnobotanical study was conducted to identify candidate plants that are traditionally used by the community to repel mosquitoes on Rusinga Island and Rambira location in western Kenya. The study revealed that the most commonly used and known repellent plants on Rusinga Island were *Ocimum americanum*, followed by *Lantana camara*, *Tagetes minuta* and *Azadirachta indica*. *Hyptis suaveolens* was the most commonly used and known plant around Rambira location followed by *L. camara* and *O. basilicum*. *Ocimum americanum*, *O. basilicum* and *L. camara* were mainly used by burning part of the plant material once each night. Overall, cutting the branches or whole plant and placing inside the house or bruising the leaves of the plant and hanging around the beds were the main methods of application for *H. suaveolens*, *Azadirachta indica* and *Tagetes minuta*. Although traditional use of several species of plants as mosquito repellents was clearly very popular in these communities, considerable proportions of the population knew about but did not use them. The utilisation of bednets, slow release mosquito coils and aerosol insecticides were the most cited reasons for not using natural or traditional mosquito repellent plants.

The repellency of the above-mentioned and other selected plants was quantified by periodic thermal expulsion and direct burning against *Anopheles gambiae* in semi-field experimental huts. In the repellency evaluation, traditional stoves, locally known as 'jikos' were modified and used for burning and thermal expulsion of the plants in experimental huts (Figure 1). Direct burning of candidate plants was carried out by placing the material directly on the burning charcoal. They were thermally expelled by placing them on an additional metal plate directly above but not in contact with the charcoal. All the plant species except *H. suaveolens* showed significant repellency by thermal expulsion and the highest repellency was exhibited by the leaves of *Eucalyptus maculata citriodon*, followed by leaves and seeds of *O. suave* and *O. kilimandscharicum* (Table 1). The results showed that thermal expulsion of the plant materials was a better method of application to repel host-seeking *Anopheles gambiae*. Furthermore, the study found this new semi-field system

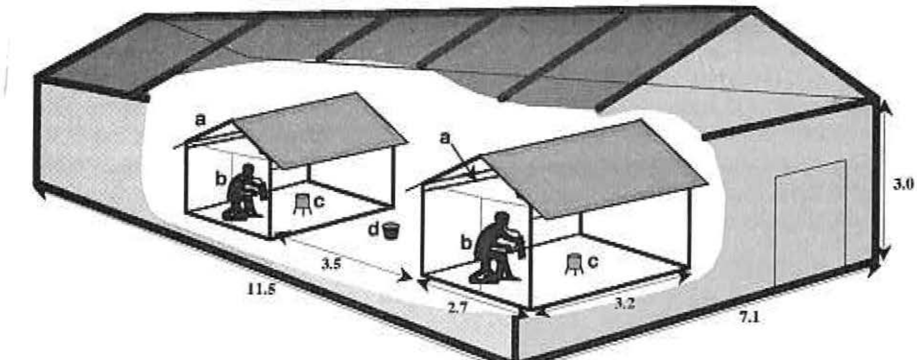


Figure 1. Semi-field experimental set-up for testing the repellency of plants by thermal expulsion and direct burning. Experimental huts with eaves (a) were constructed inside screen-walled greenhouse, within which human baits (b) and traditional stoves (c) were placed. Mosquitoes were released from a paper cup (d) placed halfway between the huts. All measurements are in meters

Table 1. The repellency of plants against *Anopheles gambiae* s.s. by periodic thermal expulsion in semi-field experimental huts

Plant species	Total no. recaptured		Intercept parameter estimate (β_o + SEM)*	Repellency (95% CI)	P
	Treatment	Control			
Azadirachta indica (Meliaceae) L	144	176	-0.2817 ± 0.1192	24.5 (4.2, 40.6)	. 0.0181
Eucalyptus maculata citriodon L	110	402	-1.3681 ± 0.1160	74.5 (67.9, 79.8)	<0.0001
Hyptis suaveolens (Lamiaceae) L+F	265	236	0.1252 ± 0.0911	-13.3 (-36.0, 5.5)	0.1691
Lantana camara (Verbenaceae) L	141	245	-0.5525 ± 0.1057	42.4 (28.9, 53.4)	<0.0001
Lantana camara (Verbenaceae) S	187	241	-0.3423 ± 0.1040	29.1 (12.7, 42.4)	0.0010
Lippia uckambensis (Verbenaceae) L	117	229	-0.6145 ± 0.1198	45.9 (31.3, 57.4)	<0.0001
Ocimum americanum (Labiatae) L+S	129	225	-0.5635 ± 0.1116	43.1 (28.8, 54.5)	<0.0001
Ocimum kilimandscharicum (Labiatae) L+S	115	233	-0.7344 ± 0.1162	52.0 (39.5, 62.0)	<0.0001
Ocimum suave (Labiatae) L+S	112	204	-0.7566 ± 0.1683	53.1 (34.3, 66.9)	<0.0001
Lcl + Oksl	240	251	-0.0468 ± 0.0916	4.6 (-14.6, 20.5)	0.6091
Lul + Oksl	172	352	-0.7951 ± 0.1007	54.8 (44.8, 63.1)	<0.0001
Ossl + Oksl	220	261	-0.1613 ± 0.0974	14.9 (-3.4, 30.0)	0.0979

Lcl, *Lantana camara* leaves; Lul, *Lippia uckambensis* leaves; Oksl, *Ocimum kilimandscharicum* seeds and leaves; Ossl, *O. suave* seeds and leaves; SEM, standard error of mean; L, leaves; S, seeds; F, flowers. *See statistical analysis.

to be ideal for screening large numbers of candidate repellents under conditions that compare well with full-field trials. This was the first time that repellents had been evaluated in a risk-free, semi-field experimental system and the results had proven extremely satisfactory.

The repellency of *A. gambiae* from human baits using live potted plants was also examined in semi-field experimental huts (Figure 2). *Ocimum americanum, L. camara* and *Lippia uckambensis*

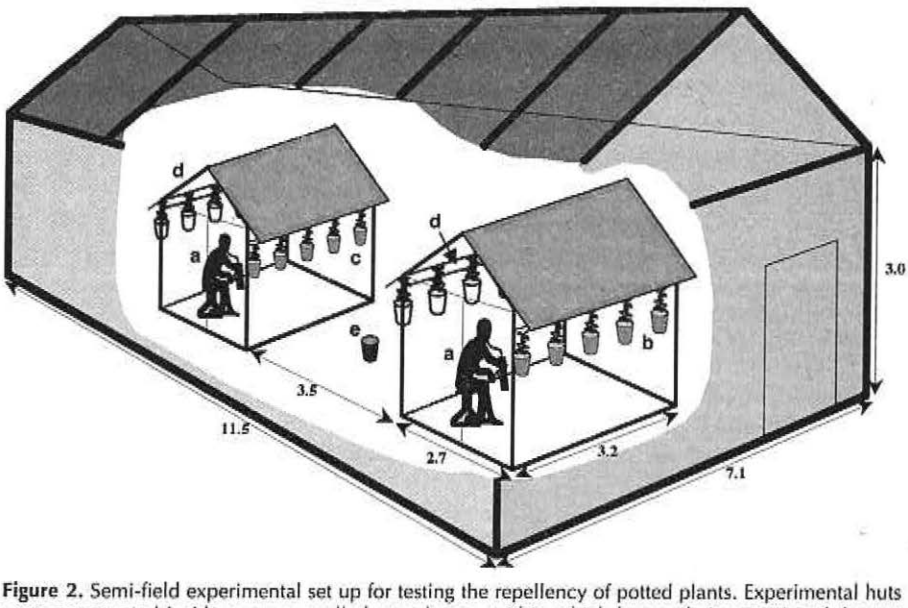


Figure 2. Semi-field experimental set up for testing the repellency of potted plants. Experimental huts were constructed inside a screen-walled greenhouse, within which human baits sat (a) and the test plants (b) as well as control plants (c) were placed under the eaves (d). Mosquitoes were released from a paper cup (e) placed halfway between the huts. Figures describe dimensions in meters

were all found to be effective repellents, reducing domestic exposure by 30 to 40%. Combining *O. americanum* with either *L. camara* or *L. uckambensis* was similarly effective but no obvious synergism was observed. Neither *Ocimum kilimandscharicum, O. suave, Corymbia citriodora, A. indica, T. minuta* nor *H. suaveolens* proved to be even mildly repellent to *A. gambiae* even though some of these plants were found to be quite potent when directly burned or thermally expelled. *Tagetes minuta, A. indica, O. kilimandscharicum, O. suave, H. suaveolens* and *C. citriodora* did not show significant repellency even though they all had been documented to show repellent or insecticidal properties to mosquitoes and other insect pests in varying forms of extracts and formulations. To our knowledge, this study was the first to demonstrate that live intact plants could repel mosquitoes to reduce domestic exposure. The study showed that intact potted plants may represent a new and readily applicable vector control tool that could be integrated into vector management programmes, particularly if used to enable or enhance zooprophylaxis.

Following the demonstration of the potential for repelling mosquitoes from human baits using selected plants under semi-field conditions, an operational field study was undertaken to evaluate community-based malaria control using mosquito repellent plant products, bednets and chemotherapy in an integrated approach. The study was undertaken in East Gembe location of Suba District, western Kenya. The mosquito repellent plant, *O. kilimandscharicum,* was used through thermal expulsion. The impact of using plants alone, bednets alone, plants and bednets, respectively, on malaria vectors and transmission at the village level, was assessed. Entomological studies revealed reductions of *A. gambiae* s.l. due to plant applications (56.18 and 62%). Parasitological surveys showed that the incidence of malaria reduced in all the four blocks, with the highest reduction in blocks with bednets alone (8.0%) and plants alone (9.68%). Contrary to expectations the reduction on the incidence of malaria in a block with combined use of plants and bednets was lower (20%). The community perceived the project to have reduced cases of malaria through routine screening, the use of the prescribed protective measures and awareness creation. The study revealed that there were opportunities for malaria prevention and control by re-introduction of cheap and improvised traditional protective measures against mosquitoes.

2. *Bioprospecting for mosquito repellent and insecticidal plants and products*

Participating scientists and students: *I. O. Ndiege, A. Hassanali, W. Lwande, M. O. Omolo[1], D. Okinyo[1], J. O. Odalo[1]*

Assisted by: *B. O. K. Wanyama, B. Njiru, M. Gitau, J. Ojude, S. Mathenge*

Donors: *UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases and Multilateral Initiative on Malaria Research in Africa, grants 990056 and A10638 and the National Institutes of Health (grant number ICIDR-U19A14511)*

Collaborator: *[1]Kenyatta University (Kenya)*

Collaborating department: *Behavioural and Chemical Ecology Department*

Studies were undertaken to identify plants with potential for use in controlling malaria vectors as repellents and insecticides from a wide range of plant species collected from East Africa. The plants were selected on the basis of ethnobotanical information, such as their uses in traditional medicine and protection against biting insects. This was augmented by field inspection of the plants for evidence of emission of aromatic volatiles and the absence of insects or insect attack on them. Essential oils extracted by hydrodistillation from the leaves, flowers or whole aerial parts of the plants were evaluated for their repellency and fumigant toxicity against *Anopheles gambiae* s.s. mosquitoes using Standard World Health Organization (WHO) procedures.

The volatile oils from the following 13 plants were found to show repellent activity against *A. gambiae*: *Conyza newii, Plectranthus marrubioides, P. longipes, Lippia javanica, L. ukambensis, Tetradenia riparia, Tarchonanthus camphoratus, Croton pseudopulchellus, C. menyharthii, Mkilua fragrans, Endostemon tereticaulis, Ocimum forskolei* and *O. fischeri*. The oils of *C. newii* (Compositeae) and *P. marrubioides* (Labiateae) were the most repellent, exhibiting RD_{50} of 8.9 x 10^{-5} mg/cm^2 (95% CI).

The oils from the following 10 plants exhibited mosquitocidal activity against *A. gambiae* s.s. in fumigation bioassays: *O. forskolei, P. longipes, M. fragrans, T. camphoratus, L. javanica, P. marruboides, T. riparia, L. ukambensis, C. newii* and *M. fragrans. Ocimum forskolei* and *P. longipes* exhibited significant insecticidal activity (LC_{50} = 2.0–5.106 x 10^{-3} mg/cm^3).

The essential oils of the plants that were found to show repellency and fumigant toxicity against *A. gambiae* s.s. were analysed further and their constituents identified by gas chromatography (GC) and gas chromatography-mass spectrometry (GC-MS). The repellency and fumigant toxicity of the volatile oils was evaluated using standard World Health Organization (WHO) bioassay procedures.

One hundred compounds were identified from the plants. In repellency bioassays against *A. gambiae*, 44 of the compounds showed activity. The compounds that exhibited relatively high repellent activity included the following: perillyl alcohol, *cis*-verbenol, *cis*-carveol, geraniol, citronellal, perillaldehyde, caryophyllene oxide, carvacrol, 4-isopropylbenzenemethanol, phytol and thymol.

Only 3 compounds, carvacrol, perillaldehyde and perillyl alcohol, showed fumigant toxicity against *A. gambiae*. Carvacrol that had been isolated from *P. longipes* had an LC_{50} value of 4.237 x 10^{-3} mg/cm^3. Perillaldehyde and perillyl alcohol, isolated from *C. newii*, exhibited higher fumigant toxicity (LD_{50} = 1.05 x 10^{-4} and 2.52 x 10^{-4} mg/cm^3, respectively) than the parent oil (2.0 x 10^{-3} mg/cm^3). None of the major constituents of *P. marruboides* which made up about 68% of the essential oil, were active at the dose range tested, suggesting that the activity of the oil may be due to additive or synergistic blend effect of some of the constituents.

The studies demonstrated the potential for discovery of volatile essential oils derived from plants that could be used as topical repellents and toxicants against *A. gambiae*.

3. *Laboratory evaluation of some East African plants of the Meliaceae family as sources of larvicidal botanicals for* Anopheles gambiae *mosquitoes*

Participating scientists and students: *M. W. Ndung'u, A. Hassanali, B. Torto, W. Lwande, B. Kaoneka, A. M. Hooper[1], F. Tayman[2], O. Zerbe[3], B. G. J. Knols*

Assisted by: *M. Gitau*

Donors: *UNDP/World Bank/WHO/TDR/MIM and NIH, German Academic Exchange Service, Dutch Government, ICSC-World Laboratory (Switzerland), Biotechnology and Biological Sciences Research Council*

Collaborators: *[1]Rothamsted Research (United Kingdom), [2]University of Cape Coast (Ghana), [3]Swiss Federal Institute of Technology (Switzerland)*

Collaborating division/department: *Behavioural and Chemical Ecology Department/Human Health Division*

Plant species belonging to the Meliaceae family were targeted for discovering potentially useful botanicals for the control of both larval and adult malaria vectors. These plants are characterised by the presence of blends of tetranortriterpenoids (limonoids), which exhibit a number of interesting anti-insect properties including anti-oviposition, antifeedant, growth disruption and toxicity. Azadirachtin, the well-known bioactive compound from the neem tree (*Azadirachta indica*) belongs to this class of compounds.

Extracts of 5 Meliaceae species comprising *Turraea abyssinica, T. wakefieldii, T. mombassana, Trichilia roka* and *Melia volkensii* were evaluated for larvicidal activity in the laboratory against *A. gambiae* s.s. Mosquito larvicidal bioassays of the extracts were carried out against *A. gambiae* s.s. larvae using standard World Health Organization procedures. All the methanol and chloroform soluble extracts and column chromatography fractions of the plants exhibited larvicidal activity against larvae of *A. gambiae* during the first 24 hours at appropriate doses. The methanol extract of *M. volkensii* was most potent while that of *T. abyssinica* was least active. In all cases, the larvae had prolonged lifespans (6–8 days) compared to those of control (4 days). Although all surviving larvae pupated and attained adulthood at 50 and 100 ppm, the adults were relatively small and malformed, indicating some growth-disrupting effects of the limonoid constituents. Interesting effects were observed with the crude methanol extract of *T. mombassana*. Although the extract was weakly active at 50 and 100 ppm as a larvicide (< 10% mortality in 24 h), longer term effects gave 100% cumulative mortality at both doses. At 50 ppm, an average of 46% died during ecdysis; about 26% failed to ecdyse to normal pupae, producing larval-pupal intermediates (Plate 1), which were short-lived; and although about 18% moulted successfully, the resulting pupae died. An average of 10% larvae attained adulthood, but were unable to expand their wings, and drowned on emergence. At the higher dose (100 ppm), about 78% died at the larval stage during the 8-day period and about 22% at the pupal stage. The study showed that *M. volkensii* and *T. mombassana* represented a promising source of a botanical agent for the control of malaria vectors similar to those of the neem tree, *Azadirachta indica*.

Two of the plants, *T. wakefieldii* and *T. floribunda*, were investigated further. Pure compounds (Figure 3) were isolated and identified from the plant extracts by chromatography, NMR and MS spectral analysis. Four new limonoid compounds comprising a vilasininoid **1** and three havanensinoids **2–4** were isolated from methanol extracts of *T. wakefieldii* and *T. floribunda*, respectively. The three limonoids **1**, **2** and **4**, showed more potent mosquito larvicidal activity than the crude extracts of the plants. No bioassays were carried out on **3** due to paucity of material. Limodoid **1** exhibited higher activity against the mosquito larvae than **2** and **4**. Compounds **1**, **2** and **4** had LD_{50} values of 7.1, 4.0 and 3.6 ppm, respectively, and were more potent than azadirachtin, which had an LD_{50} value of 57.1 ppm when tested against larvae of *A. gambiae*. Azadirachtin is widely used for insect control.

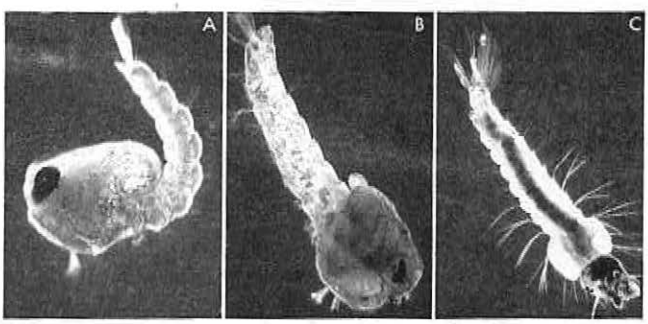


Plate 1. (A) Normal pupa, (B) larval-pupal intermediate, (C) normal larva

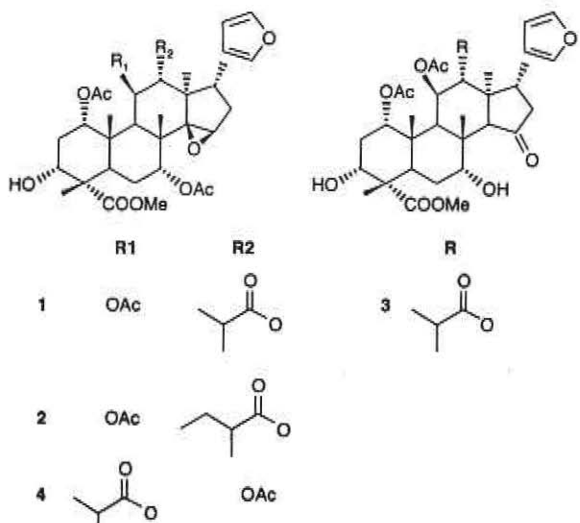


Figure 3. Chemical structures of limonoids: **1**, isolated from *Turraea wakefieldii* and **2–4**, isolated from *T. floribunda*

4. *Repellency activities of stereoisomers of* p-*menthane-3,8-diols against* Anopheles gambiae

Participating scientists and student: *S. S. Barasa, I. O. Ndiege, A. Hassanali, W. Lwande*

Assisted by: *B. O. K. Wanyama, M. Gitau, J. Ojude*

Donors: *UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases and Multilateral Initiative on Malaria Research in Africa, grant 990056 and USAID*

Collaborator: *Kenyatta University (Kenya)*

Collaborating department: *Behavioural and Chemical Ecology Department*

p-Menthane-3,8-diol, a monoterpene of relatively low volatility that is obtained from lemon eucalyptus (*Eucalyptus citriodora*) had been known for long in China for its mosquito repellent properties and it had shown particular promise in this regard. *p*-Menthane-3,8-diol that is obtained from extracts of lemon eucalyptus was associated with the aqueous residue following hydrodistillation of the essential oil from the foliage. Since common essential oil constituents of different plants (including lemon eucalyptus), such as citral, citronellol, citronellal and isopulegol, could be readily converted to *p*-menthane-3,8-diol, the possibility existed of increasing significantly the availability of this repellent for more widespread use for afro-tropical mosquito species. However, no information existed on the stereochemical requirements, if any, for the repellent action of *p*-menthane-3,8-diol, and if improvement in the activity could be effected through the use of specific stereoisomers of starting compounds, or through stereoselective procedures to specific isomers.

Four stereoisomers of *p*-menthane-3,8-diol (Figure 4), which make up the natural product obtained from *E. citriodora*, were synthesised through stereoselective procedures. Repellency assays showed that all the four were equally active against *Anopheles gambiae*. Racemic blends and the diastereoisomeric mixture of all the four isomers were also equally repellent. 1-α-terpeneol, with a single hydroxyl function at C-8 and unsaturation at C-8 and menthol, with a single hydroxyl function at C-3, were found not to be repellent. From a practical standpoint, these results implied that synthetic or semi-synthetic products of optimal repellent action against *A. gambiae* could be obtained without regard to the stereochemical form or purity of the starting material or the diol product.

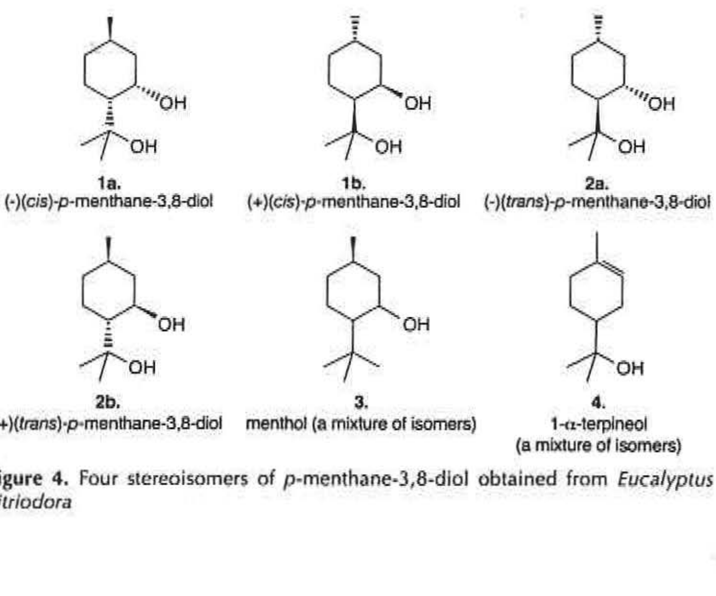


Figure 4. Four stereoisomers of *p*-menthane-3,8-diol obtained from *Eucalyptus citriodora*

5. Development of a naturally-derived mosquito repellent product (Mozigone) for personal protection

Participating scientists: *I. Ndiege, A. Hassanali, W. Lwande*

Donors: *UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases (MIM/TDR)*

Collaborator: *Kenyatta University, Kenya*

Following the successful optimisation of the conversion of *p*-menthane-3,8-diol (one of the most promising plant-derived mosquito repellent compounds) from eucalyptus oil, large-scale production was initiated to facilitate the development of repellent creams, coils and candles. Formulation of pure crystalline *p*-menthane-3,8-diol as repellent creams, mosquito coils and candles gave respectively, 100, 56 and 26% personal protection from *Anopheles gambiae* mosquitoes after 8 hours, under semi-field conditions.

Mozigone (Figure 5), a commercial mosquito repellent product, was developed by *icipe* and Kenyatta University in form of 10% *p*-menthane-3,8-diol repellent cream formulation. It is on sale in various outlets in Kenya. Mozigone was evaluated against several commercial products. It performed as well as Mijex™ (20% DEET), and was better than Protech™ (15% DEET), Autan™ (12.5% DEET), Kinga™ (essential oils) and Ballet™ (essential oils) as indicated in Table 2.

Plans are underway to identify suitable alternative plants that could be cultivated by rural communities on a commercial basis as sources of *p*-menthane-3,8-diol for manufacture of Mozigone.

Figure 5. Mozigone

Table 2. Level of protection by Mozigone and other products from *Anopheles gambiae* moquitoes after 8 hours of personal application

Product	% Level of protection from mosquitoes
Mozigone	100
Mijex™ (20% DEET)	100
Protech™ (15% DEET)	98.6 ± 1.4
Autan™ (12.5% DEET)	91.7 ± 5.4
Kinga™ (essential oils)	29.3 ± 5.5
Ballet™ (essential oils)	22.5 ± 9.9

6. Promotion of commercial cultivation and processing of multipurpose plants by communities living adjacent to Kakamega forest

Participating scientists: *W. Lwande, J. Mwangi, A. Hassanali, R. Bagine*[1]

Assisted by: *M. Ndwiga, E. Ndenga, M. Lumbasi, F. Nduguli, M. Nelima, P. Mungai*

Donors: *MacArthur Foundation, UNDP/GEF Small Grants Programme, Ford Foundation, Biovision, German Development Service, Kenya Agricultural Research Institute*

Collaborators: *University of Nairobi, Kenya Forestry Research Institute,* [1]*Kenya Wildlife Service*

Collaborating department: *Behavioural and Chemical Ecology Department*

The Programme continued to build the capacity of members of the local community living adjacent to Kakamega forest to cultivate and process two indigenous medicinal plants, *Ocimum kilimandscharicum* and *Mondia whytei,* as a means of generating alternative non-forest-derived income. Traditionally, *O. kilimandscharicum* has been used for the treatment of colds and flu, coughs and sore eyes, diarrhoea, abdominal pains and measles. It has also been used for repelling mosquitoes and for protecting stored grain. It has also been shown to have potential for use in the control of mosquitoes in rural homesteads as reported in the earlier sections of this report. It is also attractive to bees as a source of nectar. *Mondia whytei* is an indigenous medicinal plant, the roots of which have traditionally been harvested extensively and unsustainably from Kakamega and other protected forests in a well-organised trade leading to scarcity of the plant in these forests. The roots have been chewed for their sweet aromatic flavour, as an appetiser, aphrodisiac and for treatment of sexually-transmitted diseases.

More than 200 community members living adjacent to Kakamega forest were assisted to cultivate *O. kilimandscharicum*. The extract from *O. kilimandscharicum* leaves is used in the manufacture of Naturub. Naturub is a commercial natural product that was developed by *icipe*, the University of Nairobi, Kenya Wildlife Service and other partner institutions. It is sold for alleviation of flu, colds, chest congestion, aches, pains and insect bites. Naturub is on sale in more than 62 outlets in Kenya including some of the major supermarket chains. The community members harvest and dry the leaves of *O. kilimandscharicum* for processing using a hydrodistillation equipment to produce essential oil. In 2004–2005, they were assisted to construct a building for housing the hydrodistillation equipment. The farmers who planted *O. kilimandscharicum* benefitted more from this new crop than from some of the other crops that they have been cultivating.

The community was also assisted to cultivate *M. whytei* on their farms. As well as contributing to improvement of livelihoods, cultivation of the plant also contributes to conservation of the species. More than 500 members of the community were trained in *M. whytei* cultivation. Most of the community members were encouraged to intercrop their *M. whytei* plants with trees to serve as a support for the vines while at the same time promoting on-farm forestry. More than 40,000 plants of *M. whytei* were growing in rural homesteads around Kakamega forest. To add value to the *M. whytei* plants, the Project initiated the development of Mondia Tonic, a commercial product used as an antidepressant, antioxidant, revitaliser, appetiser and for clearing hangovers. Mondia Tonic is sold in the major supermarket chains in Kenya.

Output

Journal articles

Odalo B. J. O., Omolo M. O., Malebo H., Angira J., Njeru P. M. , *Ndiege I. O.* and *Hassanali A.* (2005) Repellency of essential oils of some plants from the Kenyan coast against *Anopheles gambiae*. *Acta Tropica* 95, 210–218.

Omolo M. O., Okinyo D., Ndiege I. O., Lwande W. and *Hassanali A.* (2004) Repellency of essential oils of some Kenyan plants against *Anopheles gambiae*. *Phytochemistry* 65, 2797–2802.

Omolo M. O., Okinyo D., Ndiege I. O., Lwande W. and *Hassanali A.* (2005) Fumigant toxicity of the essential oils of some African plants against *Anopheles gambiae sensu stricto*. *Phytomedicine* 12, 241–246.

Ndung'u M. W., Kaoneka B., *Hassanali A., Lwande W.,* Hooper A. M., Tayman F., Zerbe O. and Torto B. (2004) New mosquito larvicidal tetranortriterpenoids from *Turraea wakefieldii* and *Turraea floribunda*. *Journal of Agricultural and Food Chemistry* 52, 5027–5031.

Ndung'u M., Torto B., Knols B. G. J. and *Hassanali A.* (2004) Laboratory evaluation of some East African Meliaceae as sources of larvicidal botanicals for *Anopheles gambiae*. *International Journal of Tropical Insect Science* 24, 311–318.

Proposals funded

Consolidating R&D partnerships in bioprospecting for mosquito repellent and insecticidal botanicals with focus on application, UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases (TDR), 2 years (January 2005 to December 2005).

Community-to-community exchange programme in Africa, Ford Foundation, 1 year (October 2004 to November 2005).

Commercialisation of community-based cultivation of the medicinal plant, *Ocimum kilimandscharicum* and its products. Biovision, 1 year (January to December 2005).

Enhancement of sustainability of two medicinal plant-based environmental enterprises for communities adjacent to Kakamega forest, Ford Foundation, 1 year (May 2005 to April 2006).

Capacity building

PhD students

C. Kihampa (Tanzania) Characterisation and field assessment of anti-mosquito natural products from Tanzania botanicals. Dar es Salaam University, Tanzania (completed).

I. Esther (Tanzania) Bio-prospecting for botanical larvicides and repellents for the control of the malaria vector *Anopheles gambiae s.s.* Dar es Salaam University, Tanzania (completed).

E. Omulokoli (Kenya) Isolation and identification of bioactive microbial metabolites. Jomo Kenyatta University, Kenya (ongoing).

MSc students

J. O. Odalo (Kenya) Biochemical examination and identification of botanicals active against adult *Anopheles gambiae* from the coastal region of Kenya. Kenyatta University, Kenya (completed).

C. O. Ojiambo (Kenya) Structure activity studies of *p*-menthane diols as mosquito repellents. Kenyatta University, Kenya (ongoing).

S. M. Karenga (Kenya) Phytochemical investigations of anti-larval compounds and their blends from *Melia volkensii* (Gurke) against *Anopheles gambiae*. Egerton University, Kenya (completed).

P. W. Mayekhu (Kenya) Mosquito repellent activity and chemical composition of essential oils and smoke emanations of *Conyza newii* grown in different geographical locations. Kenyatta University, Kenya (completed).

J. K. Thaimuta (Kenya) Bio-prospecting for anti-mosquito compounds from *Turrea mombassana* (Meliaceae). Kenyatta University, Kenya (ongoing).

J. O. Odero (Kenya) Bio-prospecting for anti-mosquito compounds from *Turrea abyssinica* and *Turrea cormicorpia*. Jomo Kenyatta University of Agriculture and Technology, Kenya (completed).

S. M. Musyoka (Kenya) Chemical investigation of anti-larval activity of the genus *Vitex* against *Anopheles gambiae*. Kenyatta University, Kenya (ongoing).

T. Rimu (Kenya) Isolation and characterisation of anti-mosquito compounds from *Turrea nilotica* and *Turrea floribunda*. Jomo Kenyatta University of Agriculture and Technology, Kenya (ongoing).

G. N. Mokua (Kenya) Phytochemical anti-larval compounds from *Vitex schiliebeii* and *V. payos* for *Anopheles gambiae*. Kenyatta University, Kenya (ongoing).

J. O. Bwire (Kenya) Bioprospecting for insecticidal toxins from scorpion venom and identification of active constituents. Jomo Kenyatta University of Agriculture and Technology, Kenya (completed).

J. Nonoh (Kenya) Isolation, identification and micoorganisms with activity against stem borers, *Chilo partellus* and *Busseola fusca*. Jomo Kenyatta University of Agriculture and Technology, Kenya (ongoing).

Impact

- Over 300 plants from East Africa have been screened for mosquito repellency and insecticidal activity and active constituents of some of them identified.
- The potential of using repelient plants and products in reducing human exposure to mosquitoes in rural homesteads was demonstrated.
- One naturally-derived mosquito repellent product for personal protection was developed and commercialised.
- Three PhD and 13 MSc students drawn from the East African region were trained within the Programme.
- The Programme enhanced the capacity of members of the local community living adjacent to Kakamega forest to cultivate and process two indigenous medicinal plants as a means of generating alternative non-forest-derived income.

D. Commercial Insects

Developing Incentives for Community Participation in Forest Conservation through the Use of Commercial Insects in Kenya

Background, approach and objectives

This project is based on an income-generating package developed by *icipe* that utilises commercial insects (bees and silkmoths). Insects are a critical natural resource of terrestrial ecosystems. Many insects can provide direct economic returns like honey, beeswax and silk. Others provide the much needed pollination services to the natural and agricultural ecosystems. In the past, almost all research on insects in tropical Africa had focused on the destructive aspects (agricultural pests and disease vectors) caused by less than 1% of insect species. However, research interests are now rising on useful insects (Raina and Kioko, 2000: *Journal of Wild Silkmoths and Silk*, pp. 301–310). In Malawi, some studies have shown viability of insect-based enterprises (beekeeping and caterpillar utilisation) in relation to conventional agricultural enterprises (maize, beans and groundnuts). Earnings from insect-based enterprises exceeded those from conventional agriculture (Munthali and Mughogho, 1992: *Biodiversity Conservation*, pp. 143–154). In Botswana, Zimbabwe and Madagascar, wild silkmoths species have been utilised for silk production enhancing income-generating opportunities for rural communities (Chikwenhere, 1992: *Zimbabwe Journal of Agricultural Research*, pp. 133–137; Hartland-Rowe, 1992: *Botswana Notes and Records*, pp. 40–46; Peigler, 1993: *The American Entomologist*, pp. 151–160). In East Africa, over 50 indigenous wild silkmoth species have been recorded (Kioko et al., 2000: *East African Journal of Science*, pp. 1–6). Up to 95% of the world demand for commercial silk is met by *Bombyx mori* (Lepidoptera: Bombycidae); however, it has been realised that African wild silk has an exclusive niche in the silk market because of its uniqueness and its highly valued naturalness.

Kenya's forests contain a large number of endemic and globally threatened species. Many rural communities are dependent on forest resources for water, energy, poles, medicinal plants and for a variety of products to augment incomes. This dependence is particularly strong where forest-adjacent communities are poor (since forest resources are treated as free goods), and it often leads to forest degradation because resource extraction rates are unsustainable. Attempts to restrain extraction rates through a command and control approach imposed by government have proven costly and unsuccessful and have led to conflicts, undermining the local support on which conservation depends. In recognition of this failure, the GoK (in line with other governments throughout the world) has introduced a participatory multi-stakeholder approach to forest management and conservation (participatory forest management, PFM), in which local communities can negotiate sustainable forest user rights and assist in forest protection. For such an approach to work, incentives are needed to motivate sustained community involvement. Such incentives work best when they (1) are linked to the sustainable utilisation of forest resources, and (2) alleviate the poverty that drives forest degradation.

Commercial insects are particularly suitable as incentives in the context of PFM because they: (1) provide quick and significant rewards; (2) can be managed using environmentally friendly technologies; (3) provide and use renewable resources (including forest resources) in a sustainable way; and (4) they provide synergistic services and products (e.g. pollination, mulberry fodder for livestock). By linking them to productive forest buffer zones, commercial insects enterprises have motivated communities to maintain forest biodiversity and protect the environment as well as increasing their economic well-being. Impacts on economic well-being will be increased by a unique component of the *icipe* package: The empowerment of communities through ownership and operation of marketplaces in which value is added to bee and silk products through quality control, processing and packaging to national and international standards. This eliminates middlemen and generates more income at the community level.

All of this needs to operate within a supportive enabling environment at local, district and central levels requiring an investment into policy support and institutional strengthening and awareness raising so as to allow informed decision-making. The project, therefore, also has a forest management component that will facilitate the Forest Department (FD) to implement PFM initiatives in Kakamega, Arabuko-Sokoke and Mwingi forests and to upgrade their management effectiveness as measured by the management effectiveness tracking tool (METT). Through close collaboration with FD, the bee and silkmoth enterprises are focused on community groups that are actively involved in PFM initiatives at all three sites. Project impact on vertebrate and invertebrate biodiversity is being monitored by Nature Kenya and insects (bees and silkmoths) biodiversity by *icipe* Commercial Insects Programme (CIP) staff.

The overall goal of the project is that the national protected area system of forest reserves is strengthened through improved incentives for real collaborative forest management with communities. The objective of the project is to demonstrate in three forest sites (Kakamega, Arabuko-Sokoke and Mwingi) that the biodiversity of Kenya's forest protected areas can be maintained through collaborative management systems using incentives based on income from commercial insects. The project's fundamental approach is based on close integration of investments into productive rural infrastructure, forest resources and human and institutional capital, in a way that reduces pressure on the three forests and their biodiversity and resources.

Participating scientists and students: *S. K. Raina, V. V. Adolkar, E. N. Kioko, E. M. Muli, E. K. Nguku, I. Gordon, B. M. Ngoka, N. Mbahin, K. Okwae, S. Sande*

Assisted by: *J. K. Macharia, G. Kamau, G. Owino, J. Auma, F. Kiilu, R. Macharia, B. Wanjiru, J. Ng'ang'a*

Donors: *UNDP-GEF and IFAD*

Collaborators: *Nature Kenya, National Museums of Kenya, Forest Department (Kenya Forest Department), Ministry of Livestock and Fisheries, Kenya Wildlife Service, National Environmental Management Authority, non-governmental organisations, community-based organisations*

Work in progress

1. Community enterprises and forest conservation

The project has developed on-farm and in-forest livelihood support linked to buffer zone management involving village forest committees (VFC) for participatory forest management (PFM). The project has initiated development marketplaces for silk/honey products at all three sites to establish marketing linkages for the sale of commodities. The project has built capacity of communities and institutions to manage and utilise insects for both livelihood and forest conservation benefits.

Table 1 highlights some of the project achievements, the way forward and challenges.

Table 1. Summary of project achievements at the community/forest levels

Activity / Achievements todate	Way forward	Comments/Challenges
Forest management PFM training for foresters done for four districts. Reserve border demarcation in Mwingi. So far, over 631 hectares of forest land recovered in Muumoni forest. Management effectiveness tracking tool (METT) applied in all three forests.	Set PFM framework at community level in in all the three sites. Organise village forest committees into CFAs. Rehabilitate degraded forest areas. Boundary clearing/ cleaning. Maintain and expand at least one tree nursery per zone. Initiate forest disturbance transects in all forests.	This activity is undertaken by the Forest Department, coordinated from Karura but implemented through the District Forester in the four concerned districts: Kilifi, Malindi, Vihiga and Kakamega.
Biodiversity monitoring Baseline surveys to monitor the biodiversity status of selected species has been ongoing focusing on threatened species, stingless bees, honeybees and wild silkmoth species. For example, 124 stingless bees hives have been set to monitor their status at the three sites and 43 of them (34.7%) are already colonised.	To continue collecting data on the threatened species and the insects.	Biodiversity monitoring may require several years to show the impact of conservation measures. Historical data are available for some species: Monitoring of scops owls at Arabuko-Sokoke in 2005 has shown that numbers have remained more or less stable since 1979.

Continued on next page

Table 1. continued

Activity / Achievements todate	Way forward	Comments/Challenges
Long-term on-site training Ninety-two (92) farmers have taken one month ToT apiculture/sericulture residential courses at ICIPE on production as well as postharvest techniques. At least 1000 community members have received some on-site training from the trained community trainers, FD and ICIPE.	Continue with apiculture and sericulture on-site training to enhance production, value addition, branding, and market studies and linkages.	The progress has been good.
Marketplace development Construction of marketplaces completed at Gede (silk and honey) and Mwingi (wild silk); Kakamega in progress for silk and hive products.	Construction of third marketplace to be completed and equipped. Marketplaces become operational.	The progress has been good.
Apiculture production Distribution of hives among the groups undertaken, 300 in Arabuko-Sokoke, 150 in Kakamega and 120 in Mwingi. The community groups have also received bee suits, smokers and hive tools to enable them manage their colonised hives. Over 50% hive colonisation recorded. Royal jelly production initiated in Arabuko-Sokoke.	Continue hive stocking through colony division and natural swarm catching. Colony management for honey and royal jelly production. Enhance community capacity through on-site follow-up and training.	Hive colonisation and production has been slowed down by the drought at some of the sites.
Sericulture—Mulberry silk moth production Mulberry established in Kakamega (2 hectares) and Arabuko-Sokoke (1.6 hectares). 14 rearing houses constructed and one renovated in Kakamega. Two farmers' groups rearing mulberry silkworms in Kakamega.	Construction of rearing beds in the completed houses. Complete the construction of rearing houses in Arabuko-Sokoke.	The survival rate of mulberry cuttings was lower than expected due to insufficient rain after planting.
Sericulture—Wild silk moth production Farmers able to recognise and rear the potential species: *Anaphe* in Kakamega, *Argema* and *Gonometa* in Arabuko-Sokoke and *Gonometa* in Mwingi. Net sleeves and grainage breeding cages supplied to target groups. 10,000 *Bridelia micrantha* seedlings from a community nursery ready for transplanting in Kakamega.	Enhance raising of seedlings of the wild silkmoth food plants. Supply of grainage cages to increase wild silkmoth seed production for increased production.	A lot of awareness creation/ capacity building still ongoing to move the enterprise to the required levels.

2. *Variations in races of the honeybee* Apis mellifera *(Hymenoptera: Apidae) in Kenya*

Participating scientist: *S. K. Raina*

Assisted by: *D. M. Kimbu*

To select suitable races of honey bee for the three forest sites, an understanding of variations between races is required. The three races of the honeybee *Apis mellifera* Linnaeus in Kenya *(A. m. scutellata, A. m. monticola* and *A. m. litorea)* differ from each other with respect to size, cubital index and abdominal colour banding pattern. These differences were used to assess the extent of interbreeding and hybridisation between the races. This was verified on the basis of selected morphometric traits. Bee samples were collected from traditional log hives in seven geographical locations throughout Kenya ranging from lowland Mombasa in the coastal region to

Table 2. Mean values X and standard errors; F ratio (bottom) of body length and abdominal width of honeybee, *Apis mellifera* races in 7 different regions of Kenya

Localities [altitude (m)]	Body length		Abdominal width	
	S1	S2	S1	S2
Mombasa (75)	76.80 ± 0.43 dc	61.70 ± 0.93 c	23.30 ± 0.22 c	20.97 ± 0.40 c
Mwingi (650)	75.93 ± 0.37 d	65.47 ± 0.76 b	23.23 ± 0.11 c	21.63 ± 0.26 b
Kitui (850)	73.83 ± 0.54 e	63.33 ± 1.23 c	23.40 ± 0.11 c	21.53 ± 0.33 bc
Kimana (1250)	78.33 ± 0.26 ab	68.93 ± 0.56 a	24.50 ± 0.13 a	21.87 ± 0.13 ba
Kakamega (1680)	79.27 ± 0.19 a	68.50 ± 0.32 a	24.27 ± 0.14 ab	22.17 ± 0.13 ba
Central (1950)	78.67 ± 0.61 a	69.50 ± 0.15 a	24.33 ± 0.16 ab	22.37 ± 0.07 a
Kinangop (3200)	77.33 ± 0.41 bc	69.37 ± 0.14 a	23.97 ± 0.36 b	22.50 ± 0.06 a
F value	19.27	20.94	7.64	5.22

S1, category of bees with BL values of 70–82 and ABW of 22.5–26 units (1 unit = 0.1 mm).
S2, category of bees with BL values of 55–69.55 and ABW of 18–22.45 units.
Means with the same letter in a column are not significantly different ($F_{6,98}$; $P > 0.0001$) by Waller Duncan K-ratio test, at $\alpha = 0.05$.

the highland Kinangop ranges. The body length, abdominal width (Table 2), length and width of right forewings, length of proboscis, right antenna and right hindlegs were measured, and the cubital index was computed for each specimen. The bees were classified according to size and colour banding pattern. Principal components analysis (Figure 1) indicated there was hybridisation among the three races of *A. mellifera* in Kenya due to swarming and migration under seasonal pressure.

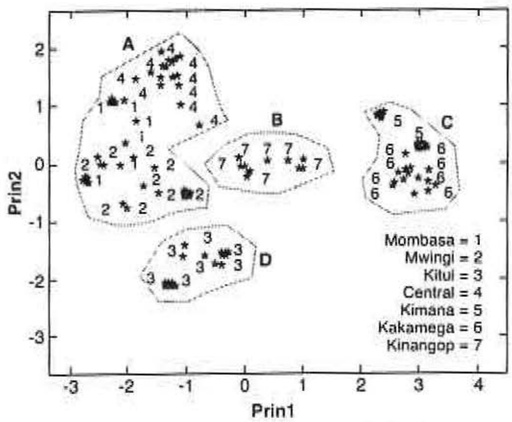


Figure 1. Principal components analysis based on morphometrics study of honeybee races in Kenya

3. *Quality status of Kenyan honey*

Participating scientist, consultant and student: *E. M. Muli, A. M. Munguti, and S. K. Raina*

The success of beekeeping as an income-generating activity depends on the quality of the honey. The honey consumed in most of Africa is harvested from traditional hives and processed using traditional methods. This work presents results on the quality characteristics of honey samples (n = 72) collected from beekeepers in various important beekeeping zones in Kenya: West Pokot, Baringo, Mwingi, Tana, North Kinangop, Mbeere, Nandi Hills, Mida Creek, Kakamega and Taita (Table 3).

The quality of the honey was compared to international standards as proposed in the Codex Alimentarius (2001). The quality markers analysed were moisture, HMF, sugar, amylase (diastase) and proline contents and free acidity. Moisture was determined using a honey refractometer, HMF and diastase content were determined through spectrophotometry, sugars were determined by high performance liquid chromatography (HPLC) and free acidity quantified by volumetry-titration technique. Average constituent values were at 16.00–21.20% (moisture); 3.70–389.36 mg/kg (HMF); 20.83–300.6 (proline); 8.03–56.98 Schade units (amylase [diastase]); 57.03–102.66% (fructose and glucose levels) and 18.00–71.85 (free acidity). Most of the samples had constituent levels within the limits set in the Codex Alimentarius.

Traditional honey harvesting and processing methods seem not to have negative effects on the major honey constituents. It seems honey adulteration is done by unscrupulous middlemen after the honey leaves the farm gate. However, excessive smoking during harvesting had compromised the aroma and flavour of some samples. In an effort to promote beekeeping as an eco-friendly, sustainable alternate source of livelihoods, training in best apiculture practices, improved extension services and establishment of honey marketplaces is being done to improve honey quality in Kenya.

Table 3. Means (± SE) of composition of 72 honey samples obtained from different regions in Kenya

Area/Standard*	Moisture *[≤21%]	HMF [≤40 mg/kg]	Amylase (diastase) [≥8 Schade units]	Proline [≥180 mg/kg]	Free acidity *[≤50 meq/kg]	Glucose and fructose *[≥65%]	Sucrose *[≤5%]
W. Pokot (n = 23)	16.74 ± 0.10	3.70 ± 0.95	20.50 ± 0.81	243.99 ± 7.44	28.16 ± 0.49	61.50 ± 1.74	Nd
Baringo (n = 26)	16.57 ± 0.11	3.70 ± 0.51	15.80 ± 0.32	300.61 ± 26.35	30.85 ± 0.99	66.50 ± 3.25	0.90 ± 0.42
Mwingi (n = 14)	16.62 ± 0.33	29.20 ± 5.35	24.10 ± 7.03	220.08 ± 10.22	63.10 ± 6.21	65.00 ± 0.48	2.23 ± 0.48
Tana (n = 2)	17.00 ± 0.44	10.30 ± 0.85	50.40 ± 0.40	122.27 ± 44.66	52.16 ± 8.50	77.83 ± 5.16	2.07 ± 0.13
Kinangop (n = 1)	21.20 ± 0.02	53.66 ± 0.47	8.03 ± 0.29	20.83 ± 3.28	18.00 ± 0.58	102.66 ± 8.57	Nd
Mbeere (n = 1)	17.00 ± 0.04	68.13 ± 1.68	13.86 ± 0.59	96.66 ± 1.20	48.33 ± 1.66	70.13 ± 6.80	Nd
Nandi Hills (n = 1)	16.00 ± 0.03	389.36 ± 8.84	13.03 ± 2.03	39.40 ± 0.67	56.33 ± 2.40	59.13 ± 3.10	Nd
Mida Creek (n = 2)	19.62 ± 0.02	151.4 ± 43.8	35.02 ± 0.35	151.70 ± 2.08	71.85 ± 0.88	57.03 ± 0.98	Nd
Kakamega (n = 1)	20.20 ± 0.04	70.30 ± 0.20	56.98 ± 6.95	234.57 ± 3.32	42.75 ± 0.75	72.96 ± 3.52	Nd
Taita (n = 1)	17.00 ± 0.03	7.97 ± 0.62	1.30 ± 1.18	276.25 ± 28.95	46.00 ± 1.35	81.5 ± 0.31	Nd
% of samples within set limits	98.61	91.67	100.00	90.27	73.61	63.88	100.00

*Honey quality standards of the Codex Alimentarius for floral honey. HMF, hydroxymethylfurfural; Nd, Not detected.

4. *Spatial distribution of the silkmoth* Anaphe panda *(Boisduval) and its host plant* Bridelia micrantha *(Hochst) in the Kakamega forest, Kenya*

Participating scientists and student: *N. Mbahin, S. K. Raina, E. N. Kioko and J. M. Mueke*

An understanding of the biology of wild silkmoths is essential if they are to be exploited for income generation. A study on the spatial distribution of the silkmoth *Anaphe panda* cocoons nests, egg-clusters and the host plant *Bridelia micrantha* (Hochst), was conducted in two blocks of the Kakamega forest (Isecheno and Ikuywa) western Kenya.

Kioko et al. (2000: *East African Journal of Science*, pp. 1–6) reported that *B. micrantha* is abundantly distributed in western Kenya and 84% of the community members had these trees in varying numbers on their land. All the Kakamega respondents confirmed having seen the *A. panda* caterpillars and the cocoons nests and 16% had seen the egg-clusters. Hence, the introduction of wild silk production in the Kakamega forest may offer an important economic incentive to farmers in western Kenya. In the Kakamega forest, more than 12,400 hectares are suitable for a possible silkworm food plant plantation. This land can be utilised for the cultivation of *B. micrantha* (12 ha for Isecheno block and 7 ha for Ikuywa block) that according to Gowdey (1953: *Bulletin of Entomological Research*, pp. 269–274) grows fast from cuttings and is ready for silkworm seeding within a year.

The mean densities of cocoons nests, egg-clusters and *B. micrantha* were significantly different in the two blocks. The host plants and the silkmoth egg-clusters were randomly distributed in the two blocks, whereas cocoon nests were random at Isecheno block and contiguous at Ikuywa block (Figures 2, 3 and 4). Flight range was recorded between 1.11–5.30 meters and was significantly higher in Isecheno than Ikuywa. This study reveals that *A. panda* tends to distribute its egg-clusters uniformly over the lower and middle crown of *B. micrantha* with a preference to eastern localisation. Knowledge on egg distribution allows greater precision in the location of eggs in the minimum time (Pottinger and LeRoux, 1971: *Memoirs of the Entomological Society of Canada*, 437 pp.). Geertsema (1975: *Annale van die Universiteit van Stellenbosch*, pp. 1–171) made similar observations in the Vyeboom and Kluitjieskraal plantation near Cape Town, South Africa.

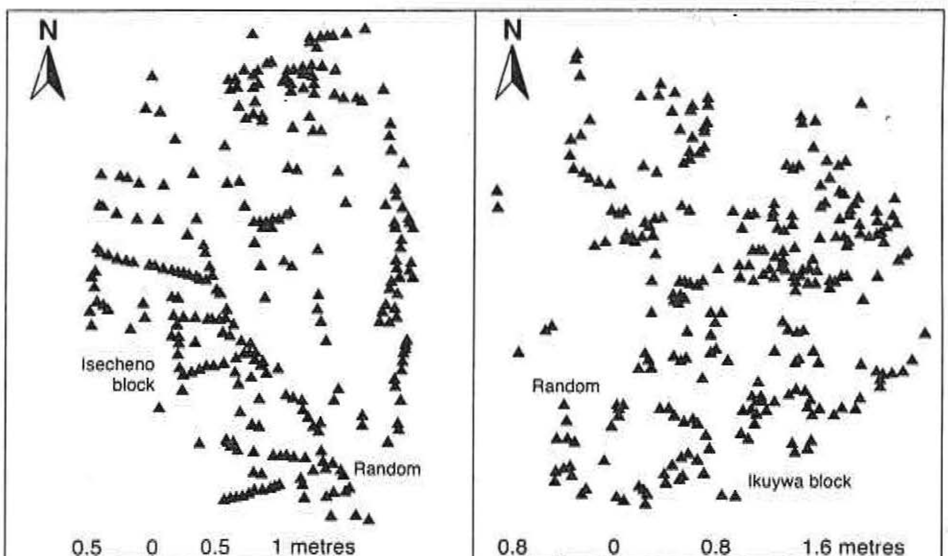


Figure 2. Dispersion pattern of *Anaphe panda* host plant *Bridelia micrantha* in the Kakamega forest

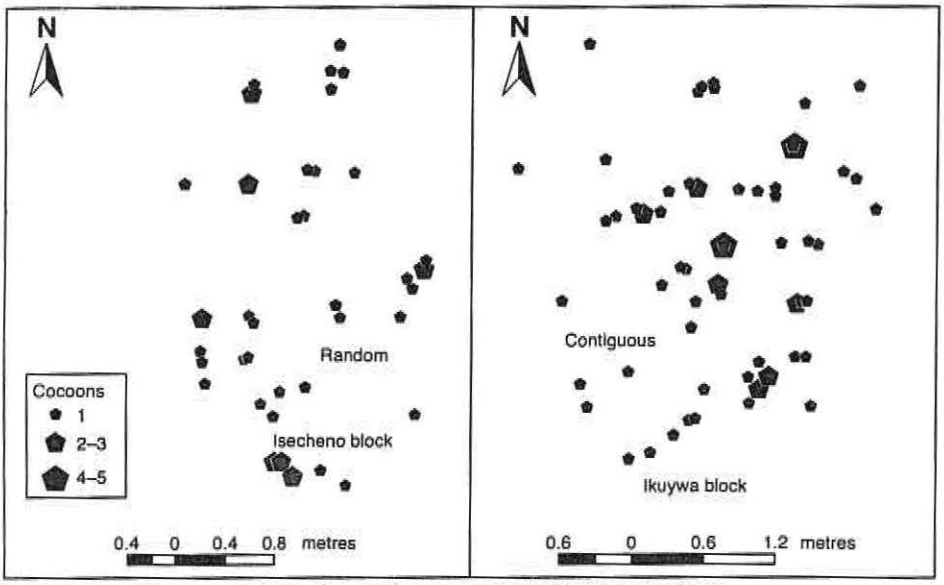


Figure 3. Dispersion pattern of *Anaphe panda* cocoon nests in the Kakamega forest

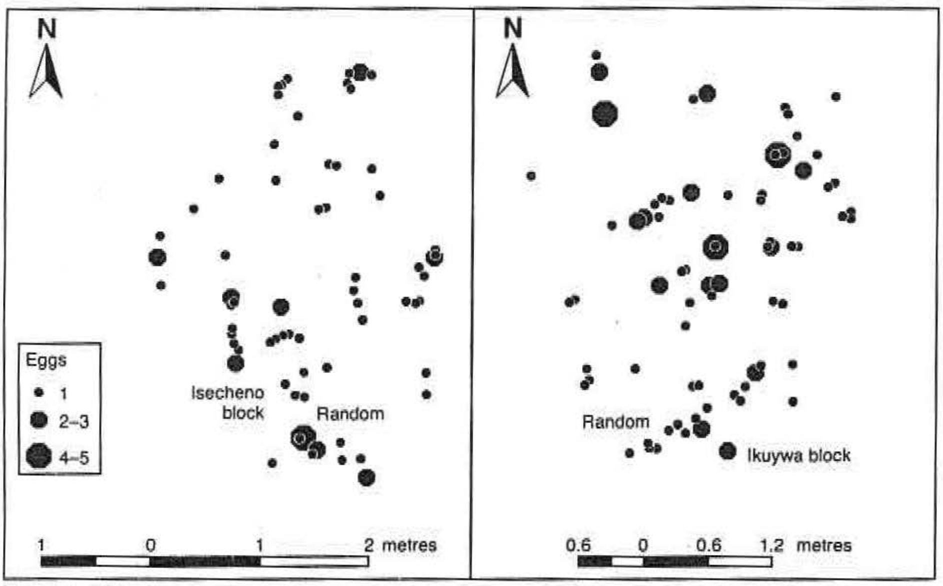


Figure 4. Dispersion pattern of *Anaphe panda* egg-clusters in the Kakamega forest

5. *Studies on cocoon characteristics of* Gonometa postica *(Lepidoptera: Lasiocampidae) from farmers' sites in Mwingi district*

Participating scientists and students: *E. N. Kioko, S. K. Raina, K. F. Okwae, B. M. Ngoka*

In Mwingi, *Gonometa postica* offers the greatest opportunity for utilising wild silkmoths. Farmers from various sites in the district (Nguni, Muumoni, Imba, Nuu and Katuuni) have been trained on the farming of *G. postica*. The farming involves rearing of the first three instars in net sleeves to protect them from predators. There is need to monitor the cocoon characteristics over time as this will give an indication of the performance of the silkmoth and farming effects on silk yield over time at the various sites. The data is also important in the differentiation of the sex of cocoons in the field, which is key in the setting up of grainage for continued egg production. The cocoons are the raw material for silk production and monitoring their parameters is important. This study, which is ongoing, determines the differences between cocoon parameters in females and males of *G. postica* from four sites in Mwingi, the frequency of observed cocoon parasitism and if cocoon parameters differ between the study localities.

The preliminary results have shown that *G. postica* shows sexual dimorphism in regard to cocoon weight, length and width. The cocoons can, therefore, be easily sexed in the field for grainage purposes and abundance studies. Out of a sample of 2634 cocoons randomly collected from the farmers in the crop of October to December 2005, 988 were females and 1646 were males. Out of these cocoons, 764 were parasitised as evidenced by presence of parasitoid emergence holes. The levels of parasitism varied across the sites (Table 4): 29.6% parasitism was recorded for the female cocoons and 28.7% for the male cocoons, while an overall parasitism rate of 29% was recorded for all the cocoons collected.

Cocoon characteristics variability between samples from the different localities showed significant differences in some of the parameters as shown in Table 5.

Table 4. Parasitism rates recorded in cocoon samples from farmers in Mwingi at the end of the 2005 short rains season

Site	No. of cocoons	No. of females	Parasitised female cocoons	% parasitism in females	No. of of males	Parasitised male cocoons	% parasitism in males
Ndithi	141	64	29	45.0	77	37	48
Imba	527	163	11	6.7	364	20	5.5
Nguni	1418	426	139	32.6	992	283	28.5
Katuuni	271	138	58	42.0	133	86	64.7
Kathiani	277	197	55	27.9	80	46	57.5

Table 5. Comparison of parameter means measured on emerged cocoon shells taken on samples from four sites in Mwingi

Cocoon parameters	Cocoon sex	Site			
		Imba	Kathiani	Katuuni	Nguni
Weight (g) of intact shell	Female	1.61 ± 0.05 A	1.36 ± 0.04 B	0.83 ± 0.03 C	1.43 ± 0.03 B
	Male	0.90 ± 0.04 a	0.87 ± 0.02 a	0.58 ± 0.02 b	0.85 ± 0.03 a
Length (cm)	Female	5.02 ± 0.05 A	4.83 ± 0.05 B	4.21 ± 0.05 C	5.03 ± 0.05 A
	Male	4.07 ± 0.05 a	3.92 ± 0.07 a	3.53 ± 0.03 b	3.99 ± 0.04 a
Width (cm)	Female	2.18 ± 0.03 A	2.20 ± 0.04 A	1.89 ± 0.02 B	2.24 ± 0.02 A
	Male	1.67 ± 0.02 a	1.69 ± 0.02 a	1.52 ± 0.02 b	1.70 ± 0.02 a
Cleaned shell weight (g)	Female	1.22 ± 0.04 A	1.03 ± 0.03 B	0.62 ± 0.02 C	1.14 ± 0.03 A
	Male	0.76 ± 0.02 a	0.69 ± 0.02 b	0.40 ± 0.01 c	0.65 ± 0.03 b

Means plus standard errors followed by the same lower case letters in the same row and sex are not significantly different (t-test $P < 0.05$).

Ongoing studies by a PhD scholar (Ken Okwae) are addressing four objectives as follows:

(i) To find out the abundance and distribution of *G. postica* on different *Acacia* spp. in Imba and Muumoni forests of Mwingi district;
(ii) To establish the diversity of parasitoids and their parasitism rates on *G. postica* found on different species of *Acacia*;
(iii) To determine the life cycle of dominant parasitoids of *G. postica*;
(iv) To investigate the roles of host plant and host odours in host location and selection by major parasitoids of *G. postica*.

Development of Sericulture and Apiculture Products for the Poor in Fragile Ecosystems Using the Value Chain Approach

Background, approach and objectives

Sustainable livelihoods can be achieved in Africa through access to a range of livelihood resources which are combined in the pursuit of different livelihood strategies. The IFAD project on wild and domesticated silkmoth rearing for silk production (sericulture) and honeybees rearing for beehive products (apiculture) is one such attempt to attain sustainability in rural incomes. The project was initiated by IFAD through *icipe* research initiatives in 1996. This has resulted in development of eco-friendly technologies being utilised by the smallholders in the marginal land areas in Africa to raise their sources of income and improve their economies. The project has created a sense of ownership to the local communities for their lands and resources.

Several attempts were made in the past by various international and national players to introduce and improvise these income-generating options. These efforts had been constrained by a lack of research and training bases in Africa for these technologies. It was only after IFAD's intervention through *icipe*'s technical backstopping efforts that these technologies on silkmoth and honeybees conservation and utilisation have been implemented and realised. This action research has enhanced the off-farm income of the rural poor and promoted IFAD's mandate on poverty alleviation. The main bottlenecks, (resolved in Africa by the IFAD project in Phases I and II), for technologies successes in the fields were: (1) scattered embryonic organisations or no groupings of the community in any enterprise development; (2) the lack of breeding programmes for selection of appropriate races in both silkmoth and honeybees adoption process and enterprise development; (3) inappropriate on-farm and in-house training facilities (or no facilities provided) by NARS for the farmers and extension workers; (4) lack of marketplaces and processing facilities for the produce; and (5) no access to the local and international market chains for the farming households.

The overall goal of this project is that the IFAD loan projects are strengthened through collaborative management with rural poor communities. The objective of the project is to demonstrate that remunerative links between smallholders and emerging apiculture and sericulture markets in East Africa can be created and that these models for sustainable livelihood can be adapted in the Near East and North African (NENA) region and other African countries.

The detailed objectives of the IFAD and co-financer's research components are to:

- Provide an understanding of marketing information system of honey- and silk-based products.
- Develop operational models in various ecosystems for honey and silk and empower communities to operate marketing channel as an integrated system.
- Incorporate molecular, hormonal and semiochemicals interventions at various levels of adaptive research to enhance the commercial production of silk- and honey-based products in the farmers' fields.
- Assist IFAD projects in the NENA region to develop community-driven income-generating integrated use of commercial insects in the Sudan, Yemen and Egypt through AFESD/KFAED/IsDB and in western Kenya and Tanzania through Movimondo and SFML.
- Complement the GEF project in developing incentives for community participation in forest conservation through the use of commercial insects in Kenya.
- Develop a framework for the analysis of the dynamics of rural livelihoods including income-generating options provided in the project.
- Provide effective project administration, coordination and monitoring to enable timely and efficient implementation of project resources.

Figure 1 shows the basic framework of the project.

Figure 1. Components of a territorial approach to rural business development

Participating scientists and students: *S. K. Raina, V. V. Adolkar, E. N. Kioko, E. M. Muli, E. K. Nguku, I. Gordon, B. M. Ngoka, N. Mbahin, K. Okwae, S. Sande*

Assisted by: *J. K. Macharia, G. Kamau, G. Owino, J. Auma, F. Kiilu, R. Macharia, B. Wanjiru, J. Ng'ang'a*

Donors: *IFAD*

Collaborators: *KENYA: National Museums of Kenya for bio-indicator studies; Nairobi University, Kenya for pollinator bee race selection and support to production for royal jelly; Kenya Agricultural Research Institute, for information on agricultural activity at project sites. RWANDA: ISAR Rwanda. Ministries of agriculture: Yemen, Egypt, Sudan, Uganda, Southern Sudan, Madagascar, Tanzania, Rwanda, Cameroon, Ghana. Coordinators of IFAD loan projects in Yemen, Egypt, Uganda and Southern Sudan. Private traders: BIOP Kenya Limited, Viking Limited, Wild Living, Paperazzi Limited*

Work in progress

1. Establishment of silk and honey enterprises

Participating scientists and students: *S. K. Raina, V. V. Adolkar, E. N. Kioko, E. M. Muli, E. K. Nguku, I. Gordon, B. M. Ngoka, N. Mbahin, K. Okwae, S. Sande*

Using a stepwise approach, and with IFAD's Technical grants support, *icipe* has developed and validated apiculture and sericulture technologies and established several training bases in Africa. At this point more than 13,000 farmers, NGOs and NARS have been given long- and short-term training courses to modernise the traditional apiculture practices and introduce a new silk farming culture. As a result of *icipe*'s research backstopping and IFAD's financial support on this action research, four marketplaces have emerged each supported by 300–2000 farm families. These marketplaces have become fully operational where farmers bring their raw material, cocoons and honeycombs which are then processed in a central location to develop final products for the market. The groups have democratically elected a chairman and were given full ownership to run their own business. These marketplaces are located in Kenya (K) and Uganda (U) in East Africa; Hoima (U) and Mwingi (K) for honey and Siaya/Othoro (K) and Bushenyi (U) for silk. With additional support from IFAD these can be adapted and replicated in different ecological climates in the NENA Region and other parts of Africa.

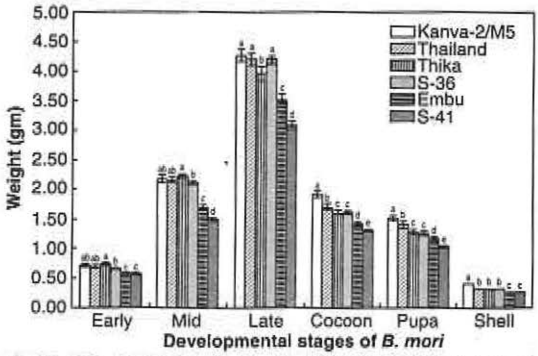


Figure 2a. Performance of the developmental stages of bivoltine hybrid (Shaanshi BV-333) race of *Bombyx mori* reared on mulberry cultivars during the short rains season. F values: early = 11.09, mid = 58.63, late = 26.67, cocoon = 33.37, pupa = 22.24, pupal shell = 26.89, $P < 0.0001$, (tabulated $F_{\alpha = 0.05, 5, 114}$), n = 20. Mean bars (± SE) followed by the same letter(s) are not significantly different in each stage, Waller-Duncan K-ratio t-test at $\alpha = 0.05$ significant level was used

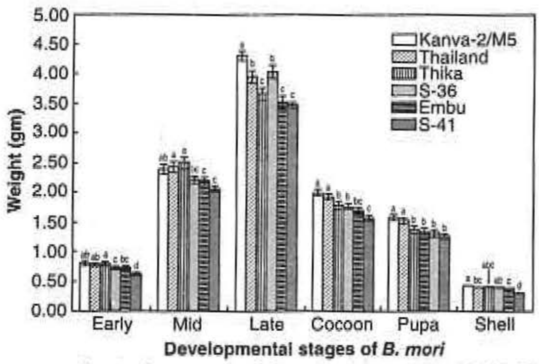


Figure 2b. Performance of the developmental stages of bivoltine hybrid (Shaanshi BV-333) race of *Bombyx mori* reared on mulberry cultivars during long rains season. F values: early = 13.30, mid = 5.29, late = 12.05, cocoon = 9.69, pupa = 6.71, pupal shell = 11.83, $P < 0.0001$, (tabulated $F_{\alpha = 0.05, 5, 114}$), n = 20. Mean bars (± SE) followed by the same letter(s) are not significantly different in each stage, Waller-Duncan K-ratio t-test at $\alpha = 0.05$ significant level was used

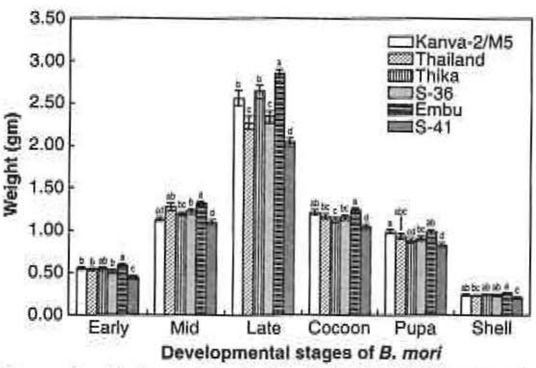


Figure 2c. Performance of the developmental stages of bivoltine hybrid (Shaanshi BV-333) race of *Bombyx mori* reared on mulberry cultivars in the dry season. F values: early = 8.11, mid = 6.93, late = 16.25, cocoon = 6.44, pupa = 5.26, pupal shell = 3.79, $P < 0.0001$, (tabulated $F_{\alpha = 0.05, 5, 114}$), n = 20. Mean bars (± SE) followed by the same letter(s) are not significantly different in each stage, Waller-Duncan K-ratio t-test at $\alpha = 0.05$ significant level was used

2. *Performance of the silkworm* Bombyx mori *(Shaanshi Bv-333) bivoltine hybrid race using various cultivars of mulberry* (Morus *spp.)*

Participating scientists and assistant: *V. V. Adolkar, S. K. Raina, D. M. Kimbu*

The performance of *Bombyx mori* L. bivoltine hybrid (Shaanshi BV-333), was evaluated on six mulberry cultivars of *Morus* spp., based on economic characters in rearing and mulberry leaf quality (Figure 2a–c). The growth rate and morphological characteristics for all the cultivars were studied using several parameters. Several characters such as disease resistance, survival percentage, cocoon weight, pupal shell weight, and single cocoon filament length were recorded during the rearing of silkworm larvae. Kanva-2/M5, Thailand, Thika and S-36 cultivars exhibited superiority in rearing performance over other cultivars tested. Thailand fed to silkworms, showed highest survival percentage in the short (S1) and long (S2) rainy seasons as compared to other cultivars (Figure 3). However, Embu exhibited lowest mortality during the dry season (S3) while S-41 showed the lowest survival rate in all seasons. Embu had significantly higher filament length and cocoon yield compared to the other cultivars during S3. However, S-41 performed poorly in survival percentage, cocoon yield, silk reeling and pupal shell weight. Waller-Duncan K-ratio t-test grouping confirmed that all cultivars were significantly different in all parameters tested ($P < 0.05$).

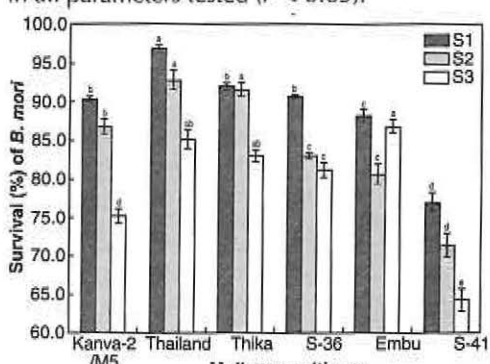


Figure 3. Survival rate of the bivoltine hybrid (Shaanshi BV-333) race of *Bombyx mori* reared on various mulberry cultivars during short (S1), long (S2) and dry (S3) seasons. F-value: S1 = 61.89, S2 = 30.16 and S3 = 33.60 (tabulated $F_{\alpha = 0.05, 8, 15}$), n = 4. Mean bars (±SE) followed by the same letter(s) are not significantly different in each cultivar, Waller-Duncan K-ratio t-test at $\alpha = 0.05$ significant level was used

3. *Performance of bivoltine* Bombyx mori L. *(Lepidoptera: Bombycidae) silkworm strains in Kenya*

Participating scientists, students and assistants: *E. K. Nguku, S. K. Raina, V. V. Adolkar, D. M. Kimbu, K. Mburugu, O. Mugenda*

Mulberry sericulture, being a new venture in this region, depends to a large extent on the introduced breeds and the stability of the silk industry greatly relies on the locally adapted breeds. In this study field performance of selected bivoltine silkworm, *Bombyx mori* strains, namely *icipe* I, Chun-Lei x Zheng Zhu (C x Z), Qui Feng x Baiyu (Q x B), Quingsong x Haoyoe (Q x H), Suju x Minghu (S x M) and 75xin x 7532 (75xin), was conducted in two locations S1 (laboratory) and S2 (field) during the long rains (LR) and short rains (SR) seasons. The study was set to analyse larval development, their performance and identification of suitable characteristics of these strains for silk production in Kenya.

Rearing of all the silkworms was done following the procedures of Jolly (1987: ICTRETS, p. 75) and Ullal and Narasimhana (1987: *Handbook of Practical Sericulture*. Third Edition. Central Silk Board, Bangalore, India. 166 pp.). The selected larvae were reared individually in the fifth instar and fed on mulberry leaves. A comparison of the average larval weight (LW) and average weight of the consumed food (FC) from the two locations (S1 and S2) was done. Weight of the consumed food was calculated as a percentage of the average larval weight to verify the relationship between larval weight and amount of food consumed. Testing for the cocoon layer and pupal weights was done.

This study indicated that the larval instar duration for the different strains varied, although the duration of the second instar was two days irrespective of the strain, location or season. There were no major variations in the larval stage duration in the six strains during the two seasons in the two locations. The larval duration was between 26 and 31 days for silkworms reared in location S1 during LR and SR.

The amount of food consumed was reflected in the larval weight. It was also noted that in location S1 average amount of food consumed as a percentage of larval weight was higher for all the strains. It was apparent that *icipe* I was able to convert the highest percentage of consumed food into its weight.

The relationship of the weight of cocoon shell and the amount of food consumed is important to determine which strain gives better percentage of silk production to the amount of mulberry leaves actually consumed. This study showed that *icipe* I had the highest cocoon shell weight (CSW) in locations S1 and S2 respectively. It was also evident that there was a positive relationship between the food consumed and the cocoon weight (Tables 1 and 2). It was evident that there were significant differences in the cocoon, shell, pupal and larval weights across the strains reared, seasons and locations (Table 3). The results indicated that *icipe* I strain performed better than the other five strains in most aspects. The study also established that silk yield and quality were different in the experimental silkworm strains, seasons and locations. Results confirmed that it is profitable to breed silkworm varieties with high silk production efficiency in Kenya and *icipe* I is by far the best breed for the field.

Table 1. Relationship of cocoon weight (CW) and cocoon shell weight (CSW) to the quantity of food consumed in location S1

Silkworm strain	Cocoon weight (CW)(gm)	Amount of food consumed (CF)(gm)	CW as % of CF	CSW (gm)	CSW as % of CF
Chun Lei x Zhen Zhu	1.95	3.84	50.57	0.33	8.59
Quingsong x Hayoe	1.94	3.69	52.57	0.35	9.49
Quifeng x Baiyu	1.84	3.69	49.86	0.32	8.67
75xin x 7532	1.73	3.17	54.17	0.30	9.46
Suju x Minghu	1.80	3.57	50.42	0.35	9.80
ICIPE I	2.14	4.10	52.20	0.38	9.27

Table 2. Relationship of cocoon weight (CW) and cocoon shell weight (CSW) to the quantity of food consumed in location S2

Silkworm strain	Cocoon weight (CW)(gm)	Amount of food consumed (CF)(gm)	CW as % of CF	CSW (gm)	CSW as % of CF
Chun Lei x Zhen Zhu	1.89	3.64	51.93	0.31	8.52
Quingsong x Hayoe	1.89	3.57	52.94	0.32	8.93
Quifeng x Baiyu	1.83	3.53	51.84	0.31	8.78
75xin x 7532	1.74	2.99	58.19	0.30	10.03
Suju x Minghu	1.78	3.50	50.85	0.35	10.00
ICIPE I	2.09	3.91	53.45	0.36	9.21

Table 3. Relationship of cocoon, pupal, shell and larval weights in the laboratory (S1) and field (S2) during the long rains (LR) and short rains (SR)

Strain	Season	Location	Mean CW	Mean PW	Mean SW	Mean LW
75xin x 7532	LR	S1	2.013 ± 0.014 c	1.731 ± 0.011 e	0.283 ± 0.005 e	3.869 ± 0.012 f
	LR	S2	1.971 ± 0.016 d	1.685 ± 0.015 d	0.284 ± 0.004 c	3.682 ± 0.014 e
	SR	S1	1.454 ± 0.030 b	1.142 ± 0.253 b	0.314 ± 0.007 d	3.608 ± 0.026 f
	SR	S2	1.517 ± 0.026 c	1.190 ± 0.024 cd	0.325 ± 0.005 c	3.335 ± 0.022 e
Chun Lei x Zhen Zhu	LR	S1	2.204 ± 0.011 b	1.878 ± 0.010 bc	0.324 ± 0.005 c	4.552 ± 0.014 b
	LR	S2	2.136 ± 0.013 c	1.831 ± 0.013 c	0.307 ± 0.003 b	4.455 ± 0.019 b
	SR	S1	1.705 ± 0.035 a	1.318 ± 0.032 a	0.338 ± 0.006 c	4.244 ± 0.012 c
	SR	S2	1.640 ± 0.033 b	1.260 ± 0.029 b	0.320 ± 0.007 c	4.088 ± 0.018 b
ICIPE I	LR	S1	2.531 ± 0.014 a	2.150 ± 0.012 a	0.379 ± 0.007 a	4.725 ± 0.010 a
	LR	S2	2.458 ± 0.009 a	2.130 ± 0.008 a	0.331 ± 0.004 a	4.566 ± 0.012 a
	SR	S1	1.741 ± 0.031 a	1.369 ± 0.028 a	0.371 ± 0.006 b	4.539 ± 0.009 a
	SR	S2	1.728 ± 0.030 a	1.352 ± 0.027 a	0.387 ± 0.005 a	4.164 ± 0.034 a
Quingsong x Hayoe	LR	S1	2.196 ± 0.012 b	1.851 ± 0.010 d	0.347 ± 0.006 b	4.345 ± 0.013 c
	LR	S2	2.142 ± 0.010 c	1.837 ± 0.008 c	0.303 ± 0.004 b	4.228 ± 0.041 c
	SR	S1	1.697 ± 0.030 a	1.340 ± 0.028 a	0.362 ± 0.005 b	4.286 ± 0.008 b
	SR	S2	1.636 ± 0.030 b	1.291 ± 0.027 ab	0.342 ± 0.005 b	4.180 ± 0.013 a
Quifeng x Baiyu	LR	S1	2.195 ± 0.013 b	1.858 ± 0.011 cd	0.328 ± 0.007 c	4.301 ± 0.012 d
	LR	S2	2.185 ± 0.012 b	1.878 ± 0.011 b	0.305 ± 0.003 b	4.201 ± 0.015 cd
	SR	S1	1.483 ± 0.027 b	1.171 ± 0.026 b	0.305 ± 0.005 d	4.196 ± 0.007 d
	SR	S2	1.468 ± 0.027 c	1.162 ± 0.024 d	0.314 ± 0.005 c	3.990 ± 0.019 c
Suju x Minghu	LR	S1	2.195 ± 0.015 b	1.886 ± 0.012 b	0.301 ± 0.005 d	4.128 ± 0.012 e
	LR	S2	2.181 ± 0.014 b	1.873 ± 0.014 b	0.308 ± 0.004 b	4.159 ± 0.015 d
	SR	S1	1.712 ± 0.034 a	1.332 ± 0.030 a	0.390 ± 0.007 a	3.985 ± 0.011 e
	SR	S2	1.63 ± 0.025 b	1.240 ± 0.023 bc	0.388 ± 0.005 a	3.857 ± 0.015 d
$F_{\alpha=0.05,\,7,352}$	LR	S1	117.61	118.94	33.48	416.24
$F_{\alpha=0.05,\,7,352}$	LR	S2	113.87	105.42	11.24	165.02
$F_{\alpha=0.05,\,7,352}$	SR	S1	11.99	8.29	21.34	378.87
$F_{\alpha=0.05,\,7,352}$	SR	S2	8.11	5.37	27.09	156.00

Means followed by the same letters in the same column are not significantly different (t-test, $\alpha = 0.05$). CW, cocoon weight; PW, pupal weight; SW, shell weight; LW, larval weight.

4. *Evaluation of raw silk produced by bivoltine silkworm* Bombyx mori *L. races in Kenya*

Participating scientists and student: *E. K. Nguku, S. K. Raina, V. V. Adolkar, K. Mburugu, O. Mugenda*

The finest quality raw silk and the highest fibre production come from the commonly domesticated silkworm, *B. mori*, (Shelagh, 2004: *Chinese Silk: A Cultural History*, British Museum Press). Although there are several commercial species of silkworms, *B. mori* is the most widely used and intensively studied, and techniques for its rearing are the most improved. The steadily growing demand for silk in the silk consuming countries indicates excellent opportunities for any country to increase her silk production, a valuable opportunity for Kenya to embark on. Consequently, to secure this opportunity, it is important for production of silk products to be of the highest quality.

In this study, evaluation of raw silk produced in location S1 (laboratory) and S2 (field) was assessed during the long rains (LR) and short rains (SR seasons), using selected bivoltine *Bombyx* *mori* silkworm strains. They included Chun Lei x Zen Zhu (C x Z), Quifeng x Baiyu (Q x B), Quingsong x Haoyoe (Q x H), 75xin x 7532, Suju x Minghu (S x M) and *icipe* 1. This study aimed at evaluating the quality of raw silk produced by the domesticated silkworm *B. mori* L. in Kenya. Silkworm rearing was done following the procedure of Jolly (1987). Setting of the silk quality control lab was done following specifications from the Chinese Academy of Agricultural Sciences (CAAS) and the International Silk Association (Lee, 1999: *FAO Agricultural Services Bulletin* No. 136).

Raw silk characteristics were evaluated and performance tested to determine its suitability for silk production. Quality tests of each postharvest production process were carried out to establish the overall quality of the product. Silk winding breaks varied among the different strains, with *icipe* I having the least counts while 75xin recorded the most counts 13, 16, 12 and 12 during/in SR S1, SR S2, LR S1 and LR S2 respectively (Figure 4).

Elongation percentages differed between the seasons and strains, between 18 and 20%. It was also observed that silkworm strains with high elongation count had the least number of winding breaks. *icipe* I had an average elongation of 20% and an average of 5 winding breaks counts, whereas 75xin had 18% and 13 of the same respectively (Figure 5).

Cleanliness and neatness percentages differed among some of the strains in S1 and S2 during LR and SR; however, they were within the acceptable ISA standards but notably *icipe* I cleanliness and neatness percentages were higher than the other silkworm strains during the two seasons, 96 and 93% respectively (Table 4). The data obtained identified *icipe* I as a more economical strain to rear for quality production of raw silk and yarn.

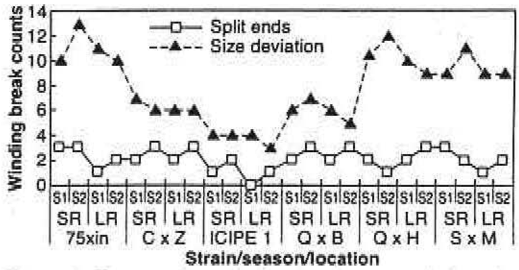


Figure 4. Comparative winding breaks count during the long rains (LR) and short rains (SR) in the laboratory (S1) and field (S2)

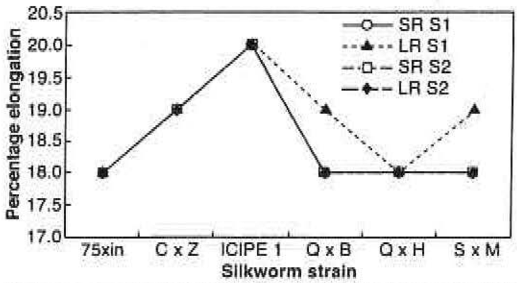


Figure 5. Percentage elongation during the long rains (LR) and short rains (SR) in the laboratory (S1) and field (S2)

Table 4. Mean cleanliness and neatness % during the long rains (LR) and short rains (SR) seasons

Strain	Season	Location	Mean cleanliness	Mean Neatness
75xin x 7532	LR	S1	92.8 ± 0.13 c	87.1 ± 0.18 d
	LR	S2	91.0 ± 0.21 e	85.0 ± 0.21 d
	SR	S1	92.0 ± 0.21 d	87.1 ± 0.38 c
	SR	S2	91.2 ± 0.36 c	85.0 ± 0.26 c
Chun Lei x Zhen Zhu	LR	S1	94.4 ± 0.16 b	88.9 ± 0.18 c
	LR	S2	94.0 ± 0.21 b	88.2 ± 0.25 b
	SR	S1	94.0 ± 0.21 b	88.0 ± 0.26 b
	SR	S2	92.9 ± 0.23 b	87.0 ± 0.21 b
ICIPE 1	LR	S1	97.0 ± 0.33 a	93.0 ± 0.39 a
	LR	S2	96.2 ± 0.36 a	92.9 ± 0.18 a
	SR	S1	96.0 ± 0.21 a	94.3 ± 0.30 a
	SR	S2	96.0 ± 0.26 a	93.3 ± 0.47 a
Quingsong x Hayoe	LR	S1	92.8 ± 0.29 c	88.3 ± 0.30 c
	LR	S2	92.0 ± 0.30 d	88.2 ± 0.29 b
	SR	S1	92.2 ± 0.13 d	87.9 ± 0.31 b
	SR	S2	90.2 ± 0.33 d	87.3 ± 0.30 b
Quifeng x Baiyu	LR	S1	89.9 ± 0.38 d	89.1 ± 0.41 b
	LR	S2	88.3 ± 0.26 f	88.0 ± 0.26 b
	SR	S1	90.0 ± 0.33 e	88.1 ± 0.18 b
	SR	S2	88.0 ± 0.42 e	87.2 ± 0.39 b
Suju x Minghu	LR	S1	94.1 ± 0.23 b	87.4 ± 0.40 d
	LR	S2	93.0 ± 0.21 c	87.3 ± 0.40 c
	SR	S1	92.9 ± 0.10 c	88.0 ± 0.33 b
	SR	S2	90.8 ± 0.13 c	85.0 ± 0.26 c
$F_{\alpha = 0.05, 7,172}$	LR	S1	172.96	97.12
$F_{\alpha = 0.05, 7,172}$	LR	S2	184.21	194.41
$F_{\alpha = 0.05, 7,172}$	SR	S1	201.58	282.20
$F_{\alpha = 0.05, 7,172}$	SR	S2	183.34	288.21

Means followed by the same letters in the same column are not significantly different (t-test, $\alpha = 0.05$).

Output

Journal articles

Raina S. K. and *Kimbu D. M.* (2005) Variations in races of the honeybee *Apis mellifera* (Hymenoptera: Apidae) in Kenya. *International Journal of Tropical Insect Science* 25, 281–291.

Muli E. M., Raina S. K. and Mueke J. M. (2005) Royal jelly production in East Africa: Performance potential of the honeybees, *Apis mellifera scutellata* and *Apis mellifera monticola* in Kenya. *Journal of Apicultural Research* 44, 137–140.

Other scholarly publications

Raina S. K. and *Nguku E. K.* (Eds) (2005) *Integrating Sericulture and Apiculture Technologies with Regional Development Operations*. Proceedings of the Trainers Course and Third International Workshop on Conservation and Utilization of Commercial Insects. *icipe* Science Press. ISBN 92 9064 14 1X, 272 pp.

Reports to donors

1st and 2nd Technical Reports, 2005. Developing Incentives for Community Participation in Forest Conservation through the Use of Commercial Insects. UNDP ID-KEN/04/G35.

1st and 2nd Technical reports, 2005. Technical Support on Apiculture and Sericulture at Arabuko-Sokoke. Sub award No: NK-*icipe*-01-0004.

Conferences attended

Conference on the Growth of the Organic Movement in Zambia. 7–10 February 2005, Zambia. Attended by: E. K. Nguku. S. K. Raina, V. V. Adolkar and E. N. Kioko.

The 16th Conference of the African Association of Insect Scientists held at Noguchi Memorial Institute for Medical Research, 6–10 June 2005, Legon, Accra, Ghana. Attended by: E. N. Kioko, S. K. Raina, B. M. Ngoka.

Research proposals

Research proposals submitted for funding to Arab banks, OPEC Fund, FAO, Ethiopia (Oromia), Rwanda, Southern Sudan and Toyota Foundation.

Consultancies

IFAD, FAO, UNDP-GEF.

Capacity building

Training courses

527 awareness and 220 intensive training for farmers, NGOs and government officials at *icipe* in sericulture and apiculture. 20 onsite farmers' training in Samburu, West Pokot, Tana, Taita Arabuko-Sokoke, Kakamega, Mwingi in Kenya; Hoima, Bushenyi in Uganda; Tanga in Tanzania; Kigali in Rwanda; Yei in Southern Sudan.

PhD students

E. Muli (Kenya) Breeding of the honey bee (*Apis mellifera* L.) and its potential for royal jelly production in Kenya. Kenyatta University, Kenya, 2004.

E. Nguku (Kenya) Assessment of the quality of silk fibre and fabric using bivoltine silkworm, *Bombyx mori*, in Nairobi, Kenya. Kenyatta University, Kenya (awaiting PhD defence).

B. Ngoka (Kenya) Relative abundance of the wild silk moth, *Argema mimosae* on different food plants and behavioral host selection by parasitoids. Kenyatta University, Kenya (PhD research in progress).

N. Mbahin (Cameroon) The ecology and economic potential of the wild silkmoth *Anaphe panda* (Biosduval) in the Kakamega forest of western Kenya. Kenyatta University, Kenya (ongoing).

K. F. Okwae (Ghana) Biology and ecology of the major parasitoids of *Gonometa postica* Walker (Lepidoptera: Lasiocampidae) on different species of *Acacia* in Mwingi, Kenya. Kenyatta University, Kenya (ongoing).

S. Sande (Kenya) Honey bees and forest conservation: A case study of the Arabuko-Sokoke Forest Kenya. Kenyatta University (ongoing).

MSc students

M. N. K. Gathumbi (Kenya) Effects of fertilisers and mulberry (*Morus alba* L.) variety on cocoon and silk quality in Kenya. Nairobi University, Kenya (awaiting MSc defence).

J. Macharia (Kenya) Relative abundance, queen rearing and colony characterisation of stingless bees in Kakamega forest of Kenya. Jomo Kenyatta University of Agriculture and Technology, Kenya (ongoing).

Impact

CIP projects have developed the capacity of the NARS, NGOs, universities and private industries. Operational models in various ecosystems for honey- and silk-based products are being developed and communities empowered to operate marketing channels as integrated systems. IFAD projects in the NENA region will be assisted to develop community-driven income-generating integrated use of commercial insects in the Sudan, Yemen and Egypt through AFESD/KFAED/ISDB and in western Kenya and Tanzania through Movimondo and SFML; Rwanda and Southern Sudan through intervention from the CGIAR consortium. The GEF project in developing incentives for community participation in forest conservation through the use of commercial insects in Kenya is generating synergies with forest conservation.

Economic returns to smallholder apiculture and sericulture practices will generate revenue in a number of ways and increase their production and income. For example, CIP interventions in Mwingi have doubled honey prices paid to farmers and increased production from 3 tonnes in 1996 to over 35 tonnes in 2005. Quality honey and wax have ready and established markets. The wax has commercial and industrial value, especially in the cosmetic and candle industries. The sale of colonies by queen rearing will provide additional income. Other high value products, such as royal jelly, bee venom, propolis and pollen are in high demand by pharmaceutical companies and may be produced at a later date. During nectar and pollen gathering, honeybees effect pollination and improve the quality and quantity of crops.

Sericulture is a lucrative product. Cocoons or raw silk provide a regular income (the cycle may be as little as 30–40 days). As well as feeding silkworms, mulberry leaves can serve as animal feed and provide fruit. After reeling, silkworm pupae can be used as fish or chicken feed.

Economic values are enhanced by quality control procedures for sericulture and apiculture products. A quality control laboratory is testing honey, hive products, cocoons, raw silk, twisted yarn and silk cloth, to ensure the products meet the industry standards. Marketplaces in several focal points in East Africa are being established with full ownership of the rural communities, with 50% women representation and market linkages for the various products are being developed through private entrepreneurs.

E. Grass/Arthropod Diversity

Conservation of Gramineae and Associated Arthropods for Sustainable Agricultural Development in Africa

Background, approach and objectives

From the point of view of human nutrition and population growth, the Gramineae (grasses) with about 10,000 species is the most important family of plants. Cultivated cereal crops (maize, rice, wheat, sorghum, millet, etc.) provide most of the world's food supply, and numerous grass species provide fodder for domesticated ungulates. Grasses are directly responsible for providing the substrate for carbohydrate metabolism, and indirectly for that of protein and fat (through livestock conversion of grass into meat and milk fat). In short, grasses are the foundation upon which human civilisation has been built. Grass species can also be serious weeds, spreading invasively, often following the unwise introduction of an alien species into a new habitat. Most of the thousands of grass species, however, are of no immediate, or obvious, importance to humankind. They go about their business in the background, invisible to the average person.

With few exceptions (arrowroot, banana, potato, etc.), cereals are the staple diet of people in the developing world. Small-scale farmers depend heavily on cereals, and their fortunes rise and fall with the success or failure of seasonal yields. Human population growth has meant that the best land for growing cereal crops has already been taken. Increasingly, marginal lands are being converted to agriculture, with or without irrigation. Since most grass species are plains or open woodland species, cereals are replacing non-cereal, native grasses. In some countries with high human population densities (e.g. Burundi, Rwanda) nearly all arable land is under cereal production and grass biodiversity has been severely reduced. The same is true, to a lesser extent, throughout the world. Wild, native grasses represent an enormous reservoir of potential value, both as sources of genetic characteristics for improving existing cereals and for possible breeding of wild species into new cultivars. Our project was designed to address the issue of conservation of native grasses in the face of continuing human population growth.

In our project, we approached grass conservation from a few different perspectives. First, we focused on field collection, deposition and, ultimately, conservation of native grass germplasm in national genebanks. Second, we publicised the value of native grasses and their conservation through brochures, handbooks, farmers' field days, and radio and television programmes. National programme officers and technical staff were educated through training sessions in grass and insect identification, and methods of manipulation and rearing of stem boring insects. Finally, working with farmers' groups, we actively encouraged grass conservation by initiating grass weaver's cooperatives and by introducing a new technology incorporating native grasses into traditional farming methods.

The project objectives were to document the diversity of Gramineae and associated insects in different selected agroecosystems and socioeconomic surroundings, and their adjacent natural habitats in Ethiopia, Kenya and Mali; to understand the relationships between certain grasses and insects; and to develop and promote the practical application of this knowledge ('best practices') in self-regulatory pest management and sustainable agriculture. Ultimately, we hoped the project would nurture a culture of conservation of native grass species among farmers, the group mostly responsible for their destruction.

Participating scientists: *Z. Khan, A. Barrion, R. Copeland, N. Yaro (Mali Country Coordinator), A. Hamadoum (Sikasso Site Supervisor), A. Kodio (Mopti Site Supervisor, Institut d'Economie Rurale, Mali), F. Muyekho, N. Ng'ang'a (Kenya Agricultural Research Institute)*

Assisted by: *S. O. Orima, E. Kidiavai, P. Ollimo, R. Odhiambo, M. Watiti, C. Msando, C. Oyugi; B. Sangare and P. Konate, IER*

Donor: *Global Environmental Facility/United Nations Environment Programme*

Collaborators: *ETHIOPIA: Ethiopian Institute of Agricultural Research; the Institute of Biodiversity Conservation and Research, Addis Ababa, Ethiopia; the National Herbarium at Addis Ababa University, Ethiopia; the Ministry of Agriculture, Addis Ababa, Ethiopia.*

MALI: Institut d'Economie Rurale, Mali. KENYA: International Plant Genetics Research Institute, Nairobi; Hyacinth Crafts, Kisumu, Kenya; Green Development Group, Kisumu, Kenya; Crop Plant Genetic Resources Centre, Genebank of Kenya; KARI; the National Museums of Kenya; East African Herbarium; Environment Liaison Centre International

Work in progress

1. Farmer evaluation of native grass-row borders on yield of maize and millet

Activities conducted during 2004–2005 built on work completed earlier in the project. Farmers in three Kenyan and two Mali districts were interviewed and asked to select favoured native grass species for use in on-farm experiments to evaluate the effects of native grass-row borders on yield of maize and millet. Farmers selected native grass species that had recognised value for them, as fodder, thatch, green manure, for weaving, and as a saleable commodity. In Kenya, these grasses were *Themeda triandra, Pennisetum purpureum, Panicum maximum, Hyparrhenia rufa* and *Cynodon dactylon*. In Mali, native grass species chosen were *Andropogon gayanus, Pennisetum pedicellatum, Schoenefeldia gracilis* and *Schyzachirium* sp.

Preliminary, randomised block design experiments were conducted on small (6 x 6 m) plots. Border rows of native grasses, chosen by the farmers, were planted around field crops (maize or millet). Toward the end of the growing season, farmer's field days were held at all experimental sites. There, farmers were interviewed and evaluated the condition of the plots. Farmers then met and selected the native grass(es) they wished to evaluate in large plot (30 x 30 m) experiments.

In Kenya, field days were held at the three study sites: Busia, Machakos and Suba districts. One hundred and fifty-six participants attended. Activities at the Suba district field day were covered by Citizen Radio and Television, which aired programmes on both media.

Following farmer evaluation of the small plot trials, preferred native grass species were selected for large plot (30 x 30 m) experiments. As was expected, there was substantial variation in results within and between sites. However, the trends were clearly positive, with maize yield consistently higher in plots surrounded by native grasses than in control plots (maize surrounded by rows of maize). In Suba District, for example, maize grain yield was 36 and 38% higher in *Hyparrhenia rufa*-surrounded and *Panicum maximum*-surrounded plots, respectively, compared to controls (3.13 vs 2.30 tons/ha in the former and 3.08 vs 2.23 tons/ha in the latter experiment) (Figure 1).

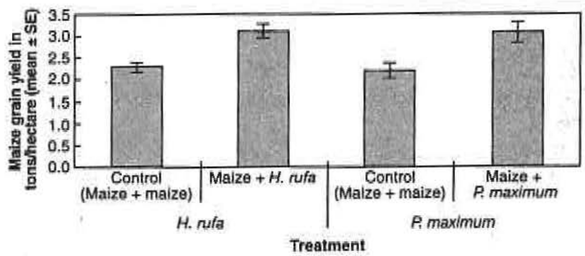


Figure 1. Effect of grass borders on maize grain yield in Suba district during the 2005 long rains

These encouraging experimental results provided the scientific basis for proceeding with the development of a manual on best practices for integrating border rows of native grass species into traditional methods of cereal crop farming. The manual provides step-by-step instructions for using the technology and contains many photographs that clearly illustrate the steps involved in establishing and maintaining grass border rows. A final draft of the manual was completed.

2. Progress on grass weaving cooperatives in Busia and Suba districts

In Busia district, 21 farmers were trained in grass-weaving techniques by Ziwa Creations, an NGO based in Kisumu. Ziwa had previously trained weavers in Suba district. Suba farmers received their first order, and their products were purchased by Ziwa for sale in Nairobi.

3. Receipt of computerised identification tool for grasses from Ethiopia, Kenya and Mali

The consultant completed and handed over an initial version of the 'Grasses Key' CD. The key was edited for accuracy and ease of use. Following the model of recent examples of electronic identification guides, the interactive CD uses a multiple-entry format, to enable users to key in values for characters they are certain of, leaving out those they are unsure of. Descriptions and images of 502 grass species from the project target areas of Ethiopia, Kenya and Mali are included, as is an extensive glossary with accompanying illustrated plates.

4. *Additional collections of wild grass germplasm made with further accessions in National Gene Bank of Kenya*

Staff of the National Gene Bank of Kenya collected additional grass germplasm, replacing species collected earlier that had failed to display a satisfactory level of germination. Twenty-four additional accessions were made, representing 19 grass species.

5. *Handbook for the identification of grass stem borers and associated parasitoids in Kenya*

A first draft of the handbook was completed. In addition to the extensive line drawings illustrating the handbook, it was felt that the addition of high resolution images of the genitalia of stem-boring moths would greatly increase its value for researchers and field workers. In general, moth stemborers are inconspicuous, straw-coloured or brownish species, blending into their grassland background. Many species are similar-looking as adults and can be exceedingly difficult to identify, particularly if rubbed of surface scales. Morphological characters occurring on the genitalia of male and female adults are the gold standard of moth identification, as they are for many insect groups. Preparations of genitalia are simple to prepare and easy to interpret under a dissecting microscope. Yet, until now, there have been no publications with high quality photographic images providing this information. When published, the handbook will fill that void, and be of great value not just in Kenya, but throughout East and Central Africa. For the handbook, images were captured using the photomontage system at the US National Museum of Natural History.

6. *Activities in Mali*

The regional co-ordinator made a 12-day trip to Mali from 26 August–6 September 2005, visiting IER headquarters in Bamako to discuss the status of activities in Mali with the country co-ordinator, Dr Niamoye Yaro, and to visit the two areas in which activities are being conducted, Sikasso and Mopti. The project is far less developed in Mali than in Kenya, due largely to an extended drought, but also to a lack of trained entomologists/taxonomists at the managerial and technical levels. Nonetheless, farmer enthusiasm for the project was very positive.

Output

Reports to donor

Quarterly reports for 2004–2005.

Capacity building

Training of 156 farmers and local extension officers in using 'grass-rows technology' to enhance yield of cereal grasses was carried out.

Impact

The 32 farmers from three districts in Kenya who were participating in the field trials accessing the efficacy of grass-row borders were interviewed by the social scientist. All but one indicated that they were going to continue to use the method after the on-farm trials ended and direct *icipe* involvement was terminated.

F. Gene Flow from Cultivated to Wild Plants

Cowpea Gene Flow

Background, approach and objectives

Transgenic crops are increasingly becoming a dominant feature of the agricultural landscapes, and genetically modified crops (GMCs) hold potential for increasing food security in Africa where traditional farming is based on mixed cropping with low agricultural inputs. However, the potential release of GMCs in Africa raises several concerns, i.e. toxicity of GMCs to non-target organisms, development of insect populations resistant to the toxins expressed in the GM plants, and more important in the case of crops with wild relatives, gene flow from cultivated to wild and weedy plants. As emphasised by Richard Cowan in an interview to *Fortune* (21st February 2000),

> the most serious environmental risk is the possibility that implanted genes will escape from cultivated crops into wild relatives, resulting in the production of super weeds. It's not clear that escaped genes would remain in wild relatives and cause adverse ecological effects. Only extensive field tests will give us answers on this.

Beyond extending basic knowledge on the relationships between an important African crop, i.e. the cowpea, and its wild progenitor, the ultimate goal is to provide reliable information in the areas of ecology and population genetics to allow for well planned deployment of genetically modified (GM) cowpea in Africa, where insect-resistant varieties are desperately needed. Since wild relatives of cultivated cowpea are widespread in Africa, and in some places very common, the current research on gene flow between cultivated and wild cowpea is fully justified.

However, studying gene flow in cowpea is not restricted to the pollen-flow from cultivated to wild plants. Although pollen flow is an important component, post-fertilisation events also need to be taken into consideration. Moreover, one needs to keep in mind that both pollen flow directions can lead to hybrid plants able to backcross with other wild plants. Therefore, pollen competitivity, fitness of hybrids and of the hybrid progenies, as well as seed predation and seed flow, are phenomena that need attention. Indeed, every piece in the chain, from flowering of the cultivated plant to the seed predation of a BC2 introgressed wild plant, need to be studied. Although one element seems very helpful so far for a GM cowpea deployment, i.e. the pollinator behaviour and the low pollen flow, not a single element alone will provide a zero-risk clearance for the release of GM cowpea. Each step of the process leading to gene establishment in a wild population needs to be examined to be sure that no major problem remains somewhere, which would hamper the release of GM cowpea.

This work is entirely done within the Molecular Biology and Biotechnology Department and Muhaka Field Station (coastal Kenya).

Participating scientists and students: *R. S. Pasquet, Y. Feleke (PhD student), E. Kouam (PhD student), I. Rabi (MSc student), C. Ager (MSc student)*

Assisted by: *B. Elesani, A. M. Gunia and V. Odero*

Donors: *Rockefeller Foundation, USAID (BBI program)*

Collaborators: *University of California, Department of Agronomy and Range Science, Davis, USA; Lund University, Department of Chemical Ecology and Ecotoxicology, Sweden; Ohio State University, Department of Evolution Ecology and Organismal Biology, Columbus, Ohio, USA; INERA/CREAF, Ouagadougou, Burkina Faso*

Work in progress

1. Analysis of pollen flow between domesticated cowpea and its wild relative: Phase 1

The first phase of the project was focusing on pollen flow between domesticated (potentially GM) cowpea and its wild relative. Pollen flow can only occur through few large-sized pollinators (several *Xylocopa* and megachilids). Pollen flow can be important in some instances, especially when a few wild plants are in the middle of a cowpea field. So far, there is no way to prevent pollen flow. Competitivity of the various pollens, flower colour or segregation distortion in the progeny of a hybrid cannot be used to prevent gene escape.

The fitness of the wild-domesticated hybrids and their progenies was checked. These hybrids are more fitted than wild plants, especially the hybrids from a domesticated plant fertilised by wild pollen. In addition, these hybrid plants and their progenies can take advantage of insect protection to boost their seed production.

Seed predation and wild plant population regulation

As there is no way of preventing gene escape and wild plants introgressed with Bt genes will likely produce more seeds, focus shifted toward seed predation and wild plant population regulation. The future introgressed wild plants will produce more seeds, but will this be enough to turn wild cowpea into invasive weeds?

Videotapes show that ants (as well as beetles and locusts), birds (*Francolinus coqui* and *Streptopelia capicola*), rodents (gerbils, Figure 1) and large mammals are all seed predators.

Very few ants were videotaped, therefore we cannot assess their role as seed dispersers yet. But beetles and locusts were clearly seed predators.

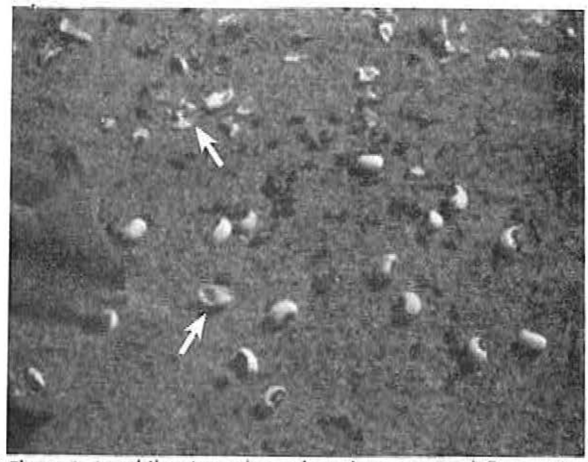


Figure 1. A gerbil eating a domesticated cowpea seed. Remnants of the seed testa (top) show the seeds already eaten. During the same night, one seed was half-eaten by a beetle (bottom). This picture was originally from a videotape

The role of rodents is more ambiguous. They eat seeds *in situ*, and these seeds are clearly destroyed. However, they are also removing and caching seeds. Since they do not locate seeds buried deeper than a few centimetres, we can expect that the seeds they are caching are lying at a depth where they can germinate. Since rodents are reputed for forgetting the location of some of their caches, we can expect that they are also involved in seed dispersion.

Although not yet taped on video, large mammals (cows, goats, horses and pigs) are seed predators, in addition to being important grazers. Preliminary feeding tests showed that if birds seem to be total predators, large mammals are destroying only 60 to 90% of the wild seeds ingested. Domesticated seeds are entirely destroyed by digestion while few hybrid seeds (produced by F_1 hybrid plants) are surviving the tests. However, in normal conditions (i.e. the dung is not immediately buried for manure), dung beetles are burying most of the seeds in their dung balls at depths where the seeds cannot germinate. A first very rough estimate would be that a maximum of 10% of the ingested seeds are dispersed. Large mammals, although important predators, seem to be the primary long distance seed dispersers.

Predation by birds (Figure 2) is in general very low. Birds do not seem to have a preference for any type of seeds. From video sequences, they seem to start with small sized seeds, but they usually consume most of the seeds offered when they come across a station.

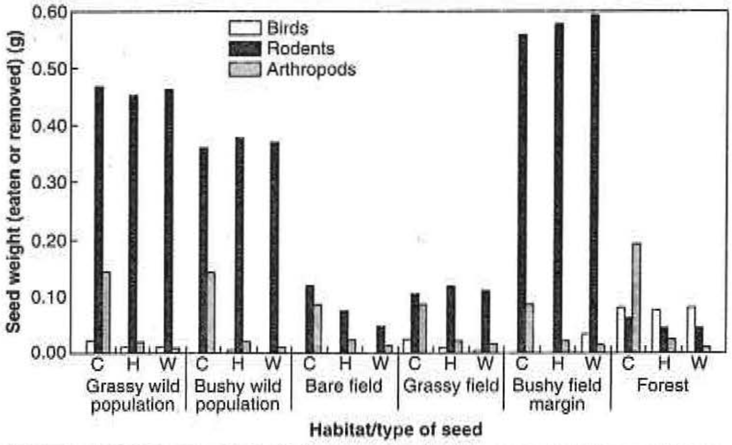


Figure 2. Predation of seeds by birds, rodents and arthropods according to ecology, predator and seed type (c, cultivated, h, hybrid or w, wild)

Predation by arthropods is also low. However, arthropods seem to prefer domesticated seeds. Seeds are eaten *in situ* and not removed.

Predation by birds is not very important and it is also not regular. With birds, all the seeds can be eaten in one day, and stay untouched for the next two days. On the other hand, once rodents have found a location with seeds, the place is visited regularly (every following night). Therefore, with rodents, we see a progression from day 1 to day 3 which does not appear with birds (Figure 3). Obviously, rodents can adapt fairly quickly to an increase in offered seeds.

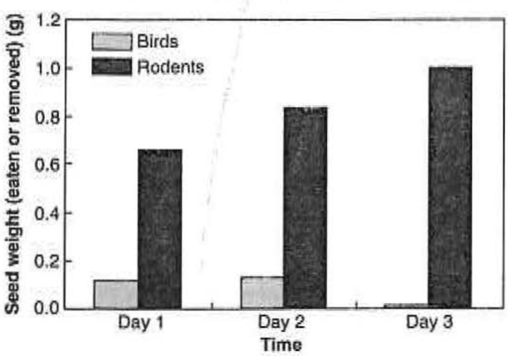


Figure 3. Predation of seeds by birds and rodents on consecutive days (3 g was offered)

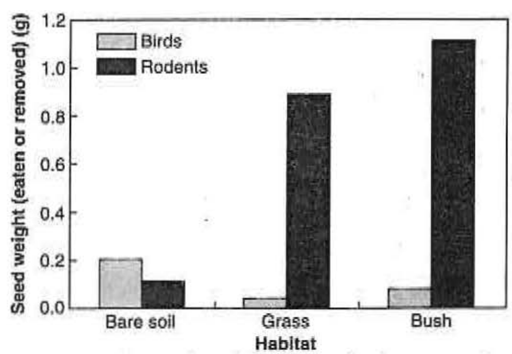


Figure 4. Predation of seeds by birds and rodents according to soil cover and vegetation (3 g was offered)

In effect, rodents would be the perfect predators if their predation was not strongly affected by vegetation and soil cover. Figure 4 clearly shows that although birds may prefer relatively open spaces, rodents are avoiding areas with bare soil.

To clarify this, we did a similar trial in which seeds were dispersed on a transect from a bushy area (Figure 5, dark area) to a bare soil area (Figure 5, light area). After 4 m of bare soil, predation dropped sharply.

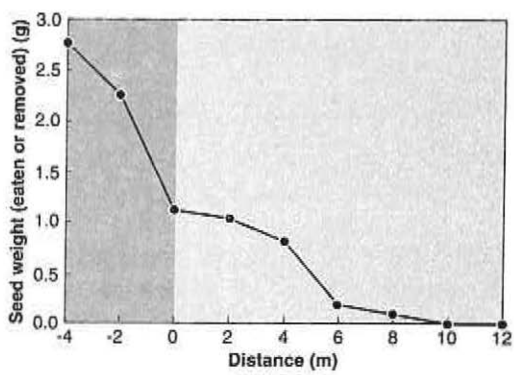


Figure 5. Predation by rodents according to soil cover (3 g was offered)

For the moment, these results should be considered as very preliminary. However, they look encouraging for the future release of Bt-cowpea in Africa.

We know that if Bt-cowpea is released in Africa, the Bt-gene will move to wild plants and the wild plants will produce more seeds; although we do not know how much more they will be able to produce with the help of just the Bt-gene since we have no Bt-plants to test yet.

Regarding predation, rodents and large mammals seem to have potential for destroying the extra seeds produced by Bt introgressed plants. This would suggest that rodents would be able to keep natural populations at a low level. However, the situation is expected to be less clear for the weedy population developing in fields. It is obvious that rodents will not be as effective as in natural populations.

Output

Journal articles

Thulin M., Lavin M., *Pasquet R.* and Delgado-Salinas A. (2004) Phylogeny and biogeography of *Wajira* (Leguminosae): A monophyletic segregate of *Vigna* centered in the Horn of Africa region. *Systematic Botany* 29, 903–920.

Pasquet R. S. (2004) New synonyms of *Vigna luteola* (Jacq.) Benth. (Leguminosae-Papilionoideae-Phaseoleae). *Kew Bulletin* 59, 637–638.

Pasquet R. S. (2004) The African centers of domestication, pp. 304–306. In *Encyclopedia of Plant and Crop Science* (Edited by R. Goodman). Marcel Dekker Inc., New York.

Capacity building

PhD students

Y. Feleke (Ethiopia) Cowpea *(Vigna unguiculata)* cpDNA polymorphism as a tool to assess gene-flow directions between cultivated and wild cowpea. Kenyatta University, Kenya (awaiting defence).

E. Kouam (Cameroon) Cowpea gene-pool organisation. Kenyatta University, Kenya (ongoing).

MSc students

I. Y. Rabi (Kenya) Molecular estimation of breeding system and gene flow of wild cowpea [Vigna unguiculata (L.) Walp.] from coastal Kenya. Kenyatta University, Kenya (March 2004).

C. A. Ager (Kenya) Chemical composition (volatile and nectar) of cowpea flowers. Kenyatta University, Kenya (awaiting defence).

Impact

Data on ecology of wild cowpea will be necessary to regulatory agencies to authorise Bt-cowpea.

G. Metapopulation Study and Management

Metapopulation Dynamics and Management. I. Connectivity Enhancement for Ecosystem Service Enhancement as Case Study

Background, approach and objectives

The objective of the Population Ecology and Ecosystem Science Department project is to make available a methodology that allows study and management of metapopulations consisting of a group of spatially separated populations of the same species which interact at some level. In the project, the state and spatial occurrence of various fruit tree species and varieties are assessed, the services that they confer to people are evaluated and recommendations are made on strategies aiming at enhancing their services. In fact, human societies may derive many benefits including the production of a diversity of *ecosystem goods*, or extractive benefits, such as food, timber, biomass fuels, and precursors to many in—*fundamental life-support processes* including pollination, water purification, renewal of soil fertility and climate regulation. Ecosystem services include *life-fulfilling functions*, encompassing aesthetic beauty and the cultural, intellectual and spiritual values derived from nature. Finally, *preservation of the option* to use these (or new) services in the future is also an important service in itself (Daily and Dasgupta, 2001, In: Levin, S. (ed.) *Encyclopedia of Biodiversity*, Vol. 2, Academic Press, London, New York, pp. 353–361).

Participating scientists: *J. Baumgärtner, M. Bieri*

Work in progress

The case study consisted of 720 patches composed of 361 fruit trees, some small apple plantations and 359 hedgerow point measurements, display 258,840 connections and yield connectivity indices for dispersal coefficients of little mobile birds and butterflies, respectively. Four strategies to place 75 additional trees for connectivity enhancement have been evaluated. They all lead to higher overall connectivity relative to the current connectivity, but the establishment of an orchard provides the highest gain in relative connectivity. The second best result is obtained by randomly placing the trees into open agricultural land. The strategy of planting the trees for shade provision along roads and paths yields a result similar to a strategy with placement of trees on transects through open agricultural land. The strategy of planting trees along paths and roads is preferred since interference with agricultural activities is minimal. In a metapopulation context, the connectivity for representative taxa should be seen as a necessary but insufficient parameter for species conservation purposes in particular and biodiversity augmentation in general.

The encouraging results obtained in this work can be seen as a further confirmation of the validity of Mitsch and Jørgensen's observation (2004: *Ecological Engineering and Ecosystem Restoration*. Wiley, New York) that ecological engineering has now matured to a point where it needs to have a prescriptive rather than descriptive aspect.

The project was concluded in 2005, but is the basis for the following species conservation project.

Output

A publication on fruit tree ecosystem service provision and enhancement has been written.

Metapopulation Dynamics and Management. II. Application of Information Theoretics to Species Conservation as Case Study

Background, approach and objectives

The first objective of the Population Ecology and Ecosystem Science Department project is to overcome the limitations of frequentist approaches and introduce information theoretics methods into study and management (see *Ecological Applications* 16, 1–116). This is important since traditional statistical inference methods applied to data from designed experiments seriously restrict work in modern ecology.

The second objective is to make available a methodology that allows study and management of metapopulations consisting of a group of spatially separated populations of the same species which interact at some level. Many species at risk of extinction suffer from decreasing abundance and deteriorating habitats. In fact, the degree of habitat fragmentation and the quality of environments that connect the habitats become critical factors for species persistence. Metapopulation models with explicit spatiality can consider combined environmental effects and hence, are useful for representing the dynamics of populations. Nevertheless, these models are rarely studied with respect to derivation of useful indices for evaluation of population conservation strategies. Some of the model features including the duration until the expected extinction or the capacity of metapopulation persistence have serious limitations that constrain model use for the evaluation of different management options. In this work, we apply an incidence function model (IMF) for the amphibians *Bufo bufo* and *Rana temporaria* and focus on the direct comparison of the estimated incidence associated with different intervention scenarios. For this purpose, we suggest an approach based on the Kullback-Leibler information, a quantity which is well-known in statistics but has only been recently used in ecology.

Collaborators: *J. Baumgärtner; G. Gilioli, Università Mediterranea di Reggio di Calabria, Italy; A. Bodini, Consiglio Nazionale per le Ricerche, Istituto di Matematica Applicata e Tecnologie Informatiche, Milano, Italy; J. Hartmann, Amt für Natur und Umwelt, Chur, Switzerland*

Assisted by: *P. Weidmann, Atragene Fachgemeinschaft für Standortskunde und Oekologie, Chur, Switzerland*

Work in progress

The combination of a metapopulation model with the Kullback-Leibler (KL) information is illustrated by the evaluation of intervention strategies aiming at the conservation of amphibians in the alpine Rhine valley (Canton of the Grisons, Switzerland). The *KL* information resulted to efficient ranking of conservation strategies obtained in cases where the Incidence Function Model (IFM) was applicable. Importantly, the method is readily applicable to the results of other models that produce scenarios for further evaluation. The existing data allowed us to rapidly analyse the actual situation and make suggestions for conserving two species out of a community of 6 species. Noteworthy, one of the two (*B. bufo*) is seen as endangered in the region, and rapid interventions may change this state.

The results are expected to allow rapid evaluation of methods for species conservation and permit strategy ranking on solid quantitative ground for discussion among a wide array of stakeholders. In this context, we recommend the improvement of data collection and the establishment of a monitoring system that (a) provides time series data that allow continuous assessment of the state of the population with particular reference to risk of extinction, (b) permits continuous evaluation of possible conservation strategies, and (c) allows revision and possible corrections of management procedures as the project evolves. These activities fall into the adaptive management system that continuously improves the understanding of the system and produces more efficient decision support tools.

The encouraging results obtained are seen as a further confirmation of the validity of Mitsch and Jørgensen's observation (2004: *Ecological Engineering and Ecosystem Restoration*. Wiley, New York) that ecological engineering has now matured to a point where it needs to have a prescriptive rather than descriptive aspect.

The results also demonstrate the opportunities provided by information theoretics and the need to go beyond traditional approaches of controlled experiments and statistical inference methods.

Output

The project was concluded in 2005, and a paper has been submitted to a high ranking and refereed ecological journal. The work is the basis for ongoing work on metapopulation models and information theoretics approaches to study and management of pest metapopulations. Moreover, a concept note has been written for mammal population conservation in the lower Tana river area, Kenya.

Conferences attended

GRASPA (Gruppo di ricerca per le applicazioni della statistica ai problemi ambientali) Conference 2005, 21–30 April, Bertinoro, Italy. Attended by: J. Baumgärtner, A. Bodini and G. Gilioli.

Società Italiana di Ecologia. Congresso Nazionale, Torino. 12–14 September, 2005, Università degli Studi e Politecnico. Attended by: G. Gilioli, A. Bodini, J. Baumgärtner, P. Weidmann and J. Hartmann.

H. Gut Symbionts of Termites

Bacterial Diversity in the Intestinal Tracts of Fungus-Cultivating Termites *Macrotermes michaelseni* (Sjöstedt) and *Odontotermes somaliensis* (Sjöstedt)

Background, approach and objectives

Termites are an important group of insects that harbour a complex community of gut microbes, which contribute to digestion, termite nutrition and gas (methane, carbon dioxide and hydrogen) emission. The abundance of microbial communities in the intestinal tracts of two fungus-cultivating termites *Macrotermes michaelseni* (Sjöstedt) and *Odontotermes somaliensis* (Sjöstedt) were investigated by the Molecular Biology and Biotechnology Department using plate counts. Diversity was assessed by DNA fingerprinting using restriction digestion and sequencing of the 16S ribosomal DNA (rDNA) genes and the identity of the microbes determined by comparison of these sequences with those in public databases.

Participating scientists and student: *W. Lwande, E. Osir, H. Boga[1], A. Muigai[2], G. Toledo[3], M. Keller[3], L. Makenzi*

Donor: *Diversa Corporation, San Diego, USA*

Collaborators: *[1]Jomo Kenyatta University of Agriculture and Technology, [2]Kenya Wildlife Service, [3]Diversa Corporation*

Collaborating department: *Molecular Biology and Biotechnology Department*

Work in progress

1. *Harnessing resources in symbiotic microbial communities for research and development*

Counts based on most probable number (MPN) showed that there were on average >10,000 cells of *Macrotermes michaelseni* (Sjöstedt) and ~500 of *Odontotermes somaliensis* (Sjöstedt) per termite gut. Both termite species contained bacteria of genera *Proteobacteria*, *Cytophaga-Flexibacter-Bacteroides*, some low G+C gram-positive bacteria, *Anaerobaculum thermoterrenum* and spirochetes. Some unique sequences showing very low similarity to known 16S rDNA were also found. The results reveal an enormous diversity of bacteria in both termite species, some species that were unique to the two species, and many new uncultured species unknown to microbiologists.

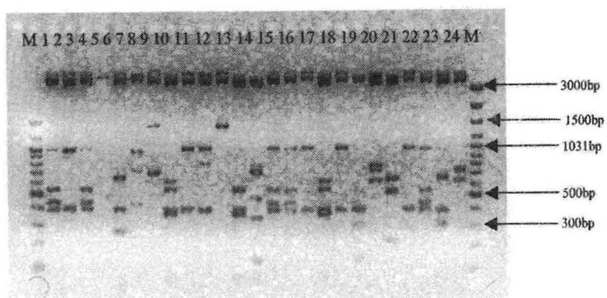


Figure 1. Fingerprinting of recombinant plasmid clones containing the 16S rDNA gene using a cocktail of 6 restriction enzymes. M, DNA size marker; lanes 1–24, individual plasmid clones showing restriction patterns generated after digestion

Figure 1 shows an example agarose gel of recombinant plasmids containing the 16S rDNA digested with a cocktail of 6 enzymes, with both unique and similar fingerprints displayed.

Capacity building

PhD student

L. M. Makenzi (Kenya) Diversity of microorganisms in the intestinal tracts of fungus-cultivating termites *Macrotermes michaelseni* (Holmgren, 1909) and *Odontotermes somaliensis* (Holmgren, 1912). Jomo Kenyatta University of Agriculture and Technology, Kenya (completed).

I. Insect Identification Services

Insect Identification and Taxonomic Information Services

Background, approach and objectives

The Biosystematics Support Unit laboratory combines services and research activities in providing the necessary taxonomic support for *icipe* activities and to a lesser extent to other institutions. The laboratory provides basic taxonomic infrastructure at *icipe* to support both identification and targeted taxonomic research. This infrastructure includes a reference collection, literature, laboratory facilities and expertise at research and technical levels. The laboratory also provides networking to the world taxonomic community. The objectives are to provide quality identification and information services to *icipe* and other institutions, and to provide research capacity to resolve taxonomic problems as needed such as the morphological and molecular studies of the recently detected invasive fruit fly species, *Bactrocera invadens*, which is currently underway.

Participating scientist: *M. K. Billah*

Assisted by: *J. N. Gitau*

Collaborators: *Primary in-country collaboration is with the National Museums of Kenya, while primary external collaborations are with the Natural History Museum, London, Royal Museum of Central Africa, Tervuren, Belgium and the Plant Protection Research Institute, Pretoria, South Africa. The BSU has also established a network of taxonomists in the following institutions who collaborate in the identification of specimens: Kenya Agricultural Research Institute; Coffee Research Foundation, Kenya; Plant Protection Research Institute, Agricultural Research Council, South Africa; CAB International, London, UK; Texas A&M University, USA; South Africa Museum, Cape Town; Wageningen Agricultural University, The Netherlands and the Royal Museum of Central Africa, Tervuren, Belgium*

Table 1. Summary of identification services in 2004–2005

Project/Client	No. of specimens
AFFI	
icipe Activities	109,158
Uganda	51,693
Kenya	5406
Tanzania	3795
Ghana	1571
Zanzibar	2567
Nigeria	373
Ethiopia	295
Madagascar	143
Sudan	63
Sri Lanka	440
India	1910
AFFI subtotal	**177,414**
Stemborer Group	
icipe Activities	20,823
Uganda	3321
Tanzania	3230
Malawi	1973
Zimbabwe	1768
Zambia	452
Cameroon	200
Ethiopia	20
WAU subtotal	**31,787**
Commercial Insects Programme	148
CIP subtotal	**148**
Other Institutions	
Indu Farm	432
Oserian Development Company	46
Other institutions subtotal	**478**
Total no. of specimens	**209,827**

Work in progress

Over 209,000 specimens were identified for various clients and projects as in Table 1. The fruit fly collection has been maintained and databased as in Table 2.

The following donations have been received or donated to other institutions:

- 100 *Ceratitis rosa* specimens to Australia through the Director General's office;
- 57 *Bactrocera invadens* specimens to AREU, Mauritius to help in the quick identification of the invasive species;
- 51 *B. zonata* from AREU, Mauritius for incorporation into AFFI/*icipe* collection.

Table 2. Summary of fruit fly collection and database

Status	No. of specimens
Dry accessioned entries	9312
Wet accessioned entries	244,059
Total database entries	253,371
Accessioned, but not entered	135,731
Total accessioned specimens	389,102
Identified, but not accessioned	477,414+

Capacity Building and Institutional Development

Capacity and Institution Building in Insect Biosciences

Background, approach and objectives

No meaningful difference can occur in the lives of target beneficiary communities, unless capacity needs of the various players in the development continuum are identified and addressed and the weak links between the institutions are strengthened. It is for this reason that *icipe*'s Capacity Building and Institutional Development Programme (CB&ID) works to build capacity through research training so as to enhance the acquisition and application of knowledge, strengthening of skills and the changing of mindsets. The programme's main goal is to capacitate individual researchers and institutions in Africa to initiate problem-solving research and development activities, and by including marginalised groups such as women and the youth empower communities to adopt and utilise eco-sustainable technologies for integrated development.

To meet this goal, the CB&ID programme's focal activities are focused on building human resource capacity in insect science and related areas, that is well trained, highly motivated and able to respond to the arthropod-related development needs of the African constituency.

One of the key elements of the training programme is the emphasis on 'hands-on' experience and regular contact with the target communities, be it through training of farmers or training of trainers (ToT) and extension workers. *icipe* believes that this contact is pivotal in ensuring that the training remains relevant and that the trainees are aware of the pressing on-the-ground problems of technology implementation and adaptation in Africa.

The capacity building programme activities are complemented by collaborative arrangements with universities and research institutions in developed countries. The training programmes are structured along the following major thrusts:

- **Higher degree training** for leadership in scientific research and policy formulation. The postgraduate training is held at PhD and MSc levels through the African Regional Postgraduate Programme in Insect Science (ARPPIS) and the Dissertation Research Internship Programme (DRIP).

- **Non-degree training** mainly targeted to practitioners in the national agricultural and health research and extension systems;
- **Professional development programmes,** where postdoctoral fellows, research associates and visiting scientists come to *icipe* to develop and share expertise; and
- **Interactive on-site training,** through collaborative research work carried out with *icipe*'s national partners.

Participating staff: *icipe's capacity building activities are implemented by staff in various programmes and projects, and coordinated through the CB&ID programme, under the general guidance of the Director of Research and Partnerships, Professor Onesmo ole-MoiYoi.*

(i) Research supervision and training: icipe scientists based in the various programmes as indicated in Tables 1 and 2.

(ii) Oversight of student affairs: Through icipe's Board of Training and Postgraduate Studies. Appointed in February 2005, the Board composed of Dr Ian Gordon, Head of Environmental Health Division, icipe (Chair); Prof. Achola Pala, Head of Social Sciences Department, icipe (Vice Chair); Prof. Penina Aloo-Obudho, Chairman, Department of Biological Sciences, Kenyatta University; Dr Esther Kioko, Scientist, Commercial Insects Programme, icipe; Mr Willis Awori, Human Resources Manager, icipe; Dr Markus Knapp, Project Coordinator, Tomato Red Spider Mite Project, icipe; Dr Josephat Shililu, Scientist, Human Health Division, icipe; Dr Sunday Ekesi, Scientist, African Fruit Fly Initiative/Arthropod Pathology Unit, icipe; Dr J. P. R. Ochieng'-Odero, Network Coordinator, ARPPIS and Head, Capacity Building and Institutional Development Programme, icipe; Ms Lucy M. Theuri, Assistant Programme Manager, Office of the Director of Research and Partnerships, icipe; Ms Lillian Igweta, Training Officer, icipe (Secretary to the Board); Dr Ellie O. Osir (February–July, 2005); Dr Slawomir A. Lux (February–June, 2005).

(iii) Office coordination/secretariat to ARPPIS: Programme coordination activities are provided through J. P. R. Ochieng'-Odero (Overall Network Coordination), L. M. Theuri (Administrative Function), L. Igweta (Training and Logistics), L. A. Omondi (Secretarial and Documentation Services), M. Ochanda (Clerical Services).

Donors: *icipe's training programmes, which include the network activities of ARPPIS, are funded through a consortium of donors. These include the German Academic Exchange Service, the Dutch Programme for Cooperation with International Institutions (Netherlands-SII), the Kirkhouse Trust of the United Kingdom, the International Centre for Scientific Culture-World Laboratory of Switzerland who provide fellowships. Other donors providing support to the training programmes include Dupont Aid to Education, Gatsby Charitable Trust, IFAD, IFS, NIH, Singeberg Foundation, Rockefeller Foundation and WHO-MIM/TDR.*

Collaborators*: The University members signatory to ARPPIS are the main collaborating partners in implementing the postgraduate training programmes. These include universities in the following countries:* ***Cameroon:*** *Dschang;* ***Egypt:*** *Assiut;* ***Ethiopia:*** *Addis Ababa, Alemaya;* ***Ghana:*** *Cape Coast, Ghana;* ***Malawi:*** *Malawi;* ***Kenya:*** *Egerton, Jomo Kenyatta University of Agriculture and Technology, Kenyatta, Maseno, Moi, Nairobi;* ***Namibia:*** *Namibia.* ***Nigeria:*** *Ahmadu Bello, Enugu State, Ibadan, University of Agriculture Makurdi, Nnamdi Azikiwe, Ogun State, Rivers State University of Science & Technology;* ***South Africa:*** *Pretoria, North West University;* ***Sudan:*** *Gezira, Khartoum;* ***Rwanda:*** *National University of Rwanda;* ***Tanzania:*** *Sokoine University of Agriculture;* ***Uganda:*** *Gulu, Makerere;* ***Zambia:*** *Zambia;* ***Zimbabwe:*** *Zimbabwe.*

Other collaborators include national research organisations in African countries signatory to the icipe Charter, international agricultural research centres, academies of science and networks such as the Third World Academy of Sciences, Third World Organization for Women in Science, African Network for Agriculture, Forestry and Environment Education and Forum for Agricultural Research in Africa programme on Building Africa's Scientific and Institutional Capacity for Agriculture and Natural Resources

Work in progress

1. *Postgraduate training*

The African Regional Postgraduate Programme in Insect Science (ARPPIS)

ARPPIS continues to be the major regional training framework for building human capacity aimed at providing leadership and policy inputs in the area of insect biosciences. The success of this innovative programme is predominantly due to the fact that it combines the excellence of *icipe*'s research and development agenda with the academic experience of its 31 partner African universities. With very few exceptions, ARPPIS graduates have remained to work in Africa. A number of alumni have risen to policy-influencing positions and have maintained linkages with *icipe* through the ARPPIS Scholars Association (ASA). These advances have been achieved despite the continent's loss of human resource capability through 'brain drain'. The success of the ARPPIS programme has resulted in an annual increase in demand for postgraduate training with requests coming from around the continent.

(i) Strengthening and revitalising the ARPPIS Network

Following the recommendations of the Strategic Review of *icipe* regarding aspects of the capacity building programme needing attention, the programme initiated early in 2005 a close consultation process with its university network partners to determine strategies for strengthening and revitalising the entire network including the sub-regional MSc centres serving East, West and Southern Africa. The ultimate aim is to strengthen the universities' role as capacity building 'agents of change' in the context of contributing to meeting appropriate Millennium Development Goals (MDGs) through implementing training programmes in insect biosciences.

The three major areas targeted for improvement are:

- ***Enhancing university participation in the network:*** Within the framework of the ARPPIS arrangement, participating African universities have played largely administrative and facilitative roles in the past. There was need therefore to revise the programme structure to enable the partner universities be more active participants in the conception of student research projects and student supervision, as well as in providing facilities for a substantial part of student research activities at the universities.
- ***Modernising the curricular and teaching methodology:*** Building university capability to offer quality higher education, especially in the area of biosciences is a major preoccupation of the programme. Strengthening the postgraduate training programme therefore needs to incorporate inter-linkages between key disciplinary competencies including modern approaches in population ecology and ecosystems science, genomics, computational biology, socioeconomics, behavioural and chemical ecology, conservation biology, biodiversity, insect pathology and environmental biology. This modernisation will significantly contribute to high-level trained brainpower, which will in turn undertake further training and hence sustain quality postgraduate training.
- ***Facilitating information access:*** Since the universities have listed capacity limitations in terms of ready access to scientific information, especially journals, there is need for *icipe* to facilitate the provision of online journals access to the universities participating in its training networks, as a way of building institutional capacity to undertake research, and hence contribute to solving critical national and regional problems.

As a result of the above, and in an effort to develop a revitalisation and capacity strengthening strategy, two key meetings related to ARPPIS were held in 2005. Based on outcomes of discussions at these two meetings, the following were identified as key areas that are being addressed in the revitalisation of the training programme:

- ***Enhancing university participation:*** The *icipe* Board of Training and Postgraduate Studies (IBTPS) discussed modalities of enhancing university participation in ARPPIS. Based on wide consultations, the Board has implemented a number of changes in the operation of the ARPPIS training programmes in a number of key aspects, especially:

- More participation of universities in student selection to PhD programmes;
- Improvement in the quality of supervision;
- Timely thesis examination; and
- Enhanced collaboration in *icipe*'s programmes resulting in the devolvement of more research and training activities to the universities.

- ***Ensuring sustainability of the network:*** Since funding continues to be the biggest and most immediate threat to the sustainability of ARPPIS, the establishment of long-term fund mobilisation plan and the diversification of the resource base are of high priority. Proposals were made on cost areas where the universities can make significant contributions, especially in respect to tuition and management-related costs in implementing the ARPPIS academic programme. Discussions are ongoing with the university partners on how they can contribute, especially through fee waivers.
- ***Providing institutional strengthening support to the university partners:*** In response to demand, and in an effort to strengthen university capacity to undertake research in insect biosciences, *icipe* has been requested to develop an institutional strengthening component, based on maximising complementary partnerships to contribute to the long-term revitalisation of university capability to offer quality higher education. The project component will assist in modernising the teaching of insect biosciences by integrating the newer approaches and scientific discoveries into the curricula. Initially, focus will be on building research and training capability of four carefully identified universities by providing key institutional support to upgrade research and training facilities, staff development, and communication capacity. It is expected that this intervention will significantly contribute high-level trained brainpower, which will in turn undertake further training and hence sustain quality postgraduate training. The project is expected to serve as a model that can be replicated in the other collaborating universities in future programmes. Since this institutional strengthening intervention essentially builds on complementary partnerships, the determination of the willingness of the universities to cost-share in the long-term running of the programme is critical.
- ***Modernising and upgrading the Network programmes:*** A specific institutional strengthening initiative to assist the partnering universities build up capacity that enables them to effectively utilise online digital resources for postgraduate training and research in insect biosciences was proposed and approved. Modalities of implementation and funding are being worked on, but will incorporate aspects of open and distance learning (ODL).

(ii) University membership in ARPPIS

During 2004 and 2005 the membership of the ARPPIS participating universities rose to 31. The new members are:

- Gulu University (Uganda)
- North West University (South Africa)
- Maseno University (Kenya)
- University of Namibia (Namibia)

(iii) Award of regional training fellowships

During 2004 and 2005, nineteen (19) PhD scholarships under the ARPPIS programme were awarded (See Table 1).

Fifteen (15) MSc scholarships were provided to the West Africa ARPPIS Sub-Regional Centre based in University of Ghana and two (2) to the southern Africa Centre based in the University of Zimbabwe.

(iv) Introductory coursework for ARPPIS

The ARPPIS programme has initiated a mandatory introductory coursework programme for scholars to update them of advances and new frontiers of knowledge. The need to have the introductory courses was necessitated by the fact that scholars come from a variety of educational backgrounds and gaps had been noted when the scholars began their research work. These courses are structured as lectures, practicals and seminars in a number of areas and are categorised in two groups:

Between September–December 2005, three short courses were held. Basic Taxonomy and Systematics, Biostatistics including introduction to statistical software and Science Writing, Communication and Oral Presentation Skills were conducted by resource persons drawn from *icipe*, National Museums of Kenya (NMK) and universities within Nairobi.

Essential courses	Additional courses
Basic Taxonomy and Systematics	Chemical Ecology
Biostatistics	Principals of Integrated Pest/Vector Management
Science writing and communication	Bioinformatics
	Functional and Population Ecology
	Project Management
	IT and Access to Online Digital Resources

The Dissertation Research Internship Programme (DRIP)

The Dissertation Research Internship Programme (DRIP) is a complementary programme to ARPPIS, offering PhD and MSc degree training for students registered in universities anywhere in the world. Funding for the student's scholarship and research comes either from a sponsor or from one of *icipe*'s projects. *icipe* provides the students with research projects and facilities as well as supervision. It is a highly flexible programme that has no limitation on age or nationality. Nine (9) PhD and twenty-five (25) MSc scholarships under the DRIP programme were awarded in 2004 and 2005 (see Table 2).

2. *Non-degree training*

Technology dissemination to NARES through group training courses

Technology dissemination to the national system through the extension and education establishments working in various areas (health, agriculture, livestock or environment) is a critical function of research institutions with a mandate to build national capacity. Over the years, the capacity building programme has hosted a scheme that sponsors Africa-wide Group Training Courses and Workshops for technologists and practitioners of national programmes. These courses specifically aim to disseminate integrated pest/vector management (IPVM) technologies to people on the ground by educating extension personnel and end users of the available technologies. The courses also offer a forum to appraise national policy-making personnel on current methodologies and arthropod diversity issues to facilitate decision-making for development planning. The ultimate aim is to enable the beneficiaries of the courses to effect technology transfer through training of trainers (ToT). Impact is, therefore, achieved through a multiplier effect. The courses run for 3–6 weeks and are held either at *icipe* or in any country in Africa, in collaboration with a locally based national or international institution. The courses are designed to be application-oriented, and include laboratory and field components as well as hands-on demonstrations. National authorities undertake nomination of course participants as part of their role in this collaboration.

An International Group Training Course on Fruit Fly Management, was held on 17 to 28 October 2005 in Nairobi, Kenya. Twenty-eight participants drawn from Kenya, Tanzania (Mainland and Zanzibar), Uganda, Sudan, Benin, Nigeria, Mozambique, Mauritius and South Africa attended the meeting. The course was designed to build national and regional capacity in various aspects of fruit fly management to enable quick, timely and efficient response to the numerous challenges imposed by the fruit pests. This was a co-sponsored activity with the African Fruit Fly Initiative (AFFI) with funding from IFAD.

Short-term internship programme

icipe believes that classroom learning alone is not enough, and hence provides undergraduate students and trainees from various colleges with the opportunity to put theory into practice in the area of insect biosciences.

The trainee is provided with training assignments together with facilities and materials necessary for the work. A supervisor is nominated to develop the training programme, coach the trainee, give intellectual guidance and assist in evaluating performance. Facilities are provided for the preparation of the post-training report, which must be submitted before departure.

During the period 2004–2005, a total of 91 students were awarded short-term internships for periods ranging from 3–6 months. These students came from African universities (32), polytechnics (45), collaborating institutions in Africa (2) and from other collaborating institutions from outside the continent (12).

3. Professional development programmes

The Postdoctoral Fellowship Programme

The professional development programmes at *icipe* allow doctoral and postdoctoral scientists to advance their careers in diverse fields in arthropod science in an international research environment.

Two postdoctoral fellows joined *icipe* during the reporting period. Dr Ben Jacobs from the University of Illinois joined in May 2005 to undertake research work on anopheline mosquitoes funded by the NIH. Dr Laure Weisskopf joined in September 2005 from the University of Neuchatel, Switzerland to study the effects of lupin on striga, under sponsorship of the Swiss National Science Foundation.

Output

Conferences attended

African Technology Policy Studies Network (ATPS) Policy Dialogue, 12 January 2004, Nairobi, Kenya. Attended by: J. P. R. Ochieng-Odero.

Nairobi Workshop on Canada–Africa Collaboration in Higher Education, 12–13 February 2004, Nairobi, Kenya. Attended by: J. P. R. Ochieng-Odero and O. K. ole-MoiYoi.

Workshop on National Science and Technology Policy, 17–18 February 2004, Nairobi, Kenya. Attended by: J. P. R. Ochieng-Odero.

28th Meeting of the Committee of Directors of ASARECA, 23–24 February 2004, Nairobi, Kenya. Attended by: O. K. ole-MoiYoi.

Annual Meeting of the European Association for International Education, 15–17 September 2005, Krakow, Poland. Attended by O. K. ole-MoiYoi.

First Regional Conference of Vice Chancellors, Provosts and Deans of Science Engineering and Technology, 14–17 November 2005, Accra, Ghana. Attended by: J. P. R. Ochieng-Odero.

Conferences organised

Planning Meeting of the ARPPIS Sub-regional Coordinators, 20–21 June 2005, Nairobi, Kenya.

A Satellite Planning Meeting of the ARPPIS Scholars Association (ASA), 20–21 June 2005, Nairobi.

32nd meeting of the ARPPIS Academic Board, 3–4 October 2005, Nairobi, Kenya.

Proposals

Promoting Women Participation in Postgraduate Research Training in the Biosciences: A Gender Analysis of the African Regional Postgraduate Programme in Insect Science (ARPPIS) May, 2005. Submitted to Rockefeller/FAWE.

Building Institutional Capacity for Postgraduate Research and Training in the Biosciences November, 2005 submitted to UNESCO.

Impact

The success in the implementation of capacity building programmes is ultimately gauged by its impact. The impact can be gauged through a number of indicators, but largely through its ability to capacitate national programmes to engage in further capacity building, thereby replicating the output of the initial investments. In terms of human resource capacity, it is the creation and retention of a new generation of scientists that will ultimately generate the multiplier effect resulting in longlasting impact. However, merely increasing the number of trainees is not the only factor in the equation. If training programmes are to make a significant impact, they must take a critical and holistic view of all the factors that continually erode and threaten individual and institutional capacity. These include a deteriorating infrastructure, lack of trained human resources, inadequate funding, isolation of African scientists from innovative work carried out elsewhere, and poor remuneration. All these factors must be addressed to stem the 'brain drain' phenomenon that continues to deprive African institutions of the much-needed human resource base.

From a perspective of building human resource capacity, *icipe*'s training programmes have significantly increased the numbers of trained scientists and practitioners in insect science. As at the end of 2005, some 180 PhD students from 29 African countries had been trained since the inception of ARPPIS. Through the sub-regional centres of ARPPIS based in Harare, Accra and Addis Ababa some 120 students had received training at MSc level. In addition, a further 235 postgraduate students have been trained from other countries through the Dissertation Research Internship Programme (DRIP). Partner institutional capacity has been built by awarding of research grants and 're-entry' grants to newly graduated ARPPIS alumni. The success of this innovative programme is predominantly due to the fact that it combines the excellence of *icipe*'s R&D agenda with the academic experience of its partner African universities. With very few exceptions, *icipe*'s graduates have remained working in Africa. A number of graduates have risen to policy-influencing positions within their governments and have maintained linkages with *icipe* through the ARPPIS Scholars Association (ASA).

In implementing its capacity building programmes, *icipe* begun discussing with its university partners a framework for strengthening of institutional capacity to deliver quality training programmes, in two major aspects:

- Availing specialised research equipment and facilities to network universities through:
  - Upgrading the research laboratories both at *icipe* and the universities;
  - Upgrading communication and IT support structures; and
  - Modernising and equipping the central ARPPIS information resource centre.
- Providing more support for staff training, infrastructure maintenance and collaboration.

A needs-assessment exercise has been carried out for universities participating in the ARPPIS network, and their response is being analysed with a view to developing a joint proposal for funding.

Table 1. ARPPIS Postgraduate Research Fellows, 2004–2005

Name	Class, Donor	Title of Thesis	ICIPE Supervisors	University Supervisors	Registered University
Eric B. Kouam (Cameroon)	2004, DAAD	Cowpea (*Vigna unguiculata*) gene pool organisation and wild-crop complex dynamics	Dr Rémy Pasquet	Dr Geoffrey Muluvi	Kenyatta University, Kenya
Simon M. Muriu (Kenya)	2004, DAAD	Impact of vector control on malaria transmission in a riceland ecosystem	Dr Josephat Shililu Dr John Githure	Prof. Lucy Irungu	University of Nairobi, Kenya
Susan Sande (Kenya)	2004, DAAD	Beekeeping and forest conservation: A case study of Arabuko-Sokoke forest, Kenya	Dr Suresh Raina Dr Ian Gordon	Prof. Robin Crewe Prof. Sue Nicholson	University of Pretoria, South Africa
Ivan Rwomushana (Uganda)	2004, DAAD	Bioecology of the new invasive *Bactrocera invadens* (Diptera: Tephritidae) and its interaction with indigenous fruit fly species	Dr Sunday Ekesi Dr Ian Gordon	Dr Callistus Ogol	Kenyatta University, Kenya
Steven G. Nyanjom (Kenya)	2004, Netherlands-SII	Characterisation of tsetse olfactory receptor proteins associated with repellency; the use of functional genomics and ligand-protein binding studies	Prof. Ahmed Hassanali	Dr Peter Lomo Dr Daniel Masiga	Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya
David B. Mugisho (Democratic Republic of Congo)	2004, Netherlands-SII	The potential of pathogenic fungi in the control of economically important spider mite species	Dr Markus Knapp Dr Nguya K. Maniania	Dr Hamadi Boga	Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya
David M. Mwangi (Kenya)	2004, Netherlands-SII	Mechanism of fungus-avoidance behaviour of termites and identification of the mediating signals	Prof. Ahmed Hassanali Dr Nguya K. Maniania	Dr Linus Gitonga Dr Mary Ndung'u	Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya
Wycliffe Wanzala (Kenya)	2004, Netherlands-SII	Evaluation of the effects of natural products used for the management of tick infestation on livestock by the Bukusu people of western Kenya	Prof. Ahmed Hassanali	Dr Wolfgang Mukabana (University of Nairobi) Dr Willem Takken (Wageningen University)	University of Nairobi in collaboration with Wageningen University
Norber Mbahin (Cameroon)	2004, DAAD	The ecology and economic potential of the wild silkmoth *Anaphe panda* (Biosduval) in the Kakamega forest of western Kenya	Dr Suresh Raina Dr Esther Kioko	Prof. Jones M. Mueke	Kenyatta University, Kenya
Duna M. Mailafiya (Nigeria)	2005, DAAD	Assessment of the diversity, ecological preference and potential of natural enemies associated with indigenous lepidopteran stemborers in Kenya	Dr Bruno Le Ru Dr Fritz Schulthess Dr Paul-Andre Calatayud Dr Stephane Dupas	Dr Eunice Kairu	Kenyatta University, Kenya
Lefulesele N. Lebesa (Lesotho)	2005, DAAD	Control of blister beetles on *Desmodium* spp. by understanding visual cues and chemical ecology	Dr Zeyaur Khan Prof. Ahmed Hassanali	Dr Kirsten Kruger	University of Pretoria, South Africa
Fathiya M. Khamis (Kenya)	2005, DAAD	Comparative studies on the morphological and genetic diversity of a new *Bactrocera* species in its aboriginal home and in Africa	Dr Sunday Ekesi Dr Maxwell Billah	Dr Daniel Masiga	Kenyatta University, Kenya
Henri Z. Tonnang (Cameroon)	2005, DAAD	Modelling of parasite–host system dynamics and its application to diamondback moth fluctuations	Prof. Lev Nedorezov Dr Bernhard Löhr	Prof. Horace Ochanda Prof. John Owino	University of Nairobi, Kenya
Meshack Obonyo (Kenya)	2005, DAAD	Basis of host recognition by the larval endoparasitoids *Cotesia flavipes* and *Cotesia sesamiae*	Dr Paul-Andre Calatayud Dr Fritz Schulthess	Prof. Johnnie Van Den Berg	North West University, South Africa

Table 1 continued

Name	Class, Donor	Title of Thesis	ICIPE Supervisors	University Supervisors	Registered University
Fening Okwae Ken (Ghana)	2005, DAAD	Behaviour and ecology of parasitoids of *Gonometa* species (Lepidoptera: Lasiocampidae) based on their host plants, and species diversity in Mwingi, Kenya	Dr Suresh Raina Dr Esther Kioko	Prof. Jones M. Mueke	Kenyatta University, Kenya
Khogali I. Idris (Sudan)	2005, DAAD	Development and evaluation of habitat management strategies for sorghum- and millet-based farming systems for drier areas of northern Africa	Dr Zeyaur Khan Prof. Ahmed Hassanali	Prof. Abdel G. Babikar Prof. A.M. Hamdoun	University of Gezira, Sudan
Faith J. Toroitich (Kenya)	2005, Netherlands-SII	Assessment of the biodiversity of African tetranychid mites using conventional and molecular taxonomic methods	Dr Markus Knapp	Prof. Pieter D. Theron Dr Eddie Ueckermann Dr Maria Navajas	North West University, South Africa
Felix Nchu (Cameroon)	2005, Netherlands-SII	Development of formulations and delivery systems for entomopathogenic fungi and botanicals for control of *Amblyomma variegatus*	Dr Nguya K. Maniania	Prof. Kobus Eloff	University of Pretoria, South Africa
Sabina W. Wachira (Kenya)	2005, Netherlands-SII	Identification of oviposition semiochemicals of *Anopheles gambiae* and exploration of their potential in control	Prof. Ahmed Hassanali Dr Peter Njagi	Dr Mary Ndung'u	Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya

Table 2. DRIP postgraduate research fellows (2004–2005)

Name	Duration	Sponsor	Title of Thesis	University of Registration	ICIPE Supervisors
(a) Training at PhD Level					
Ruth Kahuthia-Gathu (Kenya)	Jan 2004 to December 2006	BMZ	The role of wild crucifers in the management of diamondback moth and its parasitoids	University of Hannover Germany	Dr Bernhard Löhr
Elechi F. Asawalam (Nigeria)	November 2004 to May 2006	TWOWS	Evaluation of plant products for the control of *Sitophilus zeamais* "Motsch" (Coleoptera: Curculionidae) maize weevil	Michael Okpara University of Agriculture, Umudike, Nigeria	Prof. Ahmed Hassanali
Jane Gatune (Kenya)	November 2004 to October 2005	SIMA	An assessment of gender differences in prevention, treatment and impact of malaria in Mwea, Kirinyaga District	University of Nairobi, Kenya	Dr John Githure Prof. Ahmed Hassanali
Raphael Wanjogu (Kenya)	September 2004 to August 2005	SIMA	Alternating cultivation of rice and soybean as agroecosystem strategy for enhancing household incomes and reducing malaria-vector breeding habitats	University of Nairobi, Kenya	Dr John Githure Dr Josephat Shililu
Bonaventure O. Aman (Kenya)	January 2005 to December 2007	Kirkhouse Trust	Biological control of the larger grain borer	North West University, South Africa	Dr Fritz Schulthess
Benjamin Muli (Kenya)	July 2005 to June 2008	BMZ	The biology and ecology of the maize ear-borer *Mussidia* spp. (Lepidoptera: Pyralidae) and associated natural enemies in Kenya	North West University, South Africa	Dr Fritz Schulthess
Paddy Likhayo (Kenya)	August 2005 to January 2006	KARI	Isolation and purification of *Bacillus thuringiensis* (*Bt*) and development of assay protocol	Kenyatta University, Kenya	Dr Nguya K. Maniania
Solomon Asfaw (Ethiopia)	September 2005 to September 2006	BMZ	Economic impact of food safety standards on smallholder fresh export produce in Kenya: Linking contract farming, farmer health and rural poverty	University of Hannover, Germany	Dr Dagmar Mithöfer
Gounou Saka (Benin)	November 2005 to October 2006	BMZ	The performance of new and old association natural enemies on West African cereal stemborer species	University of Hannover, Germany	Dr Fritz Schulthess
(b) Training at MSc Level					
Betty Mbatia (Kenya)	January 2004 to December 2004	WHO/TDR	Functional genomics of tsetse–trypanosome interactions	University of Nairobi, Kenya	Dr Ellie Osir
Cecilia Nzau (Kenya)	February 2004 to February 2005	USAID	Application of modern biotechnology in agriculture: A risk assessment study on the effects of *Bacillus thuringiensis* (*Bt*) toxins on nodulation of the common bean, *Phaseolus vulgaris*	University of Nairobi, Kenya	Dr Ellie Osir
William Gichohi (Kenya)	March 2004 to December 2004	COLEACP-PIP -Dudutech	Evaluation of adaptation to climate regimes, host habitat preference and performance potential of *Trichogramma* species for commercial mass production in Kenya	Moi University, Kenya	Dr Srinivasan Sithanantham
Faith J. Toroitich (Kenya)	March 2004 to February 2005	BMZ	The susceptibility of the red spider mite *Tetranychus evansi* to commonly used insecticides and acaricides	University of Nairobi, Kenya	Dr Markus Knapp
Sopher Ondiako (Kenya)	April 2004 to March 2005	Rockefeller Foundation	The efficacy of entomopathogenic fungus *Beauveria bassiana* in the management of sweet potato weevil *Cylas puncticollis*, a pest infesting sweet potato (*Ipomoea batata*) tubers	University of Nairobi, Kenya	Dr Nguya K. Maniania

Table 2 continued

Name	Duration	Sponsor	Title of Thesis	University of Registration	ICIPE Supervisors
Jane W. Mwathi (Kenya)	May 2004 to April 2005	Rockefeller Foundation	Isolation and evaluation of local isolates of *Bacillus thuringiensis* against the larger grain borer (*Prostephanus truncatus*), a post harvest storage pest	Kenyatta University, Kenya	Dr Nguya K. Maniania
Meshack Obonyo (Kenya)	June 2004 to May 2005	DGIS	Performance of *Cotesia flavipes* (Hymenoptera: Braconidae) on stemborer species found on cereal crops and wild grasses	Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya	Dr Fritz Schulthess Dr Paul-Andre Calatayud
Nicholas A. Otieno (Kenya)	June 2004 to June 2005	IRD	Vegetation mosaic, diversity and abundance of wild host plants (Poaceae, Cyperaceae, Typhaceae) of lepidopteran stemborers in Kakamega forest and its environs (Kenya)	Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya	Dr Bruno Le Ru
James Kabii (Kenya)	September 2004 to September 2006	Diversa Corporation	Molecular phylogenetic characterization of symbiotic microbiota in the intestinal tracts of wild lepidopteran stemborer *Eldana saccharina* Walker (Pyralidae)	Kenyatta University, Kenya	Dr Wilber Lwande Dr Daniel Masiga
Gladys N. Mokua (Kenya)	September 2004 to September 2005	WHO	Phytochemical investigation of anti-larval activity of the genus *Vitex* (*V. payos* and *V. schiliebenii*) against *Anopheles gambiae*	Kenyatta University, Kenya	Prof. Ahmed Hassanali
Philip Ngumbi (Kenya)	October 2004 to September 2005	KEMRI	Experimental control of sandflies (Diptera: Psychodidae) using entomopathogenic fungi (hyphomycetes) in captivity and in the field	University of Nairobi, Kenya	Dr Nguya K. Maniania
Marion Gathumbi (Kenya)	October 2004 to September 2005	Self	Comparative performance of three mulberry varieties (*Morus* sp.) on silk cocoon and fibre quality in Central Province of Kenya	University of Nairobi, Kenya	Dr Suresh Raina Dr Vijay Adolkar
Onesmus Mutinda (Kenya)	November 2004 to October 2005	SIMA	An evaluation of the economic potential of rice–soya bean rotation	University of Nairobi, Kenya	Dr John Githure Dr Josephat Shililu
Peter Ng'ang'a (Kenya)	November 2004 to October 2005	SIMA	A study of factors affecting the implementation of malaria vector control measures in Mwea Division, Kirinyaga District	University of Nairobi, Kenya	Dr John Githure Dr Josephat Shililu
Fabrice Gern (Switzerland)	November 2004 to June 2005	University of Geneva, Switzerland	Investigating the extent to which bee-keeping activities under the GEF-ICIPE project benefit from the presence of the forest, using floral calendars, pollen analysis of honey quality and quantity in honey from hives at different distances from the forest	University of Geneva, Switzerland	Dr Ian Gordon
James Nonoh (Kenya)	January 2005 to December 2006	Dupont	Isolation, characterisation and identification of microorganisms from various habitats that suppress selected plant pathogens	Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya	Dr Wilber Lwande
Joan Awino (Kenya)	June 2005 to May 2006	AFFI/IFAD	The susceptibility of fruit flies species to *Metarhizium anisopliae* when reared on different mango varieties	Kenyatta University, Kenya	Dr Sunday Ekesi
Obadiah Mucheru (Kenya)	June 2005 to June 2006	Dutch Embassy (WAU Project) Netherlands	Host range and interspecific competition of two races of a tachinid parasitic fly	Kenyatta University, Kenya	Dr Fritz Schulthes Dr Nanqing Jiang
Delaide Mungai (Kenya)	July 2005 to June 2006	Netherlands-SII, Govt of New Zealand	Chemical signals mediating predation of spiders on mosquitoes	Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya	Dr Robert Jackson Prof. Ahmed Hassanali

Table 2 continued

Name	Duration	Sponsor	Title of Thesis	University of Registration	ICIPE Supervisors
Elizabeth Ouna (Kenya)	July 2005 to May 2006	IFAD/AFFI	Biological control of fruit flies using hyphomycetes fungi	Kenyatta University, Kenya	Dr Sunday Ekesi
Martina Koller (Austria)	August 2005 to January 2006	University of Vienna	Direct and indirect effect of the host plant on the performance of the predatory mite *Neoseiulus californicus* through the prey *Tetranychus evansi*	University of Vienna, Austria	Dr Markus Knapp
Lucia Akinyi Ouma (Kenya)	August 2005 to March 2006	Kenyatta University	Characterisation and expression of variant surface glycoprotein (VSG) genes in *Trypanosoma brucei rhodesiense* isolates from East Africa	Kenyatta University, Kenya	Dr Daniel Masiga
Leonard Kamaru (Kenya)	September 2005 to April 2006	SIMA	Economic assessment of alternating rice and soya bean cultivation at Mwea	University of Nairobi, Kenya	Dr Josephat Shililu Dr John Githure
Kai Mausch (Germany)	November 2005 to February 2006	BMZ	Impacts of EurepGAP standards on medium- and large-scale fruit and vegetable export produce in Kenya—A literature review and case studies	University of Hannover, Germany	Dr Dagmar Mithöfer
Kennedy Olwasi (Kenya)	December 2005 to September 2006	BMZ	Egg-laying behaviour, life-table statistics and parasitism of diamondback moth (*Plutella xylostella* L., Lepidoptera: Plutellidae) on commercial crucifer cultivars in Kenya	Egerton University, Kenya	Dr Bernhard Löhr

APPENDIX 1:

Animal Rearing and Containment Unit

Background approach and objectives

The Animal Rearing and Containment Unit (ARCU) provides cost-effective quality services from its insectaries, animal breeding and containment services to support research activities at *icipe* laboratories found at Duduville and at its *icipe*-Thomas Odhiambo campus at Mbita Point in western Kenya. Some services were provided to *icipe* collaborators including NARES, schools, and local universities. A number of students worked with ARCU as interns on attachment, and were assigned specific projects aimed at improving rearing techniques in relation to quality assessment and control. Performance of laboratory-reared insects and animals was monitored regularly to ensure that only those that met the stringent quality criteria were supplied for research.

The containment of introduced exotic organisms functioned through the provision of a functional Biologically Secure Laboratory Facility (BSLF). The facility is designed to facilitate the introduction and study of exotic natural enemies of insects and arachnid pests for use in classical biological control programmes at *icipe*, following approval by the Kenya Standing Technical Committee on Imports and Exports (KSTCIE); and also to prevent any accidental escape of these organisms from the facility. The unit, in liaison with the Kenya Plant Health Inspectorate Service (KEPHIS), assures that only biological control agents authorised for release in Kenya leave the BSLF. All other organisms that arrive with the shipment are destroyed by incineration.

Participating scientists: *J. P. R. Ochieng'-Odero, F. O. Onyango*

Assisted by: *J. H. Ongudha, J. W. Otsieno, M. M. Miti, A. Majanje, P. O. Wagara, A. G. Nyang'wara (Mbita-based), M. W. Gitau, J. A. Ojude, J. O. Kaleb, J. O. Ochieng*

Donors: *icipe core fund donors; project funding for various research projects provided by the Netherlands Government, IFAD, Gatsby Charitable Trust, Austrian Development Agency*

Collaborators: *NATIONAL RESEARCH INSTITUTES: Kenya Agricultural Research Institute; Kenya Medical Research Institute; Kenya Trypanosomiasis Research Institute; National Museums of Kenya; National Beekeeping Station, Kenya; Ministry of Agriculture and Rural Development, Kenya. UNIVERSITIES: University of Nairobi; Jomo Kenyatta University of Agriculture and Technology; Kenyatta University; Egerton University (Kenya); University of Newcastle upon Tyne (United Kingdom). INTERNATIONAL RESEARCH CENTRES: International Livestock Research Institute; International Maize and Wheat Improvement Centre. REGIONAL ORGANISATIONS: Desert Locust Control Organisation for Eastern Africa; International Red Locust Control Organisation for Central and Southern Africa*

Work in progress

Services rendered by the Unit were of three types, namely insectary, animal breeding, and containment.

1. Insectary Services

Insectary services involved the rearing and supply of both plant-feeding (phytophagous) as well as the blood-feeding (haematophagous) arthropods.

Cereal stemborers

During this period, four cereal stemborer species in culture were supplied for research and training. In Duduville, *Chilo partellus*, *Busseola fusca*, *Sesamia calamistis* and *Eldana saccharina* were reared on a large scale. At Mbita, small colonies of *C. partellus*, *B. fusca* and *S. calamistis* were maintained as a back-up to the Duduville cultures as well as to cater for the local demand. Moreover, sorghum (cv Seredo) and maize (cv Hybrid 513) were cultivated at Mbita and 6-week-old leaves processed into respective powders for compounding artificial diets for rearing all the stemborer species both at Duduville and Mbita.

In general, quantities of cereal stemborers supplied in 2005 reduced by 50% compared to 2004 (Figure 1). Nearly 70% of the stemborers supplied comprised eggs.

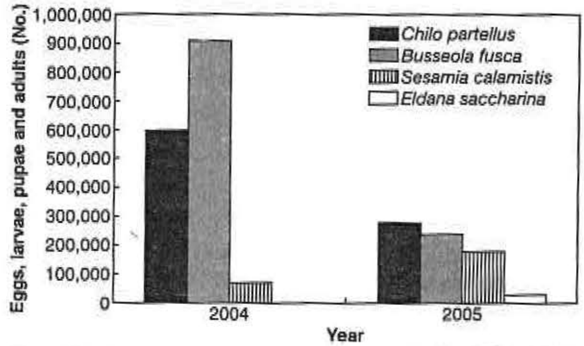


Figure 1. Quantities of cereal stemborers supplied in 2004/2005

- *Chilo partellus:* Quantities of *C. partellus* supplied to different research projects in 2005 was reduced by 50% compared to 2004. The demand for eggs increased in 2005 compared to 2004, while that of larvae and pupae decreased.
- *Busseola fusca:* The quantities of *B. fusca* supplied in 2005 decreased by 70% compared to that of 2004. Over 80% of the quantities supplied comprised eggs.
- *Sesamia calamistis:* Nearly three times more *S. calamistis* of assorted stages of development were supplied in 2005 compared to 2004. About 90% of these were eggs.
- *Eldana saccharina:* A small colony of the sugarcane borer *E. saccharina* was maintained in 2004/2005 to cater for incidental requests.
- Artificial diets: On average, about 7000 litres of artificial diet for rearing cereal stemborers was prepared during 2004/2005. Some of the diet was supplied to users for maintaining experimental insects as well as for bioassays. The remaining diet was used at the insectary for colony production and maintenance.

Desert locust

Two separate colonies of *Schistocerca gregaria* (ex-Sudan and ex-Addis) in their gregarious and solitary forms as well as *Locusta migratoria migratorioides* (ex-Senegal) were maintained at the Duduville insectaries. It is anticipated that the culture of *Locusta migratoria capito* will soon be introduced from Madagascar and maintained in the facility once importation protocols are formalised.

Mosquitoes

Three species of mosquitoes (Figure 2) were maintained at the Duduville insectaries. These were the malaria-causing *Anopheles gambiae* (Mbita strain) and *A. arabiensis* (Mwea strain) as well as the filariasis-causing *Culex quinquefasciatus*. The mosquitoes were fed either human or mice blood. The quantities of *A. gambiae* and *C. quinquefasciatus* supplied decreased in 2005 compared to 2004, though that of *A. arabiensis* slightly increased. More *A. gambiae* were supplied than any of the remaining two species.

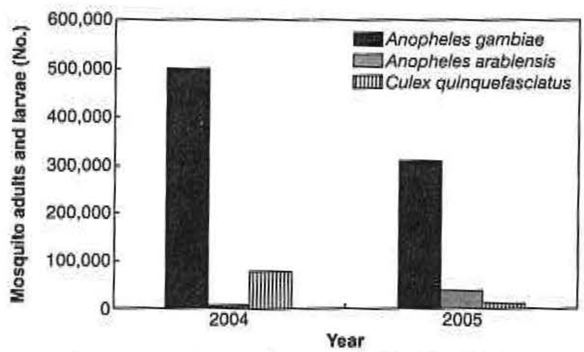


Figure 2. Quantities of mosquitoes supplied in 2004/2005

Tsetse flies

In 2004–2005, limited colonies of *Glossina fuscipes* and *Glossina morsitans* were maintained *in vitro* using pig blood procured from a local abattoir. The level of production was deliberately reduced due to the low demand from users. During the year, only a few pupae were supplied for student research in molecular biology. Rearing of *G. austeni* was phased out at the end of 2004 due to lack of demand for them.

Ticks

Tick rearing was terminated in July 2004. However, small cultures of *Rhipicephalus appendiculatus* and *Amblyomma variegatum* were initiated in 2005 due to demand. During 2005, about 1000 adult *R. appendiculatus* and *A. variegatum* were maintained. It is anticipated that the rearing of *R. evertsi* and *Boophilus decoloratus* will be initiated in the near future.

2. *Animal breeding services*

In 2004–2005, a small number of rabbits, mice and rabbits was maintained. The rabbits were used for maintaining tick colonies, the mice for feeding mosquitoes and the rats for tsetse research bioassays.

3. *Biologically Secure Laboratory Facility (BSLF)*

Cultures of exotic parasitoids maintained in the BSLF during 2004 included *Sturmiopsis parasitica* (from Benin via South Africa), *Diadegma mollipla* (from South Africa), *Telenomus isis* (from Benin) and *Cotesia plutellae* (separate cultures from Taiwan and South Africa). In August 2005, the predatory mite *Phytoseiulus longipes* of the red spider mite (RSM) *Tetranychus evansi* was introduced into the BSLF from Brazil. Arrangements are underway to introduce from Mexico, the predatory beetle *Teretrius nigrescens* of the larger grain borer (LGB) *Prostephanus truncatus*.

4. *Recharges on ARCU services*

Income accruing from recharges decreased by 40% in 2005 compared to 2004. The shortfall in 2005 was due to protracted problems encountered with *B. fusca* oviposition between December 2004 and March 2005. During this period, the few eggs which were laid by *B. fusca* moths did not hatch although larval survival and development appeared normal. This problem was attributed to the unprecedented low humidity and atmospheric pressure which affected fecundity and egg hatchability adversely. The problem was overcome by introducing a new colony in an air conditioned rearing room specifically for *B. fusca*. The failure to supply *B. fusca* as demanded resulted in less revenue being collected from recharges.

Capacity building

The ARCU continued to provide training opportunities for both resident graduate scholars (e.g. ARPPIS) and students requiring short attachment. There were no trainees in the unit during 2004. However, in 2005 three tertiary college students received training on insect rearing on specific projects aimed at improving the existing insect rearing techniques in relation to laboratory-reared insect quality assessment and control. These were:

Maureen W. Mwaura, Nairobi Technical College, on training attachment 18 August to 16 December 2005. Her research project was "Effect of brewer's yeast on survival, development, and reproduction of the maize stemborer *Busseola fusca*".

Phoebe A. Midigo, Nairobi Technical College, on training attachment 20 September to 16 December 2005. Her research project was "Effect of ascorbic acid on survival, development, and reproduction of the sorghum stemborer *Chilo partellus*".

Anne N. Chege, Nairobi Technical College, on training attachment 26 October to 16 December 2005. Her research project was "Effect of sucrose on survival, development and reproduction of the maize stemborer *Busseola fusca*".

Impact

To provide cost-effective quality services from its insectaries, animal breeding and containment services as well as in capacity building, the Unit:

- Provided insects and small laboratory mammals for experiments to *icipe* research projects and local universities, thereby enhancing their research capabilities.
- Trained scientists, scholars and technicians in insect and animal rearing/handling techniques.
- Guided *icipe* staff on importation and exportation protocols for biological organisms.
- Supplied schools, colleges and local universities with learning and examination specimens.

Future plans

The improvement of the existing as well as developing new and appropriate techniques for insectary services, animal breeding and containment services will continue to be the future focal points for the Unit. In this regard, ARCU will work towards:

- Enhancing research and development (R&D) activities at *icipe*, national agricultural and extension systems and national universities by providing quality experimental insects and animals as required.
- Training of scientists, scholars and technicians in insect and animal rearing/handling procedures.
- Developing appropriate, cost-effective insect and animal rearing procedures.
- Supporting learning institutions with teaching/learning and examination specimens.
- Guiding the Centre on importation and exportation protocols for biological organisms.
- Exploring how the Biologially Secure Laboratory Facility (BSLF) can be funded in future.

Appendix 2:

icipe Arthropod Pathogen Germplasm Centre

icipe Arthropod Germplasm Centre (IAGC) is a repository for African arthropod pathogens (fungi, viruses, bacteria and protozoa) and makes them available to investigators. Its activities include training, isolation, culture, identification and preservation. It also makes available a catalogue of all pathogen samples through the Internet.

During 2004–2005 the IAGC provided several fungal and *Bacillus thuringiensis* isolates to MSc and PhD scholars from University of Nairobi, Kenyatta University and University of Pretoria, RSA, for research on sweet potato weevil *Cylas puncticollis,* larger grain borer *Prostephanus truncatus,* fruit fly *Bactrocera invadens,* ticks *Rhipicephalus* and *Amblyomma* spp., mites *Tetranychus evansi* and *T. urticae* and termites. Training on management and conservation of germplasm to participants from IITA (Benin), Ministry of Agriculture (Ethiopia), Kenya Agricultural Research Institute, Kenyatta University, Osho Chemical Industries (Kenya), Ministry of Livestock (Sudan) and T-Stanes (India) was offered. The training covered the following areas: (i) pathogen survey and efficacy testing, (ii) techniques in management and conservation of microbial diversity and (iii) molecular characterisation of *Metarhizium anisopliae* and *Bacillus thuringiensis.* IAGC also carried out identification of over 100 fungal isolates from Mauritius.

Participating scientist: *N. K. Maniania*

Assisted by: *E. O. Ouna, R. Rotich*

Donor: *icipe core fund donors and USAID*

Output

Conferences attended

Control of Locust and Grasshopper Project Small Group Meeting, 10–11 October 2005, Dakar, Sénégal. Attended by N. K. Maniania.

Third UNEP/FAO Expert Meeting on Termite Biology and Management, 1–4 February 2005, Geneva, Switzerland. Attended by N. K. Maniania.

Capacity building

PhD students

D. Mwangi (Kenya) Mechanism of fungus-avoidance behaviour of termites and identification of the mediating signals (second year, ARPPIS).

F. Nchu (Cameroon) Development of formulations and delivery systems for entomopathogenic fungi for control of *Amblyomma variegatum* (first year, ARPPIS).

P. Ngumbi (Kenya) Experimental control of sandflies (Diptera: Psychodidae) using hyphomycetes fungi in Kenya (second year, DRIP).

APPENDIX 3:

Information and Publications Unit

Background and objectives

Information and Publications Unit (IPU) is an amalgamation of several sections, its main responsibility being the publishing (in print and electronic format) and printing of information about *cipe* and its projects. It also hosts the *International Journal of Tropical Insect Science (IJT)* Secretariat. (During the review period, IJT was co-published on behalf of *icipe* and AAIS by CABI Publishing, UK.) Expertise within the Unit constitutes writing, editing, graphics support and printing of all official documents such as annual reports, business plans, brochures, proceedings, posters and stationery. The Unit works closely with the Public Relations Office and the Information Technology and Bioinformatics Unit.

The Unit is divided into 5 sections which are:

- Editorial and Information Services
- *International Journal of Tropical Insect Science* (IJT) Secretariat
- *icipe* Science Press and Printing Services
- Publications
- Information Resources Centre (Library)

Staff: *A. Ng'eny-Mengech, I. Ogendo, D. Osogo, J. Malombe, A. Ndung'u, J. Kisini, C. Sanginga, E. Wasike, J. Lago, W. Ambaka, E. Mung'aya, J. Oburo, M. Kageche*

Donors: *icipe core fund donors, CTA, 3rd party clients*

Collaborators: *CABI Publishing, UK; INASP-PERI*

Work in progress

1. Editorial and Information Services

Participating staff: *A. Ng'eny-Mengech, D. Osogo, A. Ndung'u*

This Section is involved in the writing and compilation of information on *icipe*'s projects and activities, as well as providing editorial assistance to *icipe* scientific staff. The main responsibility is to ensure that all scientific manuscripts undergo preliminary editing and internal peer review before submission to international journals, as well as editing project proposals and donor reports. The unit head also contributes information for the web page as well as other PR materials for the institution; not forgetting provision of information about *icipe* activities to the general public, media and scientific collaborators.

2. International Journal of Tropical Insect Science (IJT)

Participating staff and consultant: *H. R. Herren, A. Hassanali, A. Ng'eny-Mengech, B. Le Rü, C. Sanginga, J. C. Nsengimana, D. Osogo, I. Ogendo, A. Ndung'u*

The maiden issue of the *International Journal of Tropical Insect Science* (IJT) [formerly *Insect Science and Its Application* (ISA)] was published in 2004 under the aegis of *icipe* and the African Association of Insect Scientists (AAIS). As an international peer-reviewed scientific journal, it serves as a forum for original research findings on tropical insects and related arthropods and their sustainable management, conservation and utilisation.

The journal has been co-published under a collaborative agreement with CABI Publishing (UK) and distributed by CABI on behalf of *icipe*. This agreement aimed to take advantage of CABI's specialised publishing services and its expansive distribution network. From 2004 to 2005, 8 issues have been published. *icipe* continues to host the IJT Secretariat and perform the screening of manuscripts, selection and appointment of peer reviewers, as well as the scientific editing of the manuscripts, and liaises with the journal's Editorial Board who determine the journal's policies independently of *icipe*. IJT is available online via the CABI website but will soon be co-published and hosted by Cambridge University Press. IJT is also accessible under the AGORA scheme.

Hans Herren served as Editor-in-Chief with Ahmed Hassanali and William Overholt as Associate Editors for Volumes 24 (2004) and 25 (2005). For Volume 26 (2006) Christian Borgemeister was appointed Editor-in-Chief, together with four Regional Editors and a new 24-member Editorial Board.

3. *icipe Science Press (ISP) and printing services*

Participating staff: *J. Malombe, E. Mung'aya, J. Oburo, M. Kageche, J. Kisini*

Started in 1988, with an aim to promoting scientific writing and publishing in Africa, the Press publishes work for the Centre's core departments, project-related activities and third party clients.

This has been a cost-recovery unit for the past several years and all work done is quoted and paid for, either by *icipe* or by third party clients such as BirdLife International, Regional Centre for Mapping of Resources and Development, USAID and Jaramogi Oginga Odinga Foundation just to mention a few.

This Section printed the majority of the *icipe* stationery, name cards, duplicate and order books and programmes. The Section also printed *Development and Dissemination of IPM for Vegetables in Eastern Africa* book, a proceedings and other miscellaneous publications.

4. *Publications section*

Participating staff: *A. Ng'eny-Mengech, I. Ogendo, D. Osogo, A. Ndung'u, J. Kisini*

Important reference books written by *icipe* staff and edited for production were the Biennial Scientific Report, Annual Report Highlights, the ARPPIS Calendar, and the Push-pull and IPM manuals. (Several IPM manuals were produced by consultants.)

The Graphics Section assists in the production of some of the documents, as well as posters, brochures/fliers, Powerpoint presentations and other materials, including stationery.

(See the list of icipe Science Press publications in the general icipe publications lists.)

5. *Information Resources Centre*

Participating staff: *E. Wasike, J. Lago, W. Ambaka, M. Kageche*

The Information Resources Centre (*icipe* Library) serves as Africa's insect science information hub and offers a wide range of services. These include Current Awareness (CAS) by providing tables of contents of e-journals via e-mails sent to scientists, reference services, circulation of books to users, training of users in the use of electronic resources, document delivery service and also reprographic service at a small fee.

The Library not only serves the *icipe* scientists, but also caters for visiting scientists, postgraduate and MSc students, and other students on attachment from tertiary institutions. Over the review period, about 5500 users were served and 150 literature searches were done. About 2500 materials were borrowed with 300 new titles being added to the 12,000+ books housed by the Library. There are currently 20 entomology journals accessible online and several CD-ROM databases. Fifteen titles were received in print format.

The staff at the Library analyse all current publications in the *icipe*'s research interests and enter them into the Pest Management Documentation and Information System and Service (PMDISS) database which is available to all clients. Over the review period, the Library maintained an active resource-sharing policy with other research centres and organisations. The IRC is a member of the Kenya Libraries and Information Services Consortium (KLISC) which was established during this period. The Library provides updated information to FAO, which in turn avails its AGRIS database in CD-ROM format to *icipe*. This is done in exchange for *International Journal of Tropical Insect Science*.

6. Work done in liaison with the Public Relations Office

Consultant: *E. Ng'ang'a*

A Press Officer was recruited on a consultancy basis, commencing duties in February 2004. During the review period, the Press Office facilitated the writing and publication of over 100 articles, as well as the airing of news items on various *icipe* activities, in both the local, regional and international media. This free publicity amounted to over US$100,000 in advertising value. In addition to maintaining general liaison, and ensuring good relations with the media, the Press Office also worked with the Public Relations Office with the organisation and publicity of events. These included the renaming of the Thomas Odhiambo Campus, Mbita Point in May 2004 and the events surrounding the departure of the former Director General, Dr Hans R. Herren.

7. Work done in liaison with the Information Technology and Bioinformatics Unit

Participating staff and consultant: *G. Sequiera, I. Ogendo, K. Kebaara*

A consultant had been hired in Nov/Dec 2005 to update the web page content. So far, the latest *icipe* highlights have been put up and also profiling of *icipe* staff has been done.

Output

Publications

(See the list of icipe Science Press Publications in the general icipe Publications lists.)

Conference report

Report of the Symposium for the Enhancement of Scientific Collaboration in Africa. The symposium, organised by the Johns Hopkins University School of Medicine and *icipe*, was held on 7–8 August 2005 at *icipe*, Duduville. Attended by: Annalee N. Mengech and D. Osogo.

Capacity building

A one-week course on science communication was offered to ARPPIS and DRIP students in 2005. Several attachment students/interns have also received on-the-job training in editing, printing and information science.

Impact

- Providing cost-effective quality services to *icipe* and third party clients;
- Increased activity in PR liaison with general public and the media, and organisation and publicity of events;
- Improved web page content and accessibility;
- Increased use of library facilities to both internal and external users.

Appendix 4:

icipe Publications for 2004 (as at 31 December 2005)

A. Articles Published in Refereed Journals

(icipe staff names, including visiting scientists, scholars and technicians', are italicised. Publications with a 2003 date that have not previously been reported in the icipe Publications List are included here. Reprints of articles with a call number at the end of the citation can be ordered from the Documentalist, icipe. The list includes peer-reviewed online journals.)

Ba F. S., *Pasquet R. S.* and Gepts P. (2004) Genetic diversity in cowpea [*Vigna unguiculata* (L.) Walp.] as revealed by RAPD markers. *Genetic Resources Crop Evolution* 51, 539–550.

***Baliraine F. N.*, Bonizzoni M., Guglielmino C. R., *Osir E. O.*, *Lux S. A.*, Mulaa F. J., Gomulski L. M., Zheng L., Quilici S., Gasperi G. and Malacrida A. R.** (2004) Population genetics of the potentially invasive African fruit fly species, *Ceratitis rosa* and *Ceratitis fasciventris* (Diptera: Tephritidae). *Molecular Ecology* 13, 683–695. 04-1784

***Baumgärtner J.*, *Getachew T.*, *Melaku G.*, Sciarretta A., *Shifa B.* and Trematerra P.** (2003) Cases for adaptive ecological systems management. *REDIA* LXXXVI, 165–172. 03-1776

Bousema J. T., *Gouagna L. C.*, Drakeley C. J., Meutstege A. M., *Okech B. A.*, Akim I. N. J., *Beier J. C.*, *Githure J. I.* and Sauerwein R. W. (2004) *Plasmodium falciparum* gametocyte carriage in asymptomatic children in western Kenya. *Malaria Journal* 3, 18–28. 04-1816

Carlson J., Byrd B. D. and *Omlin F. X.* (2004) Field assessments in western Kenya link malaria vectors to environmentally disturbed habitats during the dry season. *BMC Public Health* 4, 33–39. 04-1895

Carlson J., Keating J., *Mbogo C. M.*, Kahindi S. and *Beier J. C.* (2004) Ecological limitations on aquatic mosquito predator colonization in the urban environment. *Journal of Vector Ecology* 29, 331–339. 04-1915

Chabi-Olaye A., *Fiaboé M. K.* and *Schulthess F.* (2004) Host suitability and thermal requirements of *Lathromeris ovicida* Risbec (Hymenoptera: Trichogrammatidae), an egg parasitoid of cereal stemborers in Africa. *Biological Control* 30, 617–623. 04-1755

***Chinwada P.*, Overholt W. A., *Omwega C. O.* and Mueke J. M.** (2004) Biology of *Sturmiopsis parasitica* (Diptera: Tachinidae) and suitability of three cereal stem borers (Lepidoptera: Crambidae, Noctuidae) for its development. *Annals of the Entomological Society of America* 97, 153–160. 04-1721

Depinay J. M. O., *Mbogo C. M.*, Killeen G., Knols B., Beier J. C., Carlson J., Dushoff J., Billingsley P., Mwambi H., *Githure J.*, Toure A. M. and McKenzie F. E. (2004) A simulation model of African *Anopheles* ecology and population dynamics for the analysis of malaria transmission. *Malaria Journal* 3, 29. 04-1817

***Dimbi S.*, *Maniania N. K.*, *Lux S. A.* and Mueke J. K.** (2004) Effect of constant temperatures on germination, radial growth and virulence of *Metarhizium anisopliae* to three species of African tephritid fruit flies. *BioControl* 49, 83–94. 04-1729

***Fiaboé K. K. M.*, de Moraes G. J. and Gondim Jr M. G. C.** (2004) A new genus and a new species of phytoseiid mite (Acari: Phytoseiidae) from northeastern Brazil. *Zootaxa* 599, 1–4. 04-1804

***Getu E.*, *Overholt W. A.* and Kairu E.** (2004) Comparative studies on the influence of relative humidity and temperature on life table parameters of two populations of *Cotesia flavipes* (Hymenoptera: Braconidae). *Biocontrol Science and Technology* 14, 595–605. 04-1898

Gilioli G., *Baumgärtner J.* and Vacante V. (2003) Biological control as an ecosystem management tool for enhancing environmental sustainability. *REDIA* LXXXVI, 173–185. 03-1777

Gouagna L. C.*, Ferguson H. M., *Okech B. A.*, *Killeen G. F.*, Kabiru E. W., *Beier J. C.*, *Githure J. I.* and *Yan G. (2004) *Plasmodium falciparum* malaria disease manifestations in humans and transmission to *Anopheles gambiae*: A field study in western Kenya. *Parasitology* 128, 235–243. 04-1736

Gouagna L. C.*, *Okech B. A.*, *Obare P.*, *Miyare P.*, Ombonya S., Kabiru E. W., *Beier J. C.*, *Yan G.*, Knols B. G. J., *Githure J. I.* and *Killeen G. F. (2004) Seasonality of *Plasmodium falciparum* infection and risk factors for gametocyte carriage in patients attending a rural health centre in western Kenya. *East African Medical Journal* 80, 627–634.

Gounou S.* and *Schulthess F. (2004) Spatial distribution of lepidopterous stem borers on indigenous host plants in West Africa and its implications for sampling schemes. *African Entomology* 12, 171–178. 04-1897

Hernandez-Valladares M., Naessens J., Gibson J. P., Musoke A. J., Nagda S., Rihet P., *ole-MoiYoi O. K.* and Iraqi F. A. (2004) Confirmation and dissection of QTL controlling resistance to malaria in mice. *Mammalian Genome* 15, 390–398.

Hernandez-Valladares M. H., Rihet P., *ole-MoiYoi O. K.* and Iraqi F. A. (2004) Mapping of a new quantitative trait locus for resistance to malaria in mice by a comparative approach of human chromosome 5q31-q33. *Immunogenetics* 56, 115–117. 04-1843

Impoinvil D. E.*, *Kongere J. O.*, Foster W. A., *Njiru B. N.*, *Killeen G. F.*, *Githure J. I.*, Beier J. C., *Hassanali A.* and *Knols B. G. J. (2004) Feeding and survival of the malaria vector *Anopheles gambiae* on

plants growing in Kenya. *Medical and Veterinary Entomology* 18, 108–115. 04-1737

Jiang N., Sétamou M., Ngi-Song A. and *Omwega C.* (2004) Performance of *Cotesia flavipes* (Hymenoptera: Braconidae) in parasitizing *Chilo partellus* (Lepidoptera: Crambidae) as affected by temperature and host stage. *Biological Control* 31, 155–164. 04-1762

Kanya J. I., Ngi-Song A. J., Sétamou M. F., Overholt W., **Ochora J.** and *Osir E. O.* (2004) Diversity of alternative hosts of maize stemborers in Trans-Nzoia district of Kenya. *Environmental Biosafety Research* 3, 159–168. 04-1779

Keating J., Macintrye K., *Mbogo C. M., Githure J. I.* and *Beier J. C.* (2004) Characterization of potential larval habitats for *Anopheles* mosquitoes in relation to urban land-use in Malindi, Kenya. *International Journal of Health Geographics* 3, 9–12. 04-1815

Kenya E. U., *Osir E. O.,* **Imbuga M. O. and Manohar R.** (2004) The effect of *Bacillus thuringiensis* δ-endotoxin on midgut ATPase from the tsetse fly, *Glossina morsitans centralis*. *Journal of Nature Conservators* 16, 235–241. 04-1766

Kithusi G. G., Knapp M., **Shibairo S. I., Nderitu J. H. and Njoroge K.** (2004) Effects of four biopesticides on the spider mite *Tetranychus evansi* Baker and Pritchard in the laboratory. *Phytophaga* XIV, 549–556. 04-1825

Masiga D. K. and **Isokpehi R. D.** (2004) Opportunities in Africa for training in genome science. *African Journal of Biotechnology* 3, 117–122. 04-1767
URL: http://www.academicjournals.org/AJB/PDF/Pdf2004/Feb/Masiga%20and%20Isokpehi.pdf

Mathenge E. M., Omweri G. O., **Irungu L. W., Ndegwa P. N., Walczak E., Smith T. A., Killeen G. F. and Knols B. G.** (2004) Comparative field evaluation of the Mbita trap, the Centers for Disease Control light trap, and the human landing catch for sampling of malaria vectors in western Kenya. *American Journal of Tropical Medicine and Hygiene* 70, 33–37.

Midega C. A. O., **Ogol C. K. P. O. and** *Overholt W. A.* (2004) Effect of agroecosystem diversity on natural enemies of maize stemborers in coastal Kenya. *International Journal of Tropical Insect Science* 24, 280–286. 04-1771

Mohamed M. H., Khan Z. R., Overholt W. A. and **Elizabeth D. K.** (2004) Behaviour and biology of *Chilo partellus* (Lepidoptera: Pyralidae) on maize and wild gramineous plants. *International Journal of Tropical Insect Science* 24, 287–297. 04-1768

Mukabana W. R., **Takken W., Killeen G. F. and Knols B. G.** (2004) Allomonal effect of breath contributes to differential attractiveness of humans to the African malaria vector *Anopheles gambiae*. *Malaria Journal* 3, 1. 04-1759

Musyoki J. M., *Osir E. O.,* **Kiara H. K. and Kokwaro E. D.** (2004) Comparative studies on the infectivity of *Theileria parva* in ticks fed *in vitro* and those fed on cattle. *Experimental and Applied Acaralogy* 32, 51–67. 04-1730

Mutero C. M., *Kabutha C.,* **Kimani V., Kabuage L., Gitau G.,** *Ssennyonga J., Githure J.,* **Muthami L., Kaida A., Musyoka L., Kiarie E. and Oganda M.** (2004) A transdisciplinary perspective on the links between malaria and agroecosystems in Kenya. *Acta Tropica* 89, 171–186. 04-1728

Mutero C. M., *Ng'ang'a P. N., Wekoyela P., Githure J.* **and Konradsen F.** (2004) Ammonium sulphate fertiliser increases larval populations of *Anopheles arabiensis* and culicine mosquitoes in rice fields. *Acta Tropica* 89, 187–192. 04-1720

Mwangangi J. M., *Mbogo C. M.,* **Nzovu J. G., Kabiru E. W., Mwambi H.,** *Githure J. I.* and *Beier J. C.* (2004) Relationships between body size of *Anopheles* mosquitoes and *Plasmodium falciparum* sporozoite rates along the Kenya coast. *Journal of the American Mosquito Control Association* 20, 390–394.

Ndung'u M. W., Kaoneka B., Hassanali A., Lwande W., **Hooper A. M., Tayman F., Zerbe O. and** *Torto B.* (2004) New mosquito larvicidal tetranortriterpenoids from *Turraea wakefieldii* and *Turraea floribunda*. *Journal of Agricultural and Food Chemistry* 52, 5027–5031. 04-1826

Ndung'u M., Torto B., Knols B. G. J. and *Hassanali A.* (2004) Laboratory evaluation of some East African Meliaceae as sources of larvicidal botanicals for *Anopheles gambiae*. *International Journal of Tropical Insect Science* 24, 311–318. 04-1773

Nedorezov L. V. **and Sadykov A. M.** (2004) Influence of winter conditions in the dynamics of an isolated population of insects. *Euro-Asian Entomological Journal* 3, 169–172.

Niyibigira E. I., Overholt W. A. **and Stouthamer R.** (2004a) *Cotesia flavipes* Cameron and *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae) do not exhibit complementary sex determination: Evidence from field populations. *Applied Entomology and Zoology* 39, 705–715. 04-1901

Niyibigira E. I., Overholt W. A. **and Stouthamer R.** (2004b) *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) does not exhibit complementary sex determination (ii) Evidence from laboratory experiments. *Applied Entomology and Zoology* 39, 717–725. 04-1900

Okech B. A., Gouagna L. C., **Kabiru E. W.,** *Walczak E., Beier J. C., Yan G.* and *Githure J. I.* (2004) Resistance of early midgut stages of natural *Plasmodium falciparum* parasites to high temperatures in experimentally infected *Anopheles gambiae* (Diptera: Culicidae). *The Journal of Parasitology* 90, 764–768. 04-1802

Okech B. A., Gouagna L. C., Knols B. G. J., **Kabiru E. W.,** *Killeen G. F., Beier J. C.,* **Yan G. and** *Githure J. I.* (2004) Influence of indoor microclimate and diet on survival of *Anopheles gambiae* s. s. (Diptera: Culicidae) in village house conditions in western Kenya. *International Journal of Tropical Insect Science* 24, 207–212. 04-1769

Okech B. A., Gouagna L. C., **Walczak E., Kabiru E. W.,** *Beier J. C., Yan G.* and *Githure J. I.* (2004) The development of *Plasmodium falciparum* in experimentally infected *Anopheles gambiae* (Diptera: Culicidae) under ambient microhabitat temperature in western Kenya. *Acta Tropica* 92, 99–108. 04-1820

Omolo M. O., Okinyo D., **Ndiege I. O.,** *Lwande W.* and *Hassanali A.* (2004) Repellency of essential oils of some Kenyan plants against *Anopheles gambiae*. *Phytochemistry* 65, 2797–2802. 04-1761

Shi W. P. and *Njagi P. G. N.* (2004) Disruption of aggregation behaviour of oriental migratory locusts (*Locusta migratoria manilensis*) infected with

Nosema locustae. *Journal of Applied Entomology* 128, 414–418. 04-1749

Shililu J. I., Ghebremeskel T., Seulu F., Mengistu S., Fekadu H., Zerom M., Asmelash G. E., Sintasath D., Mbogo C., Githure J. I., Brantly E., Beier J. C. and Novak R. J. (2004) Seasonal abundance, vector behavior, and malaria parasite transmission in Eritrea. *Journal of the American Mosquito Control Association* 20, 155–164. 04-1807

Shililu J. I., Grueber W. B., Mbogo C. M., Githure J. I., Riddiford L. M. and Beier J. C. (2004) Development and survival of *Anopheles gambiae* eggs in drying soil: Influence of the rate of drying, egg age, and soil type. *Journal of the American Mosquito Control Association* 20, 243–247. 04-1806

Sumba L. A., Guda T. O., Deng A. L., Hassanali A., Beier J. C. and Knols B. G. J. (2004) (Short Communication) Mediation of oviposition site selection in the African malaria mosquito *Anopheles gambiae* (Diptera: Culicidae) by semiochemicals of microbial origin. *International Journal of Tropical Insect Science* 24, 260–265. 04-1770

Sumba L. A., Okoth K., Deng A. L., Githure J., Knols B. G. J., Beier J. C. and Hassanali A. (2004) Daily oviposition patterns of the African malaria mosquito *Anopheles gambiae* Giles (Diptera: Culicidae) on different types of aqueous substrates. *Journal of Circadian Rhythms* 2, 6 (13 December 2004). Available online at: http://www.jciradianrhythms.com/content/2/1/6. BioMed Central Ltd. 04-1765

Wanzala W., Noel S. F. K., Gule S. and Hassanali A. (2004) Attractive and repellent host odours guide ticks to their respective feeding sites. *Chemoecology* 14, 229–232. 04-1760

Wagener B., Reineke A., Löhr B. and Zebitz C. P. W. (2004) A PCR-based approach to distinguish important *Diadegma* species (Hymenoptera: Ichneumonidae) associated with diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *Bulletin of Entomological Research* 94, 465–471. 04-1902

B. Books and Other Publications

(Includes papers in published conference proceedings, books, chapters in books, patents and review articles.

Barrion A. and Khan Z. R. (2004) *How to Handle Grass Stem Borer Larvae*. Development Communication Ltd, Nairobi. Kenya. ISBN 9966-9856-1-1. 37 pp. 632.7(036) BAR

Birch N., Wheatly R., Anyango B., Arpaia S., Capalbo D., Getu D. E., Fontes E., Kalama P., Lelmen E., Løvei G., Melo I. S., Muyekho F., Ngi-Song A., Ochieno D., Ogwang J., Piletti R., Schuler T., Sétamou M., Sithanantham S., Smith J., Van Son N., Songa J., Sujii E., Tan T. Q., Wan F.-H. and Hilbeck A. (2004) Biodiversity and non-target impacts: A case study of *Bt* maize in Kenya, pp. 117–185. In *Environmental Risk Assessment of Genetically Modified Organisms, Volume 1: A Case Study of* Bt *Maize in Kenya* (Edited by A. Hilbeck and D. A. Andow). CABI Publishing, UK.

Burgess N., Salehe J., Doggart N., Clarke G. P., Gordon I., Sumbi P. and Rodgers A. (2004) Coastal forests of eastern Africa, pp. 230–239. In *Hotspots Revisited*. CEMEX, Mexico City.

Copeland R. S., White I. M., Okumu M., Machera P. and Wharton R. A. (2004) Insects associated with fruits of the Oleaceae (Asteridae: Lamiales) in Kenya, with special reference to the Tephritidae (Diptera). *D. Elmo Hardy Memorial Volume: Contributions to the Systematics and Evolution of Diptera* (Edited by N. L. Evenhuis and K. Y. Kaneshiro). *Bishop Museum Bulletin of Entomology* 12, 135–164.

Fitt G., Andow D., Carriere Y., Moar W., Schuler T., Omoto C., Kanya J., Okech M., Arama P. and Maniania N. K. (2004) Resistance risks and management associated with *Bt* maize in Kenya, pp. 209–250. In *Environmental Risk Assessment of Genetically Modified Organisms, Volume 1: A Case Study of* Bt *Maize in Kenya* (Edited by A. Hilbeck and D. A. Andow). CABI Publishing, UK.

Hilbeck A., Andow D. A., Birch N. E., Fitt G. P., Johnston J., Nelson K. C., Osir E., Songa J., Underwood E. and Wheatly R. (2004) Risk assessment of *Bt* maize in Kenya: Synthesis and recommendations, pp. 251–271. In *Environmental Risk Assessment of Genetically Modified Organisms, Volume 1: A Case Study of* Bt *Maize in Kenya* (Edited by A. Hilbeck and D. A. Andow). CABI Publishing, UK.

Jackson R. R. (2004) Blood-thirsty spiders and syringes with wings. *Nature East Africa* 34, 30–35.

Khan Z. R. and Pickett J. A. (2004) The 'push-pull' strategy for stemborer management: A case study in exploiting biodiversity and chemical ecology, pp. 155–164. In *Ecological Engineering for Pest Management: Advances in Habitat Manipulations for Arthropods* (Edited by G. Gurr, S. D. Wratten and M. A. Altieri). CSIRO, Australia and CABI Publishing, UK.

Masiga D. K. and Turner C. M. R. (2004) Amplified (restriction) fragment length polymorphism (AFLP) analysis, pp. 173–286. In *Methods in Molecular Biology: Parasite Genomics Protocols* (Edited by S. E. Melville). The Humana Press Inc., USA.

Muyekho F. N., Barrion A. T. and Khan Z. R. (2004) *A Primer on Grass Identification and Their Uses in Kenya*. Development Communication Ltd, Nairobi, Kenya. ISBN 9966-9856-0-3. 84 pp.

Saini R. K. (2004) New technologies for tsetse control—Development of repellent collars. Agfax Resource pack. (http://www.agfax.net/) WREN Media.

Saini R. K. (2004) Repellents: A harmonious approach, pp. 32–39. In *Recent Advances in Livestock Keeper-based Tsetse Control: The Way Forward* (Edited by S. Parrot and G. Ink). Pragat Offset Pvt Ltd and Sue Hainsworth Publishing, UK.

Saini R. K. and Hassanali A. (2004) A novel method for controlling tsetse flies and other blood feeding insects. Patent No. KE00185. Kenya Industrial Property Organisation (KIPO).

Sithanatham S. (2004) *Development and Dissemination of IPM for Vegetables in Eastern Africa*. (K. Kebaara, Ed.). *icipe* Science Press, Nairobi. 51 pp. ISBN 92 9064 166 5.

Somers D. A., Andow D. A., Amugune N., Aragao F., Ghosh K., Magiri E., Moar W. and Osir E. (2004) Transgene locus structure and expression of *Bt* maize, pp. 83–116. In *Environmental Risk Assessment of Genetically Modified Organisms, Volume 1: A Case Study of* Bt *Maize in Kenya*

(Edited by A. Hilbeck and D. A. Andow). CABI Publishing, UK.

Torto B. (2004) Chemical signals as attractants, repellents and aggregation stimulants. In *Encyclopedia of Life Support Systems (EOLSS)*, developed under the auspices of the UNESCO. Eolss Publishers, Oxford, UK. [http:www.eolss.net]

Varela A.* and *Seif A. (2004) *A Guide to IPM and Hygiene Standards in Okra Production in Kenya.* (K. Kebaara, Ed.). *icipe* Science Press, Nairobi. 116 pp. + Colour insert. ISBN 92 9064 161 5. 635.648(676.2) VAR

C. Publications by icipe Science Press

Journal

- **International Journal of Tropical Insect Science** (formerly *Insect Science and Its Application*). Founded by Thomas R. Odhiambo. Editor-in-Chief: H. R. Herren. ISSN 1742-7584. Published by CABI Publishing, a division of CAB International on behalf of *icipe* and AAIS.
    - Volume 24 (2004), Numbers 1–4, pp. 1–344.

  (Volume 24, Number 1—Special issue—African Pollination Ecology. Guest Editors: Barbara Gemmill, Connal Desmond Eardley, Wanja Kinuthia and Dino J. Martins).

  (Also available as electronic version.)

Pest Management and Other Field Guides

- **A Guide to IPM and Hygiene Standards in Okra Production in Kenya.** By A. M. Varela and A. Seif. (K. Kebaara, Ed.). 116 pp. + Colour insert. ISBN 92 9064 161 5.

Annual Report

- *icipe* **Annual Scientific Report 2002–2003.** International Centre of Insect Physiology and Ecology (*icipe*). (Compiled and Edited by A. N. Mengech). 271 pp. ISBN 92 9064 165 7.

D. Doctoral and Masters Theses by Graduates of icipe's Postgraduate Training Progammmes

PhD Theses

Elteraifi I. E. (2004) Ecological viability in neem growth, oil and limonoids in the Sudan. (DRIP). Gezira University, Sudan. *icipe* Supervisor: Prof. A. Hassanali. TH 582.6(624) ELT

Kane C. M. H. (2004) Cross-stage physiological effects of the desert locust, *Schistocerca gregaria* aggregation pheromones on their behaviour and susceptibility to control agents. (ARPPIS). Kenyatta University, Kenya. *icipe* Supervisor(s): Prof. A. Hassanali, Dr P. G. N. Njagi.

Mohamed M. H. (2004) Studies on the interactions between *Striga hermonthica* (Del.) Benth, maize (*Zea mays* L.) and stemborer *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae). (ARPPIS). Kenyatta University, Nairobi. *icipe* Supervisor: Prof. A. Hassanali.

Sumba L. (2004) Oviposition behaviour of the African malaria mosquito *Anopheles gambiae* Giles (Diptera: Culicidae): Influence of external factors on oviposition site selection. (ARPPIS). Egerton University, Kenya. *icipe* Supervisor: Prof. A. Hassanali.

MSc Theses

Amenya D. (2004) Lectin expression associated with plasmodium infection in *Anopheles* species. (DRIP). University of Nairobi. *icipe* Supervisor: Dr E. Osir.

Bosibori G. (2004) Characterisation of cell cycle regulator genes in mature in vitro *Plasmodium falciparum* gametocytes. (DRIP). University of Nairobi. *icipe* Supervisor: Dr E. Osir.

Burugu M. W. (2004) Expression of the lectin-trypsin gene in tsetse flies and other haematophagous arthropods. (DRIP). Kenyattta University. *icipe* Supervisor: Dr E. Osir.

Lelmen E. (2004) Effect of *Bacillus thuringiensis* δ-endotoxins on the diversity and function of Glomalean fungi forming arbuscular mycorrhizae with maize *(Zea mays)* and sorghum *(Sorghum bicolor)*. (DRIP). Jomo Kenyatta University of Agriculture and Technology. *icipe* Supervisor: Dr E. Osir.

Mbarak F. (2004) Studies on biochemical changes associated with pheromone-induced maternal transfer of gregarious phase to offspring in the desert locust, *Schistocerca gregaria*. (DRIP). Jomo Kenyatta University of Agriculture and Technology. *icipe* Supervisor: Dr E. Osir.

Ng'ayo M. (2004) Molecular characterisation of trypanosomes in small ruminants and pigs from W. Kenya. (DRIP). Kenyatta University. *icipe* Supervisor(s): Dr E. Osir, Dr D. Masiga.

Ngei C. N. (2004) Responses of *Chilo partellus* populations in Kenya to *Bacillus thuringiensis* formulations. (DRIP). University of Nairobi. *icipe* Supervisor: Dr E. Osir.

Ochieno D. W. (2004) Effects of Bt toxins on non-target arthropods. (DRIP). University of Nairobi. *icipe* Supervisor(s): Dr E. Osir, Dr A. Ngi-Song.

Odalo J. O. (2004) Biochemical examination and identification of bioactive botanicals from the coastal region of Kenya against adult *Anopheles gambiae*. (DRIP). Kenyatta University, Nairobi. *icipe* Supervisor: Prof. A. Hassanali.

E. Other Publications by icipe Scientists

(Publications by icipe staff on work not directly related to icipe and scholars' publications done under icipe's ARPPIS postgraduate sub-regional MSc training programme.)

Bruce A., Gounou S., Chabi-Olaye A., Smith H.* and *Schulthess F. (2004) The effect of neem (*Azadirachta*

indica A. Juss) oil on oviposition, development and reproductive potentials of *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) and *Eldana saccharina* Walker (Lepidoptera: Pyralidae). *Agricultural and Forest Entomology* 6, 223–232.

Chabi-Olaye A., *Fiaboe M. K.* and *Schulthess F.* (2004) Host suitability and thermal requirements of *Lathromeris ovicida* Risbec (Hymenoptera: Trichogrammatidae) egg parasitoid of cereal stemborers in Africa. *Biological Control* 30, 617–623.

Hernandez-Valladares M., Naessens J., Nagda S., Musoke A. J., Rihet P., *ole-MoiYoi O. K.* and Iraqi F. A. (2004) Comparison of pathology in susceptible A/J and resistant C57BL/6J mice after infection with different sub-strains of *Plasmodium chabaudi*. *Experimental Parasitology* (USA) 108, 134–141.

***Omondi-Aman B.*, Obeng-Ofori D., Danquah E. Y. and Offei S. K.** (2004) Genetic diversity and oviposition host preference of *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) infesting four crops in Ghana. *Journal of the Ghana Science Association* 6, 105–116. 04-1803

Pasquet R. (2004) The African centers of domestication, pp. 304–306. In *Encyclopedia of Plant and Crop Science* (Edited by R. Goodman). Marcel Dekker Inc., New York.

Pasquet R. (2004) New synonyms of *Vigna luteola* (Jacq.) Benth. (Leguminosae-Papilionoideae-Phaseoleae). *Kew Bulletin* 59 (4), 637–638.

***Schulthess F.*, Chabi-Olaye A. and Gounou S.** (2004) Multi-trophic level interactions in a cassava–maize relay cropping system in the humid tropics of West Africa. *Bulletin of Entomological Research* 94, 261–272.

Schneider H., *Borgemeister C.*, *Sétamou M.*, Affognon H., Bell A., Zweigert M. E., Poehling H.-M. and *Schulthess F.* (2004) Biological control of the larger grain borer *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) by its predator *Teretrius nigrescens* Lewis (Coleoptera: Histeridae) in Togo and Benin. *Biological Control* 30, 241–255.

Sétamou M. and *Schulthess F.* (2004) Pest status of *Mussidia nigrivenella* Ragonot, a cob-borer of maize in western Africa, p. 980. In *Encyclopedia of Entomology* (Edited by J. L. Capinera). Kluwer Academic Publishers, the Netherlands.

Thulin M., Lavin M., *Pasquet R.* and Delgado-Salinas A. (2004) Phylogeny and biogeography of *Wajira* (Leguminosae): A monophyletic segregate of *Vigna* centered in the Horn of Africa region. *Systematic Botany* 29, 903–920.

APPENDIX 5:

icipe Publications for 2005 (as at 31 August 2006)

B. ARTICLES PUBLISHED IN REFEREED JOURNALS

(icipe staff names, including visiting scientists, scholars and technicians', are italicised. Reprints of articles with a call number at the end of the citation can be ordered from the Documentalist, icipe.)

Ayub M., Smulski C., *Nyambega B.*, Becovich N., *Masiga D.*, Vazquez M., Aguilar C. F. and Levin M. J. (2005) Protein–protein interaction map of the *Trypanosoma cruzi* ribosomal P protein complex. *Gene* 357, 129–136.

***Billah M. K.*, Kimani-Njogu S., Overholt W. A., Wharton R. A., Wilson D. D. and Cobblah M. A.** (2005) The effect of host larvae on three *Psyttalia* species (Hymenoptera: Braconidae), parasitoids of fruit-infesting flies (Diptera: Tephritidae). *International Journal of Tropical Insect Science* 25, 168–175. 05-1790

***Copeland R. S.*, Okeka W., Freidberg A., Merz B., White I. M., De Meyer M. and Luke Q.** (2005) Fruit flies (Diptera: Tephritidae) of Kakamega Forest, Kenya. *Journal of East African Natural History* 94, 247–278. 05-1841

Cross F. R. and *Jackson R. R.* (2005) (Commentary) Spider heuristics. *Behavioural Processses* 69, 125–127. 05-1829

De Meyer M. and *Copeland R. S.* (2005) Description of new *Ceratitis* MacLeay (Diptera, Tephritidae) species from Africa. *Journal of Natural History* 39, 1283–1297. 05-1844

Ekesi S., Maniania N. K., Mohamed S. A.* and *Lux S. A. (2005) Effect of soil application of different formulations of *Metarhizium anisopliae* on African tephritid fruit flies and their associated endoparasitoids. *Biological Control* 35, 83–91. 05-1838

Ferguson H. M., *Gouagna L. C., Obare P.*, Read A. F., Babiker H., *Githure J.* and *Beier J. C.* (2005) The presence of *Plasmodium falciparum* gametocytes in human blood increases the gravidity of *Anopheles gambiae* mosquitoes. *American Journal of Tropical Medicine and Hygiene* 73, 312–320. 05-1823

Furtado I. P.*, Kreiter S., de Moraes G. J., Tixier M.-S., Fletchmann C. H. W. and *Knapp M. (2004) [2005] Plant mites (Acari) from northeastern Brazil, with descriptions of two new species of the family Phytoseiidae (Mesostigmata). *Acarologia* XLV, 131–143. 05-1800

Gilioli G., *Baumgärtner J.* and Vacante V. (2005) Temperature influences on the functional response of *Coenosia attenuata* (Diptera, Muscidae) individuals. *Journal of Economic Entomology* 98, 1524–1530. 05-1839

***Gitau C. W., Ngi-Song A. J.*, Overholt W. A. and Otieno S. A.** (2005) Acceptance and suitability of four lepidopteran stemborers for the development of the pupal parasitoid *Xanthopimpla stemmator* (Hymenoptera: Ichneumonidae). *Biocontrol Science and Technology* 15, 585–600. 05-1810

***Gohole L. S., Overholt W. A., Khan Z. R.* and Vet L. E. M.** (2005) Close-range host searching behavior of the stemborer parasitoids *Cotesia sesamiae* and *Dentichasmias busseolae*: Influence of a non-host plant *Melinis minutiflora*. *Journal of Insect Behavior* 18, 149–167. 05-1801

Hassanali A., Bashir M. O., Njagi P. G. N.* and *Sidi Ould E. (2005) Desert locust gregarization: A conceptual kinetic model. *Journal of Orthoptera Research* 14, 223–226. 05-1880

Hassanali A., Njagi P. G.* and *Bashir M. O. (2005) Chemical ecology of locusts and related acridids. *Annual Review of Entomology* 50, 223–245. 05-1778

Jackson R. R.*, Nelson X. J. and *Sune G. O. (2005) A spider that feeds indirectly on vertebrate blood by choosing female mosquitoes as prey. *Proceedings of the National Academy of Sciences of the USA (PNAS)* 102, 15155–15160. www.pnas.org/cgi/doi/10.1073/pnas.0507398102 05-1793

Jacob B. G., Arheart K. L., Griffith D. A., Mbogo C. M., Githeko A. K., Regens J. L., *Githure J. I.*, Novak R. and Beier J. C. (2005) Evaluation of environmental data for identification of *Anopheles* (Diptera: Culicidae) aquatic larval habitats in Kisumu and Malindi, Kenya. *Journal of Medical Entomology* 42, 751–755. 05-1798

Jacob B., Regens J. L., *Mbogo C. M.*, Githeko A. K., Swalm C. M., *Githure J. I.* and *Beier J. C.* (2005) Capabilities of multispectral thermal data for identification of *Anopheles gambiae* mosquito larval habitats in African urban environments. *International Journal of Remote Sensing* 26, 523–534. 05-1896

Jiang N.* and *Schulthess F. (2005) The effect of nitrogen fertilizer application to maize and sorghum on the bionomics of *Chilo partellus* (Lepidoptera: Crambidae) and the performance of its larval parasitoid *Cotesia flavipes* (Hymenoptera: Braconidae). *Bulletin of Entomological Research* 95, 495–504. 05-1794

Kalyebi A., Overholt W. A., Schulthess F.*, Mueke J. M., Hassan S. A. and *Sithanantham S. (2005) Functional response of six indigenous trichogrammatid egg parasitoids (Hymenoptera: Trichogrammatidae) in Kenya: Influence of temperature and relative humidity. *Biological Control* 32, 164–171. 05-1772

***Kalyebi A., Sithanantham S.*, Overholt W. A., Hassan S. A. and Mueke J. M.** (2005) Parasitism, longevity and progeny production of six indigenous Kenyan trichogrammatid egg parasitoids (Hymenoptera: Trichogrammatidae) at different temperature and relative humidity regimes. *Biocontrol Science and Technology* 15, 255–270. 05-1808

Keating J., Macintyre K., *Mbogo C. M., Githure J. I.* and *Beier J. C.* (2005) Self-reported malaria and mosquito avoidance in relation to household risk

factors in a Kenyan coastal city. *Journal of Biosocial Science* 37, 761–771. 05-1912

Keating J., *Mbogo C. M.*, Mwangangi J., Nzovu J. G., Gu W., Regens J. L., Yan G., *Githure J. I.* and *Beier J. C.* (2005) *Anopheles gambiae* s.l. and *Anopheles funestus* mosquito distributions at 30 villages along the Kenyan coast. *Journal of Medical Entomology* 42, 241–246. 05-1819

Kergoat G. J., Delobel A., Fedière G., *Le Rü B.* and Silvain J. F. (2005) Both host-plant phylogeny and chemistry have shaped the African seed-beetle radiation. *Molecular Phylogenetics and Evolution* 35, 602–611.

***Macharia I., Löhr B.* and De Groote H.** (2005) Assessing the potential impact of biological control of *Plutella xylostella* (diamondback moth) in cabbage production in Kenya. *Crop Protection* 24, 981–989. 05-1788

Manda H., Gouagna L. C.*, Kabiru E. W., *Hassanali A.*, Yan G., *Beier J. C.* and *Githure J. (2005) *Plasmodium falciparum* development in the midgut of *Anopheles gambiae s.s.* feeding on some predominant plants in western Kenya. *Acta Tropica* 95S, 17–18.

Maranga R. O., Kaaya G. P., Mueke J. M. and *Hassanali A.* (2005) Effects of combining the fungi *Beauveria basssiana* and *Metarhizium anisopliae* on the mortality of the tick *Amblyomma variegatum* (Ixodidae) in relation to seasonal changes. *Mycopathologia* 159, 527–532. 05-1827

Menge D. M., *Guda T.*, Zhong D., Pai A., Zhou G., *Beier J. C., Gouagna L.* and Yan G. (2005) Fitness consequences of *Anopheles gambiae* population hybridization. *Malaria Journal* 4, 44–50. 05-1903

***Midega C. A. O., Khan Z. R.*, Van den Berg J. and Ogol C. K. P. O.** (2005) Habitat management and its impact on maize stemborer colonization and crop damage levels in Kenya and South Africa. *African Entomology* 13, 333–340. 05-1905

Midega C. A. O.*, Ogol C. K. P. O. and *Overholt W. A. (2005) Life tables, key factor analysis and density relations of natural populations of the spotted maize stemborer, *Chilo partellus* (Lepidoptera: Crambidae), under different cropping systems at the Kenyan coast. *International Journal of Tropical Insect Science* 25, 86–95. 05-1899

***Muli E. M., Raina S. K.* and Mueke J. M.** (2005) Royal jelly production in East Africa: Performance potential of the honey bees *Apis mellifera scutellata* and *Apis mellifera monticola* in Kenya. *Journal of Apicultural Research* 44, 137–140. 05-1840

Muturi J. J., Ngi-Song A. J., Sétamou M.*, Mueke J. M. and *Schulthess F. (2005) Location of stemborer pupae in various host plants and implications for the performance of natural enemies with emphasis on the pupal parasitoid *Xanthopimpla stemmator* (Hymenoptera: Ichneumonidae). *International Journal of Tropical Insect Science* 25, 12–18. 05-1836

***Nedorezov L. V.* and Sadykova D. L.** (2005) A contribution to the problem of selecting a mathematical model of population dynamics with particular reference to the green oak tortrix. *Euro-Asian Entomological Journal* 4, 263–272.

***Nedorezov L. V.* and Volkova E. V.** (2005) On the impact of winter conditions on the dynamics of a population with non-overlapping generations: A model approach. *Journal of General Biology* 66, 484–490. 05-1878

Nelson X. J., *Jackson R. R.* and *Sune G. O.* (2005) Use of *Anopheles*-specific prey-capture behavior by the small juveniles of *Evarcha culicivora*, a mosquito-eating jumping spider. *The Journal of Arachnology* 33, 541–548. 05-1830

Ng'ayo M. O., Njiru Z. K., Kenya E. U., Muluvi G. M., *Osir E. O.* and *Masiga D. K.* (2005) Detection of trypanosomes in small ruminants and pigs in western Kenya: Important reservoirs in the epidemiology of sleeping sickness? *Kinetoplastid Biology and Disease* 4, 5. www.kinetoplastids.com/content/4/1/5 05-1834

Ngumbi E. N., Ngi-Song A. J.*, Njagi E. N. M., Torto R., Wadhams L. J., Birkett M. A., Pickett J. A., Overholt W. A. and *Torto B. (2005) Responses of the stem borer larval endoparasitoid *Cotesia flavipes* (Hymenoptera: Braconidae) to plant derived synomones: Laboratory and field cage experiments. *Biocontrol Science and Technology* 15, 271–279. 05-1809

***Njiru Z. K.*, Constantine C. C., *Masiga D. K.*, Reid S. A., Thompson R. C. and Gibson W. C.** (2005) Characterization of *Trypanosoma evansi* Type B. *Infection, Genetics and Evolution* 6, 292–300.

Odalo B. J. O., Omolo M. O.*, Malebo H., *Angira J., Njeru P. M., Ndiege I. O.* and *Hassanali A. (2005) Repellency of essential oils of some plants from the Kenyan coast against *Anopheles gambiae*. *Acta Tropica* 95, 210–218. 05-1791

Ogembo J. G.*, Kunjeku E. C. and *Sithanantham S. (2005) A preliminary study on the pathogenicity of two isolates of nucleopolyhedroviruses infecting African bollworm, *Helicoverpa armigera* (Lepidoptera: Noctuidae). *International Journal of Tropical Insect Science* 25, 218–222. 05-1795

Omolo M. O., Okinyo D., Ndiege I. O., Lwande W.* and *Hassanali A. (2005) Fumigant toxicity of the essential oils of some African plants against *Anopheles gambiae sensu stricto*. *Phytomedicine* 12, 241–246. 05-1780

Raina S. K.* and *Kimbu D. M. (2005) Variations in races of the honeybee *Apis mellifera* (Hymenoptera: Apidae) in Kenya. *International Journal of Tropical Insect Science* 25, 281–291. 05-1833

Rosa A. A., Gondim M. G. C. Jr, *Fiaboe K. K. M.*, de Moraes G. J. and *Knapp M.* (2005) (Scientific Note) Predatory mites associated with *Tetranychus evansi* Baker & Pritchard (Acari: Tetranychidae) on native solanaceous plants of coastal Pernambuco State, Brazil. *Neotropical Entomology* 34, 689–692. 05-1786

***Rossbach A., Löhr B.* and Vidal S.** (2005) Generalism versus specialism: Responses of *Diadegma mollipla* (Holmgren) and *Diadegma semiclausum* (Hellen), to the host shift of the diamondback moth (*Plutella xylostella* L.) to peas. *Journal of Insect Behaviour* 18, 491–503. 05-1824

Rwomushana I.*, Kyamanywa S., *Ngi-Song A. J.* and *Omwega C. O. (2005) Incidence of larval and pupal parasitoids of Lepidoptera in Uganda with special reference to new associations. *International Journal of Tropical Insect Science* 25, 274–280. 05-1805

Sciarretta A., *Baumgärtner J., Getachew T., Melaku G.* and Trematerra P. (2005) Design of a trapping system for monitoring the spatio-temporal occurrence of tsetse (*Glossina* spp.). *Rivista Italiana di Agrometeorologia (Italian Journal of Agrometeorology)* 3, 24–29. 05-1861

Sciarretta A., *Melaku G., Getachew T., Lulseged B., Shifa B.* and *Baumgärtner J.* (2005) Development of an adaptive tsetse population management scheme for the Luke community, Ethiopia. *Journal of Medical Entomology* 42, 1006–1019. 05-1797

Sétamou M., Jiang N.* and *Schulthess F. (2005) Effect of the host plant on the survivorship of parasitized *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) larvae and performance of its larval parasitoid *Cotesia flavipes* Cameron (Hymenoptera: Braconidae). *Biological Control* 32, 183–190. 05-1774

Sintasath D., Lynch M., Kleinau E., Bretas G., *Shililu J.*, Brantly E., Graves P. M., Gebremeskel T. and *Beier J. C.* (2005) Malaria prevalence and associated risk factors in Eritrea. *American Journal of Tropical Medicine and Hygiene* 72, 682–687.

***Wekesa V. W., Maniania N. K., Knapp M.* and Boga H. I.** (2005) Pathogenicity of *Beauveria bassiana* and *Metarhizium anisopliae* to the tobacco spider mite *Tetranychus evansi*. *Experimental and Applied Acarology* 36, 41–50. 05-1796

B. Books and Other Publications

(Includes papers in published conference proceedings, books, chapters in books, review articles and invited papers)

***Baumgärtner J.* and Schneider D. C.** (2004) Scale and hierarchy in integrated pest management, pp. 1954–1958. In *Encyclopaedia of Entomology* (Edited by J. Capinera). Kluwer Academic Publishers, Dordrecht, The Netherlands.

De Meyer M., *Copeland R. S.*, Wharton R. A. and McPheron B. A. (2004) On the geographical origin of the medfly, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), pp. 45–53. In *Proceedings of the 6th International Symposium on Fruit Flies of Economic Importance*, 6–10 May 2002, Stellenbosch, South Africa, (Edited by B. N. Barnes). Isteg Scientific Publications, Irene, South Africa.

Herren H. R., Schulthess F.* and *Knapp M. (2005) Towards zero pesticide use in tropical agroecosystems, pp. 135–146. In *The Pesticide Detox: Solutions for Safe Agriculture* (Edited by J. Pretty). Earthscan Publications Ltd, London.

Kariuki C., Njihia S., *Sithanantham S., Baya J.* and *Matoka C. M.* (2005) Current collaborative research and linkage activities on the African bollworm, *Helicoverpa armigera* (Hb.) biocontrol with *Trichogramma* in Kenya, pp. 55–58. In Helicoverpa *Management in Kenya: Research Status and Needs*. Proceedings of the KARI-*icipe* Workshop on Biocontrol-based IPM of the African Bollworm in Kenya, 16 November 2002, Nairobi, Kenya (Edited by S. Sithanantham, C. Kariuki and J. Baya). *icipe* Science Press, Nairobi.

***Löhr B.* and Kfir R.** (2004) Diamondback moth, *Plutella xylostella* L. in Africa: A review with emphasis on biological control, pp. 71–84. In *Proceedings of an International Symposium on Improving Biocontrol of* Plutella xylostella 21–24 October 2002, Montpellier, France (Edited by A. Kirk and D. Bordat). CIRAD, Montpellier. 04-1835

Maniania N. K.* and *Löhr B. (2005) Biopesticides in pest management systems: Recent developments and future needs in Africa, pp. 195–201. In *International Symposium on Biopesticides for Developing Countries 2003: Proceedings*, Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica (Edited by U. Roettger and R. Muschler). PAN: GTZ: CATIE. ISBN 9977-57-40-0 CATIE.

Maniania N. K.* and *Varela A. M. (2005) Production of biopesticides and botanicals in Africa, pp. 117–125. In *International Symposium on Biopesticides for Developing Countries 2003: Proceedings*, Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica (Edited by U. Roettger and R. Muschler). PAN: GTZ: CATIE. ISBN 9977-57-40-0 CATIE.

***Nedorezov L. V., Hassanali A.* and Sadykov A. M.** (2005) Individual-based model of mosquito choices up odour plumes to alternative hosts, pp. 136–137. In *Proceedings of the Fifth European Conference on Ecological Modelling—ECEM 2005* 19–23 September 2005, Puschino, Russia, (Edited by A. S. Komarov). IPBSS RAN, Russia.

Nyambo B.* and *Löhr B. (2005) The role and significance of farmer participation in biocontrol-based IPM for brassica crops in East Africa, pp. 290–301. In *Second International Symposium on Biological Control of Arthropods*, 12–16 September 2005 (Compiled by M. S. Hoddle). Forest Health Technology Enterprise Team—Morgantown, West Virginia. 05-1828

Ochiel G. R. S. and *Sithanantham S.* (2005) Overview of past research on *Trichogramma* in Kenya and future needs, pp. 17–21. In Helicoverpa *Management in Kenya: Research Status and Needs*. Proceedings of the KARI-*icipe* Workshop on Biocontrol-based IPM of the African Bollworm in Kenya, 16 November 2002, Nairobi, Kenya (Edited by S. Sithanantham, C. Kariuki and J. Baya). *icipe* Science Press, Nairobi.

Raina S. K. (Compiler) (2004) *Commercial Insects: A Practical Guide for Raising and Utilizing Silkmoths and Honey Bees in Africa*. Volumes 1–3. Three books published in 7 languages (English, French, Kiswahili, Spanish, Luganda, Arabic and Amharic). Overholt K. (Ed., English); Jones H. R. (Overall Ed., International Bee Research Association, UK). (173 pp.) ISBN 0 86098 246 7 English, French, Swahili; (183 pp.) ISBN 0 86098 241 6 English, Spanish, Lugandan; (192 pp.) ISBN 086098 247 5 English, Arabic, Amharic. *icipe* Science Press, Nairobi.

Raina S. K.* and *Nguku E. K. (Eds) (2005) *Integrating Sericulture and Apiculture Technologies with Regional Development Operations*. 272 pp. ISBN 92 9064 141 X. *icipe* Science Press, Nairobi.

Raina S. K., Kimbu D., Kioko E., Adolkar V.* and *Herren H. R. (2003) [2005] Products of *icipe*'s R&D: Integrating apiculture and sericulture technologies withregionaldevelopmentoperations—Wilderness to marketplace partnerships: Development of global marketing facilities for honeybee and silkmoth products, pp. 9–19. In *Integrating Sericulture and Apiculture Technologies with Regional Development Operations.* Proceedings of the Trainers Course and Third International Workshop on Conservation and Utilisation of Commercial Insects. 13 November–8 December 2000, Nairobi, Kenya (Edited by S. K. Raina and E. K. Nguku). ISBN 92 9064 141 X. *icipe* Science Press, Nairobi.

***Raina S. K., Kioko E. N., Adolkar V. V., Muli E., Nguku E., Kimbu D., Muiru H.* et al.** (Contributers) (2004) *Commercial Insects: A Practical Guide for Raising and Utilizing Silkmoths and Honey Bees in Africa.* Volumes 1–3. Three books published in 7 languages (English, French, Kiswahili, Spanish, Luganda, Arabic and Amharic). Raina S. K. (Compiler); Overholt K. (Ed., English); Jones H. R. (Overall Ed., International Bee Research Association, UK). (173 pp.) ISBN 0 86098 246 7 English, French, Swahili; (183 pp.) ISBN 0 86098 241 6 English, Spanish, Lugandan; (192 pp.) ISBN 086098 247 5 English, Arabic, Amharic. *icipe* Science Press, Nairobi.

Sithanantham S. (2004) *Development and Dissemination of IPM for Vegetables in Eastern Africa.* 51 pp. (Edited by K. Kebaara). ISBN 92 9064 166 5. *icipe* Science Press, Nairobi.

Sithanantham S.* and *Baya J. (2005) Biological control of *Helicoverpa armigera*: Global scenario and scope in Africa, pp. 25–34. In Helicoverpa *Management in Kenya: Research Status and Needs.* Proceedings of the KARI-*icipe* Workshop on Biocontrol-based IPM of the African Bollworm in Kenya, 16 November 2002, Nairobi, Kenya (Edited by S. Sithanantham, C. Kariuki and J. Baya). *Icipe* Science Press, Nairobi.

Sithanantham S., Baumgärtner J.* and *Matoka C. (2004) Ecosystem approach for management of *Helicoverpa armigera*: Scope in eastern Africa, pp. 129–134. In *African Bollworm Management in Ethiopia: Status and Needs* (Edited by M. Dwad, S. Sithanantham and T. Gebremedhin). Proceedings of the National Workshop on African Bollworm Management Research in Ethiopia, held at the Plant Protection Centre, Ambo, Ethiopia 17–19 April 2002. The Ethiopian Agricultural Research Organisation (EARO), Addis Ababa, Ethiopia.

Sithanantham S., Baya J., Kalyebi A., Muholo C., Momanyi G., Migiro L.* and *Matoka C. M. (2005) Research and training in promoting *Trichogramma* utilisation for biocontrol of the African bollworm in eastern Africa, pp. 49–53. In Helicoverpa *Management in Kenya: Research Status and Needs.* Proceedings of the KARI-*icipe* Workshop on Biocontrol-based IPM of the African Bollworm in Kenya, 16 November 2002, Nairobi, Kenya (Edited by S. Sithanantham, C. Kariuki and J. Baya). *icipe* Science Press, Nairobi.

***Sithanantham S.,* Kariuki C., *Matoka C., Baya J.,* Ochiel L. and Labuschagne L.** (2005) Mass production and utilisation of *Trichogramma* for biocontrol of caterpillar pests: Experiences elsewhere and future Kenyan scenario, pp. 43–48. In Helicoverpa *Management in Kenya: Research Status and Needs.* Proceedings of the KARI-*icipe* Workshop on Biocontrol-based IPM of the African Bollworm in Kenya, 16 November 2002, Nairobi, Kenya (Edited by S. Sithanantham, C. Kariuki and J. Baya). *icipe* Science Press, Nairobi.

***Sithanantham S.,* Zebitz C. P. W., Monje J. C., Hassan S., *Matoka C.,* Kariuki C., Njihia S., Ogwang J., Mohamed D., Pallangyo B. and Ensami E.** (2005) Regional initiatives for promoting the utilisation of native egg parasitoids for biocontrol of the African bollworm in vegetable-based cropping systems in eastern Africa, pp. 35–42. In Helicoverpa *Management in Kenya: Research Status and Needs.* Proceedings of the KARI-*icipe* Workshop on Biocontrol-based IPM of the African Bollworm in Kenya, 16 November 2002, Nairobi, Kenya (Edited by S. Sithanantham, C. Kariuki and J. Baya). *icipe* Science Press, Nairobi.

Varela A. M., Seif A., Nyambo B.* and *Löhr B. (2005) *A Guide to IPM in Cut Flower Production in Kenya.* (Edited by K. Kebaara). *icipe* Science Press, Nairobi. 128 pp. ISBN 92 9064 167 3.

C. Publications by *icipe* Science Press

Journal

- **International Journal of Tropical Insect Science.** Editor-in-Chief: H. R. Herren. ISSN 1742-7584. Volume 25 (2005), numbers 1 to 4, pp. 1–300. Co-published with CABI Publishing, UK.

Pest Management and Other Field Guides

- **A Guide to IPM in Cut Flower Production in Kenya.** Varela A. M., Seif A., Nyambo B. and Löhr B. (Kebaara K., Ed.). 2005, 128 pp. ISBN 92 9064 167 3.
- **A Guide to IPM in Mango Production in Kenya.** Varela A. M. and Seif A. (Sections A–F). (van Houten H., Ed.). 2005, 66 pp. ISBN 92 9064 167 3. (First edition).
- **A Primer on Planting and Managing 'Push-Pull' Fields for Stemborer and Striga Weed Control in Maize—A Step-by-Step Guide for Farmers.** Khan Z. R., Muyekho F. N., Njuguna E., Pickett J. A., Wadhams L. J., Dibogo N., Ndiege A., Genga G. and Lusweti C. (Ngeny-Mengech A., Ed.). 2005, 48 pp. ISBN 92 9064 170 3.
- **Commercial Insects: A Practical Guide for Raising and Utilizing Silkmoths and Honey Bees in Africa** Volumes 1–3. Three books published in 7 languages (English, French, Kiswahili, Spanish, Luganda, Arabic and Amharic). Raina S. K. (Compiler); Overholt K. (Ed., English); Jones H. R. (Overall Ed., International Bee Research Association, UK). 2004, (173 pp.) ISBN 0 86098 246 7 English, French, Swahili; (183 pp.) ISBN 0 86098 241 6 English, Spanish, Lugandan; (192 pp.) ISBN 086098 247 5 English, Arabic, Amharic.

Training Manuals

- **Training Format for IPM in Mango Production in East Africa.** Nyambo B. (van Houten H., Ed.). 2005, 20 pp. ISBN 92 9064 171 6.

Conference Proceedings

- ***Helicoverpa* Management in Kenya: Research Status and Needs.** Sithanantham S., Kariuki C. and Baya J. (Eds) 2005, 113 pp. ISBN 92 9064 169 X.
- **Integrating Sericulture and Apiculture Technologies with Regional Development Operations.** Raina S. K. and Nguku E. K. (Eds) 2005, 272 pp. ISBN 92 9064 141 X.

Books

- **Development and Dissemination of IPM for Vegetables in Eastern Africa.** Sithanantham S. (Kebaara K., Ed.) 2004, 51 pp. ISBN 92 9064 166 5.

Miscellaneous Publications

- **ARPPIS: Training Programmes in Insect Biosciences (2005–2007).** African Regional Postgraduate Programme in Insect Science (ARPPIS), *icipe*. Ochieng-Odero J. P. R. (Coordinator); Osogo D. (Ed.). 2005, 71 pp. ISBN 92 9064 173 8.
- **African Insect Science Bulletin.** Bulletin of the African Association of Insect Scientists (AAIS). Amadou Bocar Bal (Ed.), 2005, 43 pp.
- ***icipe* Annual Report Highlights 2004/5.** Compiled and edited by Ng'eny-Mengech A. 2005, 132 pp. ISBN 92 9064 174 6.
- ***icipe* Annual Scientific Report 2002–2003 (Reprint).** International Centre of Insect Physiology and Ecology (*icipe*). Compiled and edited by Ng'eny-Mengech A., 2004, 271 pp. ISBN 92 9064 165 7.
- ***icipe* Publications from 2000 to 2004 with Addendum to September 2005.** Compiled and edited by Osogo D. 2005, 72 pp. ISBN 92 9064 175 5.
- ***icipe* Security and Transport Manual (Reprint).** International Centre of Insect Physiology and Ecology (*icipe*). 2004, 16 pp.

D. Doctoral and Masters Theses by Graduates of icipe's Postgraduate Training Progammmes

PhD Thesis

Billah M. K. (2004) Biosystematic studies of *Psyttalia* species (Hymenoptera: Braconidae): Parasitoids attacking fruit-infesting flies (Diptera: Tephritidae) in Africa. (ARPPIS). University of Ghana, Legon-Ghana. (*icipe* Supervisors: S. Kimani-Njogu and W. Overholt). TH 595.77 BIL

MSc Theses

Juma G. (2005) Role of the plant's volatile and surface metabolites in mediating host selection of *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). (DRIP). Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya. (*icipe* Supervisors: P.-A. Calatayud, A. Hassanali).

Kithusi G. G. (2005) Evaluation of biopesticides in control of red spider mites (*Tetranychus evansi*) on tomatoes (*Lycopersicon esculentum*). (DRIP). Univeristy of Nairobi, Kenya. (*icipe* Supervisor: M. Knapp).

Machini J. M. (2005) Study of the efficacy of Oberon 240c (spiromesifen) and DC-Tron Plus on red spider mites (*Tetranychus evansi* Baker & Pritchard) on tomatoes (*Lycopersicon esculentum*) and their effect on predatory mites (*Phytoseilus persimilis* Athias-Henriot). (DRIP). University of Nairobi, Kenya. (*icipe* Supervisor: M. Knapp).

Murungi L. K. (2005) Chemical composition and activity of volatile compounds and essential oils in tomato accessions against the tobacco spider mite, *Tetranychus evansi* (Baker & Pritchard). (DRIP). Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya. (*icipe* Supervisors: M. Knapp, A. Hassanali).

Obonyo O. M. (2005) Performance of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) on stem borers of cereal and wild crops. (DRIP). Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya. (*icipe* Supervisors: F. Schulthess, P.-A. Calatayud).

Onyambu G. K. (2005) The role of trichomes and non-volatile phytochemicals in the resistance of *Lycopersicon* species to the tobacco spider mite (*Tetranychus evansi* Baker & Pritchard). (DRIP). Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya. (*icipe* Supervisors: M. Knapp, A. Hassanali).

Wekesa V. W. (2004) Evaluation of pathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* for the control of tobacco spider mite, *Tetranychus evansi* Baker & Pritchard (Acarina: Tetranychidae) infesting tomatoes. (DRIP). Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya. (*icipe* Supervisors: N. K. Maniania, M. Knapp).

E. Other Publications by icipe Scientists

(Publications by icipe staff on work not directly related to icipe and scholars' publications done under icipe's ARPPIS postgraduate sub-regional MSc training programme)

Atachi P., Sekloka E. T. and *Schulthess F.* (2005) Study on some bioecological aspects of *Eldana saccharina* Walker (Lep.: Pyralidae) on *Zea mays* L. and alternative host plants. *Journal of Applied Entomology* 129, 447–455.

Cerveira A. M. and *Jackson R. R.* (2005) Specialised predation by *Palpimanus* sp. on jumping spiders. *Journal of East African Natural History* 94, 303–317.

Chabi-Olaye A., Nolte C., *Schulthess F.* and *Borgemeister* C. (2005a) Abundance, dispersion and parasitism of the stem borer *Busseola fusca* (Lepidoptera: Noctuidae) in mono- and intercropped maize in the humid forest zone of southern Cameroon. *Bulletin of Entomological Research* 95, 169–177. 05-1787

Chabi-Olaye A., Nolte C., *Schulthess F.* and *Borgemeister* C. (2005b) Effects of grain legumes and cover crops on maize yield and plant damage by *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) in the humid forest of southern Cameroon. *Agriculture, Ecosystems & Environment* 108, 17–28.

Chabi-Olaye A., Nolte C., *Schulthess F.* and *Borgemeister* C. (2005c) Relationships of intercropped maize, stem borer damage to maize yield and land-use efficiency in the humid forest of Cameroon. *Bulletin of Entomological Research* 95, 417–427. 05-1799

***Gachoka K. K.*, Obeng-Ofori D. and Danquah E. Y.** (2005) Host suitability of two Ghanaian biotypes of *Bemisia tabaci* (Homoptera: Aleyrodidae) on five common tropical weeds. *International Journal of Tropical Insect Science* 25, 236–244.

Hondelmann P., *Borgemeister C.* and Poehling H.-M. (2005) Restriction fragment-length polymorphisms of different DNA regions as genetic markers in the hoverfly *Episyrphus balteatus* (Diptera: Syrphidae). *Bulletin of Entomological Research* 95, 349–359.

Jaramillo J., *Borgemeister C.*, Ebssa L., Gaigl A., Tobón R. and Zimmermann G. (2005) Effect of combined applications of *Metarhizium anisopliae* (Metsch.) Sorokin (Deuteromycotina: Hyphomycetes) strain CIAT 224 and different dosages of Imidacloprid on the subterranean burrower bug *Cyrtomenus bergi* Froeschner (Hemiptera: Cydnidae). *Biological Control* 34, 12–20.

Jaramillo J., Bustillo A. E., Montoya E. C. and *Borgemeister* C. (2005) Biological control of the coffee berry borer *Hypothenemus hampei* (Ferrari) (Coleoptera: Curculionidae, Scolytinae) by *Phymastichus coffea* LaSalle (Hymenoptera: Eulophidae) in Colombia. *Bulletin of Entomological Research* 95, 467–472.

Lambson B., Nene V., Obura M., Shah T., Pandit P., *ole-MoiYoi O. K.*, Delroux K., Wellburn S., Skilton R., De Villiers E. and Bishop R. (2005) Identification of candidate sialome components expressed in ixodid tick salivary glands using secretion signal complementation in mammalian cells. *Insect Molecular Biology* 14, 403–414. 05-1842

Lehmann I. and *Kioko E.* (2005) Lepidoptera diversity, floristic composition and structure of three Kaya forests on the South Coast of Kenya. *Journal of East African Natural History* 94, 121–163. 05-1812

Mutwiwa U. N., *Borgemeister C.*, von Elsner B. and Tantau H.-J. (2005) Effects of UV-absorbing plastic films on the greenhouse whitefly *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae). *Journal of Economic Entomology* 98, 1221–1228.

***Nedorezov L. V.* and Sadykova D. L.** (2005) Application of simplest discrete models to the description of green oak tortrix fluctuations, pp. 138–139. In *Proceedings of the Fifth European Conference on Ecological Modelling—ECEM 2005*, 19–23 September 2005, Puschino, Russia, (Edited by A. S. Komarov). IPBSS RAN, Russia.

***Nedorezov L. V.* and Utyupin Yu. V.** (2005) About continuous-discrete model of predator–prey system dynamics with saturation effect, pp. 140–141. In *Proceedings of the Fifth European Conference on Ecological Modelling—ECEM 2005*, 19–23 September 2005, Puschino, Russia, (Edited by A. S. Komarov). IPBSS RAN, Russia.

Ogembo J. G.*, Kunjeku E. C. and *Sithanantham S. (2005) A preliminary study on the pathogenicity of two isolates of nucleopolyhedroviruses infecting African bollworm, *Helicoverpa armigera* (Lepidoptera: Noctuidae). *International Journal of Tropical Insect Science* 25, 218–222. 05-1795

***Omondi B. A.*, Obeng-Ofori D., Kyerematen R. and Danquah E. Y.** (2005) Host suitability and preference of some selected crops for two biotypes of *Bemisia tabaci* in Ghana. *Entomologia Experimentalis et Applicata* 115, 393–400. 05-1785

***Omondi B. A.*, Sseruwagi P., Obeng-Ofori D., Danquah E. Y. and Kyerematen R.** (2005) Mating interactions between okra and cassava biotypes of *Bemisia tabaci* (Homoptera: Aleyrodidae) on eggplant. *International Journal of Tropical Insect Science* 25, 159–167. 05-1789

Premachandra D. W. T. S. D., *Borgemeister C.*, Achilles T. and Poehling H.-M. (2005) Distribution and population dynamics of *Ceratothripoides claratris* (Thysanoptera: Thripidae) on tomatoes in Thailand. *Environmental Entomology* 34, 883–890.

Premachandra D. W. T. S. D., *Borgemeister C.* and Poehling H.-M. (2005) Effects of neem and Spinosad on *Ceratothripoides claratris* (Shumsher) (Thysanoptera: Thripidae), an important vegetable pest in Thailand under laboratory and greenhouse conditions. *Journal of Economic Entomology* 98, 438–448.

Premachandra D. W. T. S. D., *Borgemeister C.*, Maiss E., Knierim D. and Poehling H.-M. (2005) *Ceratothripoides claratris*, a new vector of a capsicum chlorosis virus isolate infecting tomatoes in Thailand. *Phytopathology* 95, 659–663.

Sarr M., *Maniania N. K.*, Russell-Smith A. and Niassy A. (2005) (Mini Review) Diversité des termites (Isoptera) au Sénégal et leurs dégâts sur les cultures et périmètres reboisés. *International Journal of Tropical Insect Science* 25, 147–158. 05-1792

Tounou A.-K., Gounou S., *Borgemeister C.*, Goumedzoe Y. M. D. and *Schulthess F.* (2005) Susceptibility of *Eldana saccharina* (Lepidoptera: Pyralidae), *Busseola fusca* and *Sesamia calamistis* (Lepidoptera: Noctuidae) to *Bacillus thuringiensis* Cry toxins and potential side effects on the larval parasitoid *Cotesia sesamiae* (Hymenoptera: Braconidae). *Biocontrol, Science and Technology* 15, 127–137.

***van Schayk I. M. C. J.*, Agwanda R. O., *Githure J. I.*, Beier J. C. and Knols B. G. J.** (2005) El Niño causes dramatic outbreak of *Paederus dermatitis* in East Africa, pp. 240–247. In *Climate Change and Africa* (Edited by Pak Sum Low). Cambridge University Press, New York. 05-1811

Yano E., *Jiang N.*, Hemerik L., Mochizuki M., Mitsunaga T. and Shimoda T. (2005) Time allocation of *Orius sauteri* in attacking *Thrips palmi* on an eggplant leaf. *Entomologia Experimentalis et Applicata* 117, 177–184. 05-1904

Appendix 6:

icipe Collaborations

ARIs/NARES

Ethiopia
Benshangul Gumuz Bureau of Agriculture
Ethiopian Institute of Agricultural Research

France
Institut National de la Recherche Agronomique

Ghana
Plant Protection and Regulatory Services Directorate

Kenya
Coffee Research Foundation
Genebank of Kenya
Kenya Agricultural Research Institute
Kenya Forestry Research Institute
Kenya Plant Health Inspectorate Services
National Beekeeping Station
Tea Research Foundation

Kazakhstan
Kazakh Scientific Research Institute for Plant Protection

Madagascar
Centre National Antiacridien
Malagasy Research Centre
Projet de Lutte Preventive Antiacridienne

Malawi
Bvumbwe Agricultural Research Station

Mali
Institut d'Economie Rurale

Mauritania
Centre pour la Lutte Antiacridienne

Niger
Centre Regional de Formation et d'Application en Agrométéorologie et Hydrologie

Republic of South Africa
Plant Protection Research Institute

Russia
Institute of Systematics and Animal Ecology
V. N. Sukachev Institute of Forestry

Rwanda
Institut des Sciences Agronomiques du Rwanda

Sudan
Plant Protection Directorate

Tanzania (Mainland and Zanzibar)
Agricultural Research Institute

Uganda
Kawanda Agricultural Research Institute
National Agricultural Research Organisation
National Forest Authority

United Kingdom
Rothamsted Research

USA
US Department of Agriculture-Agricultural Research Service

Zimbabwe
Plant Protection Research Institute

Research Laboratories

Burkina Faso
Laboratoire d'Entomologie Agricole de Kamboinsé

Ethiopia
Institute of Biodiversity Conservation and Research

France
Centre National de la Recherche Scientifique
Institut de Recherche pour le Développement

Germany
Max Planck Institut für Chemische Ökologie

Kenya
Kenya Medical Research Institute
Kenya Trypanosomiasis Research Institute
Veterinary Investigation Laboratories

Russia
Institute of Molecular Biology and Biophysics

Switzerland
Swiss Federal Institute of Technology

United Kingdom
The Wellcome Trust Sanger Institute
Centre for Ecological Entomology

Ministries/Government Agencies/Local Councils

Cameroon
Ministry of Agriculture

Egypt
Ministry of Agriculture

Eritrea
Ministry of Agriculture
Ministry of Health

Ethiopia
Ethiopian Social Rehabilitation and Development Fund
Gurage Zone Administration
Ministry of Agriculture

Ghana
Ministry of Agriculture

Kazakhstan
Ministry of Agriculture

Kenya
Arabuko-Sokoke Forest Management Team
Kenya Prisons Service
Kenya Wildlife Service
Mbeere County Council
Ministry of Agriculture and Rural Development
Ministry of Education, Science and Technology
Ministry of Environment and Natural Resources and Wildlife

Ministry of Health
Ministry of Livestock and Fisheries Development
Municipal Council of Malindi
National Environmental Management Authority
National Irrigation Board
National Malaria Control Programme
Tana Delta Irrigation Project

Madagascar
Ministère de l'Agriculture
Ministère des Universités et de la Recherche

Rwanda
Ministry of Agriculture

Sudan
Ministry of Agriculture

Tanzania (Mainland and Zanzibar)
Ministry of Agriculture and Food Security

Uganda
Ministry of Agriculture, Animal Industry and Fisheries

Yemen
Ministry of Agriculture

NGOs

Ethiopia
Sasakawa Global 2000

Kenya
Business Services Market Development Project
Environment Liaison Centre International
Heifer International
Kenya Gatsby Trust
Kenya Institute of Organic Farming
Nature Kenya
Pact Kenya
Population Services International
Pride Africa
TechnoServe-Kenya

Tanzania
Tanzania Forest Conservation Group
Wildlife Conservation Society of Tanzania

Uganda
Africa 2000 Network

USA
Critical Ecosystem Partnership Fund

Private Organisations

Kenya
ADHEK Ltd
Africert Ltd
Agribusiness and Allied Ltd
Antioch Enterprises Ltd
BIOP Kenya Ltd
East African Growers Ltd
Freshlink Ltd
Frigoken Ltd
Greenlands Agroproducers Ltd
Green Development Group
Hyacinth Crafts
InduFarm (K) Ltd
Kenya Horticulture Exporters Ltd
Myner Exporters Ltd
Paperazzi Ltd
Ukulima East Africa Ltd
Viking Ltd
Wild Living

USA
Diversa Corporation
Valent BioSciences Corporation

Museums

Belgium
Royal Museum of Central Africa

Kenya
National Museums of Kenya

Republic of South Africa
South Africa Museum
Transvaal Museum

United Kingdom
Natural History Museum

USA
Missouri Botanical Gardens

Networks/Consortia

African Network for Agriculture, Forestry and Environment Education
African Forum for Health Sciences
African Malaria Network Trust
Forum for Agricultural Research in Africa programme on Building Africa's Scientific and Institutional Capacity for Agriculture and Natural Resources
Pan African Tsetse and Trypanosomosis Eradication Campaign
Third World Academy of Sciences
Third World Organization for Women in Science

International Organisations

CAB International
Centro Internacional de Agricultura Tropical
Centro Internacional de Mejoramiento de Maiz y Trigo
Conservation International
Food and Agriculture Organization of the United Nations/Emergency Prevention System
International Atomic Energy Agency
International Crops Research Institute for the Semi-Arid Tropics
Japan International Research Centre for Tropical Agricultural Sciences
Japan Society for the Promotion of Science
International Institute of Tropical Agriculture
International Livestock Research Institute
International Plant Genetics Research institute
International Water Management Institute
United Nations Development Programme/Global Environment Facility Small Grants Programme
World Agroforestry Centre
World Health Organization
World Vegetable Centre
World Wide Fund for Nature

Regional Organisations

African Union
Desert Locust Control Organisation for Eastern Africa
East African Herbarium
East African Wildlife Society
International Red Locust Control Organisation for Central and Southern Africa

Regional Centre for Mapping of Resources for Development

Universities

Brazil
University of Sao Paulo
Universidae Federal Rural de Pernambuco
Universidae Federal Rural de Cariri
Universidade de Lavras

Cameroon
University of Dschang

Egypt
Assiut University

Ethiopia
Addis Ababa University
Alemaya University

Eritrea
University of Asmara

France
Ecole Nationale Superieure Agronomique

Germany
University of Göttingen
University of Hannover

Ghana
University of Cape Coast
University of Ghana

Kenya
Egerton University
Jomo Kenyatta University of Agriculture and Technology
Kenyatta University
Maseno University
Moi University
University of Nairobi

Italy
University of Reggio di Calabria

Malawi
University of Malawi

Mozambique
Eduardo Mondlane University

Namibia
University of Namibia

Norway
University of Oslo

Nigeria
Ahmadu Bello University
Enugu State University
University of Ibadan
University of Agriculture at Makurdi
Nnamdi Azikiwe University
Ogun State University
Rivers State University of Science and Technology

Republic of South Africa
North West University
University of Natal
University of Pretoria
University of the Western Cape

Russia
Novosibirsk State University

Rwanda
National University of Rwanda

Sudan
University of Gezira
Khartoum University

Sweden
Lund University
Swedish University of Agricultural Sciences
Uppsala University

Syria
University of Aleppo

Tanzania
Sokoine University of Agriculture
University of Dar es Salaam

The Netherlands
University of Amsterdam
University of Nijmegen
Wageningen Agricultural University
Wageningen University and Research Centre

Uganda
Gulu University
Makerere University

United Kingdom
Glasgow University
Oxford University
University of Greenwich
University of Newcastle upon Tyne

USA
Miami University
Ohio State University
New York State University
Texas A&M University
Tulane University
University of California
University of Illinois
University of Virginia

Zambia
University of Zambia

Zimbabwe
University of Zimbabwe

APPENDIX 7:

Seminars at *icipe* during 2004

Date	Presenter	Title
4 Feb	J. Baumgärtner	Ecological System Management
8 June	V. J. Adolkar	Strategies for Development of Organic Silk Farming in Kenya
22 June	A. Barrion	Harnessing Grass and Insect Diversity: A Case of Livelihood Improvement Through Ecology
25 June	Brian Merlin, Abbot Laboratories, Chicago, Illinois, USA	Production of Larvicides for Agricultural and Public Health Use
6 July	A. Ngi-Song	Assessment of the Potential Risk of Classical Biological Control of Cereal Stemborers on Non-target Lepidoptera in Kenya
20 July	W. Lwande	Towards Conservation of Montane and Rainforests in Kenya and Uganda
17 August	S. Raina	Towards Sustainable Rural Livelihood Initiatives for African Farmers
10 September	Dennis Grab, Johns Hopkins University School of Medicine, Baltimore, USA	Taking a Tryp Across the Human Blood–Brain Barrier: A New Adventure!
14 September	P. Njagi	Mode of Action of Phenylacetonitrile on Nymphal *S. gregaria*: Some Physiological Effects
21 September	L. Gouagna	Malaria and Vectors: Highlight of Natural Regulations of Vector Competence and Prospects for Malaria Control
28 September	J. Shililu	Vector Ecology and Control: Implications for Malaria Control
16 November	Julius Arinaitwe (Birdlife)	Birds, People and the Environment: Ideas for Sustainable Natural Resources Management in Africa
23 November	R. Saini	Repellents for Integrated Tsetse Management

Appendix 8:

Seminars at *icipe* during 2005

Date	Presenter	Title
29 March	Milton Lore Bridgeworks Africa	Bridgeworks—Commercialising Research at *icipe*
26 April	Ellie O. Osir	Candidate Genes for Paratransgenesis of Disease Vectors
24 May	Peter Roesingh University of Amsterdam, The Netherlands	Chemoreception in Insects: The Locks and Keys of Speciation
31 May	Solomon Asfaw University of Hannover, Germany	Economic Impact Assessment as a Decision-Making Tool for Resource Allocation in Horticultural Research in East Africa
9 August	Cyrus Watuku	Introducing the Leave Management Software
23 August	I. Ogendo	Creating a PowerPoint Presentation
13 September	S. Raina	Endocrine Regulation and Behavioural Physiology of Stingless Bees, *Meliponula* sp. of Coastal and Rainforests in Kenya
20 September	J. Baumgärtner	Ecosocial System Management: Some Principles and Their Application
	Gianni Gilioli Università Mediterranea di Reggio Calabria, Italy	Epidemiology Modelling Within An Ecosocial System Framework
27 September	Z. Khan, A. Hassanali	*Desmodium* in the Control of Witchweeds (*Striga* spp): Status of Downstream and Upstream R&D at *icipe*
18 October	J. Shililu	Managing Malaria in a Rice Agroecosystem: The Case of Mwea Irrigation Scheme, Kenya
1 November	I. Gordon	Conservation through Livelihood Support: Does It Work?
8 November	V. Adolkar	Establishment of Grainage for Silkworm Races in Mbita Point Field Station
15 November	Juliana Jaramillo	Biological Control of the Coffee Berry Borer *Hypothenemus hampei* (Ferrari) (Coleoptera: Scolytinae) by *Phymastichus coffea* LaSalle (Hymenoptera: Eulophidae)

APPENDIX 9:

Audited Financial Statements 2004, 2005

BALANCE SHEET

AS AT 31 DECEMBER 2005

	2005 (US$)	2004 (US$)
NON-CURRENT ASSETS		
Property and Equipment	571,682	606,987
Joint Venture Project	45,084	65,084
	616,766	672,071
CURRENT ASSETS		
Consumable Stores	109,481	94,328
Grants Receivable	1,254,963	1,106,248
Debtors and Prepayments	1,515,935	1,356,450
Bank and Cash Balances	1,523,564	1.334,659
	4,403.943	3,891,685
TOTAL ASSETS	5,020,709	4,563,756
CURRENT LIABILITIES		
Creditors and Accruals	2,263,810	2,223,738
Unexpended Operating Grants	2,530,970	2,164,278
	4,794,780	4,388,016
LONG TERM LIABILITIES		
Provision for Staff Separation and Relocation Pay	223,687	415,589
TOTAL LIABILITIES	5,018,467	4,803,605
TOTAL ASSETS LESS TOTAL LIABILITIES	2,242	(239,849)
FINANCED BY:		
Accumulated surplus/(deficit)	2,242	(239,849)

Income and Expenditure Account

FOR THE YEAR ENDED 31 DECEMBER 2005

	2005 (US$)	2004 (US$)
INCOME		
Unrestricted Core Grants	2,662,892	2,941,320
Restricted Projects Grants	7,810,627	6,941,874
Miscellaneous Income	628,607	474,548
Currency Translation Gain	4,893	90,220
Total Income	11,107,019	10,447,962
EXPENDITURE		
Project and Support Costs		
Centre Management	959,704	922,449
Research and NRES Strengthening	8,239,149	7,619,004
International Cooperation	–	333
Administration and Finance	649,654	766,526
Other Support Units	554,945	520,745
Utilities	585,919	618,601
Overhead Recovery	(446,459)	(455,355)
Total Project and Support Expenses	10,542,912	9,992,303
Purchase of Fixed Assets		
Scientific Equipment	15,066	15,661
Office Equipment and Furniture	73,694	34,801
Others	28,163	1,705
Vehicles	205,093	98,977
Total	322,016	151,144
Total Expenditure	10,864,928	10,143,447
SURPLUS FOR THE YEAR	242,091	304,515

SCHEDULE OF GRANTS (2004)

DONOR	Income (US $)
UNRESTRICTED GRANTS	
Danish International Development Agency (DANIDA)	496,690
French Government	39,000
Japanese Society for the Promotion of Science (JSPS)	6,000
Kenya Government	9,314
Norwegian Government	288,163
Swedish International Development Agency (SIDA)	1,093,546
Swiss Government	1,008,607
Total unrestricted grants	**2,941,320**
RESTRICTED GRANTS	
Australian Centre for International Agricultural Research (ACIAR)	2,505
Biovision Foundation	444,120
CAB International	12,530
Conservation International	248,969
Department for International Development (DFID), UK	281,827
Diversa Corporation	79,483
DuPont Corporation	94,169
European Union	53,528
Finnish Government	146,547
Food and Agriculture Organisation of the United Nations (FAO)	68,097
Ford Foundation	98
Gatsby Charitable Foundation	425,477
German Academic Exchange Service (DAAD)	140,040
German Federal Ministry of Economic Co-operation, German Technical Cooperation (BMZ)	744,708
International Centre for Scientific Culture-World Laboratory, Switzerland	17,624
International Fund for Agricultural Development (IFAD)	301,331
International Fund for Agricultural Development (IFAD)-*icipe*/ILRI/KETRI Collaborative Tsetse Project	249,321
International Institute of Tropical Agriculture (IITA)	767
International Water Management Institute (IWMI)	64,544
Japan International Research Centre for Agricultural Sciences (JIRCAS)	203,784
MacArthur Foundation	64,492
National Institutes of Health (NIH), USA	464,732
National Science Foundation (NSF), USA	33,657
Netherlands Government, Directorate for NGO, International Education and Research Programme (DPO)	1,152,661
Rockefeller Foundation	165,664
Sundry Grants	259,170
Swiss Government Special Grant	149,006
Texas A&M Research Foundation	1,464
United Nations Development Programme (UNDP)	203,046
United Nations Children's Fund (UNICEF)	17
United Nations Environment Programme (UNEP)	238,600
United States Agency for International Development (USAID)	256,812
United States Department of Agriculture (USDA)	121,186
World Health Organisation (WHO)	251,899
Total restricted grants	**6,941,874**
Total operating grants	**9,883,194**

SCHEDULE OF GRANTS (2005)

DONOR	Income (US $)
UNRESTRICTED GRANTS	
Danish International Development Agency (DANIDA)	475,231
French Government	58,784
Japan International Research Centre for Agricultural Sciences (JIRCAS)	6,000
Kenya Government	13,344
Swedish International Development Agency (SIDA)	1,036,040
Swiss Government Special Grant	1,073,493
Total unrestricted grants	**2,662,892**
RESTRICTED GRANTS	
African Fund for Development	808
Biovision Foundation	690,708
Conservation International	267,625
Department for International Development (DFID), UK	179,271
Diversa Corporation	54,290
DuPont Corporation	132,421
European Union	23,833
Finnish Government	178,251
Food and Agriculture Organisation of the United Nations (FAO)	19,130
Ford Foundation	166,744
French Government	34,188
Gatsby Charitable Foundation	412,642
German Academic Exchange Service (DAAD)	207,636
German Federal Ministry of Economic Co-operation, German Technical Cooperation (BMZ)	932,118
International Centre for Scientific Culture-World Laboratory, Switzerland	8,568
International Fund for Agricultural Development (IFAD)	595,054
International Fund for Agricultural Development (IFAD)-*icipe*/ILRI/KETRI Collaborative Tsetse Project	142,279
International Water Management Institute (IWMI)	163,396
Japan International Research Centre for Agricultural Sciences (JIRCAS)	5,918
National Institutes of Health (NIH), USA	434,513
National Science Foundation (NSF), USA	28,965
Netherlands Government, Directorate for NGO, International Education and Research Programme (DPO)	1,353,687
Rockefeller Foundation	166,357
Sundry Grants	817,762
Swedish International Development Agency (SIDA)	15
Swiss Government Special Grant	15
Texas A&M Research Foundation	1,559
Toyota Foundation	69,785
United Nations Development Programme (UNDP)	292,110
United Nations Children's Fund (UNICEF)	16,564
United Nations Environment Programme (UNEP)	165,884
United States Agency for International Development (USAID)	62,159
United States Department of Agriculture (USDA)	107,056
World Health Organisation (WHO)	79,316
Total restricted grants	**7,810,627**
Total operating grants	**10,473,519**

Appendix 10:

icipe Staff and Governing Council Members
(as at 31st December 2004)

Research Management

Office of the Director General
Hans Rudolf Herren, *Director General and CEO*
Enock Kimanzi Nguthu, *Internal Auditor****
Susan Kariuki, *Executive Officer*
Elizabeth N. Ng'ang'a, *Consultant Press Officer*
Kristine Wambui Karanja, *Receptionist****
Francis Omondi Ujiji, *Driver*
Fredrick Chichi Makhulo, *Office Assistant*

Office of the Director of Research and Partnerships
Onesmo K. ole-MoiYoi, *Director of Research and Partnerships*
Lucy M. Theuri, *Assistant Programme Manager*

Research Divisions

Plant Health
Bernhard Löhr, *Principal Scientist and Division Head*

Staple Food Crops
Fritz Schulthess, *Principal Scientist and Coordinator, Biological Control of Cereal Stemborers in Eastern and Southern Africa Project*
Zeyaur Rahman Khan, *Principal Scientist*
Charles Omambia Omwega, *Senior Scientist and Regional Coordinator, Biological Control of Cereal Stemborers in Eastern and Southern Africa Project*
Adele Josee Ngi-Song, *Scientist***
Nanqin Jiang, *Research Scientist*
Isaac Njaci, *Project Documentalist****
Eric Muchugu, *GIS Specialist*
Joseph Owino Ochieng', *Technician*
Daniel Kinyanjui Mungai, *Technician/Driver*
Gerphas Okuku Ogola, *Technician*
Peter Omolo Owuor, *Technical Assistant*
Hellen Heya Mwadime, *Technical Assistant*
Julius Obonyo Ochieng, *Technical Assistant*
Carolyne Akal, *Project Secretary*
Jane Wacera Kiarie, *Technical Assistant****

Horticultural Crops
Bernhard Löhr, *Principal Scientist and Head, Horticultural Crops Sub-Division*
Slawomir Antoni Lux, *Principal Scientist and African Fruit Fly Initiative Programme Leader*
Srinivasan Sithanantham, *Senior Scientist and African Bollworm Egg Parasitoid Project Leader***
Markus Knapp, *Scientist and Tomato Red Spider Mite Project Leader*
Ana Milena Varela, *Consultant*
Abdurabi Seif, *Consultant*
Andrea Rossbach, *Visiting Scientist*
Susanne Michalik, Visiting Scientist
El-Sayed El-Banhawy, *Visiting Scientist****
Paul Mbugua, *Visiting Scientist****
Linus Gitonga, *Visiting Scientist****
Gatama Gichini, *Senior Research Assistant****
Ibrahim Macharia, *Research Assistant*
Peterson Wachira Nderitu, *Research Assistant*
Constance Andeyo Muholo, *Research Assistant***
Caleb Mose Momanyi, *Research Assistant, Pesticide Initiative Programme***
Nicholas Mungula Mwikya, *Technician*
Miriam Mwarania Kungu, *Technician*
Bernard Musembi Muia, *Technician*
Faith Wamurango Nyamu, *Technician*
Gideon Jira Chigunda, *Technician***
John Mbatha Kiilu, *Technical Assistant*
Andrew Wanyonyi, *Technical Assistant***
Judith Mumo Kiluvu, *Technical Assistant***
Raphael Mukiti, *Technical Assistant*
Carlos Maweu, *Technical Assistant*
Lydia Vutsigwa Masambu, *Technical Assistant/Survey Data Processing and Documentation***
Martin Amugune Wanyonyi, *Technical Assistant***
Gladys Kemunto Onyambu, *Technical Assistant****
Everlyne Nafula Wosula, *Technical Assistant****
Charles Muchina Kanyi, *Driver/Mechanic*
Geoffrey Gachanja Kinyanjui, *Driver*
Peris Karimi Machera, *Technical Assistant***
Joseph Gachugu Mucheru, *Driver***
Rose Atieno Ogolla, *Secretary*
Beatrice Muthoni Gikaria, *Secretary*

Mbita Point-based
George Genga, *Technician*
Pascal Agola Oreng, *Technical Assistant*
Aloice Ouma Ndiege, *Technical Assistant*
Dickens Nyagol, *Technical Assistant*
Nahashon Ogongo Otieno, *Field Assistant/Driver****

Locusts and Migratory Pests
Ahmed Hassanali, *Principal Scientist and Head, Locusts and Migratory Pests Sub-Division*
Yoshida Takao, *Coordinator, icipe-JIRCAS Project***

Port Sudan Field Station-based
Magzoub Omer Bashir, *Consultant and Scientist-in-Charge, Port Sudan Field Station*
Sidi Ould Ely, *Visiting Scientist*
Abdul Rahim W. Bashir, *Technician*
Haidar H. Korena, *Technician*

Animal Health
Rajinder K. Saini, *Principal Scientist and Ag Division Head; Tsetse Research Programme Leader*
John Akiri Andoke, *Research Assistant*
Peter Nthale Muasa, *Technical Assistant*
Richard Ouma Tumba, *Technical Assistant/Driver*
Carolyne Muthoni Muya, *Secretary*

Nguruman-based

Mariaso ole Pukare, *Technical Assistant***

Human Health

John Githure, *Visiting Scientist and Ag Division Head (seconded by KEMRI); Malaria Vectors Programme Leader*

John Beier, *Visiting Scientist-University of Miami, USA*

Josephat Shililu, *Visiting Scientist*

Guiyun Yan, *Visiting Scientist-State University of New York, USA*

Ulrike Fillinger, *Visiting Scientist***

Weiner Spitteler, *Visiting Scientist****

Pamela Beatrice Seda, *Research Assistant*

Peter Baraza Wekoyela, *Research Assistant****

Ephantus Juma Muturi, *Research Assistant****

Milcah Gitau, *Technician*

Enock Mpanga, *Technician*

Charles Muriuki, *Technical Assistant*

Nelly Gatwiri Gitonga, *Technical Assistant*

Faith Kyengo, *Secretary*

Mbita Point-based

Louis Gouagna, *Visiting Scientist-OCEAC, Cameroon***

David Simon, *Visiting Scientist****

Robert Ray Jackson, *Visiting Scientist*

Evans Mathenge, *Visiting Scientist***

Basilio Ngari Njiru, *Technician*

Jackton Arija, *Technical Assistant*

Peter O. Obare, *Technical Assistant***

Lawrence Omukuba, *Technical Assistant***

Kisii-based

François Omlin, *Visiting Scientist, Cape Town University, RSA*

Emmanuel Mushinzimana, *Consultant*

Samson Kiriri Gichia, *Research Assistant***

Wycliffe Lumumba Migiro, *Technician***

Jared Kaunda Aroko, *Driver/Mechanic***

Abel Omari Mainya, *Driver***

Eric Olielo Odhiambo, *Field Assistant***

Kilifi-based

Charles Mbogo, *Visiting Scientist, KEMRI*

Mwea-based

Nicholas Gachiki Kamari, *Field Assistant****

Martin Ngigi Njigoya, *Field Assistant****

Charles Chomba Kiura, *Field Assistant****

Susan Wanjiku Mugo, *Field Assistant****

Christine Wangari Maina, *Field Assistant****

Nelson Muchiri Maingi, *Field Assistant****

Isabel Wanjiku Marui, *Field Assistant****

Peter Muriuki Mutiga, *Field Assistant****

William Waweru Michiri, *Field Assistant****

Paul Kibuchi Mwangi, *Field Assistant****

Environmental Health

Ian Gordon, *Principal Scientist and Division Head*

Alberto Barrion, *Scientist and Head of Biosystematics Support Unit; Assistant Coordinator GEF Grass Project***

Suresh Kumar Raina, *Principal Scientist and Commercial Insects Programme Leader*

Wilber Lwande, *Senior Scientist and Programme Leader Kakamega/Echuya Forests Conservation Projects*

Vijay Vishnu Adolkar, *Scientist*

Esther Ndaisi Kioko, *Scientist*

Robert Copeland, *Visiting Scientist-Texas A&M University, USA*

Bruno P. Le Ru, *Visiting Scientist-Institut de Recherche pour Developpement*

Paul-Andre Calatayud, *Visiting Scientist-Institut de Recherche pour Developpement*

Scott E. Miller, *Visiting Scientist*

Viola Clausnitzer, *Visiting Scientist*

Thomas Bergsdolf, *Visiting Scientist*

Guy D'Ieteren, *Visiting Scientist*

Barbel Bleher, *Visiting Scientist*

Nina Farwig, *Visiting Scientist*

Lucie Rogo, *Visiting Scientist*

James C. Register, *Visiting Scientist***

Rafael Hermman, *Visiting Scientist***

Bill McCutchen, *Visiting Scientist*

Ronald Flannagan, *Visiting Scientist***

Martin Keller, *Visiting Scientist***

James Pesnail, *Visiting Scientist***

Eric Jan Mathur, *Visiting Scientist***

Leif Pierce Christoffersen, *Visiting Scientist***

Susan Alison Wren, *Visiting Scientist****

Rolf Gloor, *Visiting Scientist*

Matilda Okech, *Senior Research Assistant*

Jael Auma Lumumba, *Technical Assistant*

Benard Nixon Onyimbo, *Technical Assistant*

George Owino Oduor, *Technical Assistant*

George Kamau Nyakiringa, *Technical Assistant*

James Kimani Ng'ang'a, *Technical Assistant*

Boaz Kimanzi Musyoka, *Technical Assistant*

Joseph Ndungu Gitau, *Technical Assistant****

Beatrice Wanjiru Njuguna, *Technical Assistant***

Rose Anyango Onyango, *Administrative Secretary*

Everline Alison Ndenga, *Administrative Assistant*

Mercy Gicichu Ndwiga, *Project Assistant****

Mbita Point-based

Zeyaur Rahman Khan, *Principal Scientist and Grass/Arthropod Diversity Project Coordinator*

Robert Copeland, *Visiting Scientist-Texas A&M University, USA and Assistant Coordinator, Grass/Arthropod Diversity Project*

Francis N. Muyekho, *Visiting Scientist, KARI Kitale; Country Coordinator Grass/Arthropod Diversity Project***

Shinsaku Koji, *Visiting Scientist****

Nancy Mwihaki Ng'ang'a, *Social Scientist, KARI***

Stephen Onyango Osore, *Web Page Designer***

Busia-based

Peter Odhiambo Ollimo, *Technician*

Kitale-based

Naphtali Ochieng Dibogo, *Technical Assistant*

Machakos-based

Eshmael Kidiavai, *Technician*

Capacity Building and Institutional Development Programme

James Patrick Ochieng'-Odero, *Head, Capacity Building and Institutional Development Programme*

African Regional Postgraduate Programme in Insect Science (ARPPIS) Scholars

PhD Scholars

Daniel Ndem Amin, Hortance Manda (Cameroon); Abebe Yonas Feleke, Ferede Melaku Wale, Gashawbeza Ayalew (Ethiopia); Maxwell Billah (Ghana); Anderson Kipkoech, Catherine Wanjiku Gitau, Charles Aura Midega, Esther Mwihaki Njuguna, Janet Theresa Midega, Leunita Asande Sumba, Matthews Kipchumba Bett, Salome Guchu, Spala Ohaga Oduor (Kenya); Cugala Domingos (Mozambique); Aruna Manrakhan (Mauritius); Alioune Toure (Senegal); Charles Kihampa, Innocent Ester (Tanzania); Bruce Yaovi Anani, Fiaboe Komi Mokpokpo (Togo); Andrew Kalyebi, Teddy Kauma Matama (Uganda)

MSc Scholars

Olivia Achuonduh (Cameroon); Charo Samuel Kahindi, Jacinter Atieno O. Odhiambo (Kenya); Audu Abdullahi, Zakka Usman (Nigeria)

Dissertation Research Internship Programme (DRIP) Scholars

PhD Scholars

Elliud Muli Maundu, Emmah Omulokoli, Everlyn Kamene Nguku, Joseph Msanzu Baya, Joseph Odhiambo, Maurice Vincent Omollo, Paul Odhiambo Mireji, Ruth Gathu, Wilfred Injera (Kenya); Radoslaw T. Brzezowski (Poland)

MSc Scholars

Abdallah Ali, Allen Mweke, Cecilia Nzau, Consolata Atieno Ager, Dennis Wanyama Ochieno, Evans Okoth, Faith Toroitich, Franscisca Malenge, Gerald Juma, James Ireri Kanya, James Mutuku Mutunga, Jamleck John Muturi, John Bwire Ocholla, Joseph Odero Owino, Joseph K. Thamuta, Lucy Kanani Murungi, Lucy Kibe, Lucy Mwende Mackenzie, Marion Wariga Burugu, Patrick Shem, Philip Wafula Mayeku, Priscillar Mumo Mutungi, Samuel Karenga, Selwyn Aloo, Sopher Ondiako, Stephen Makali Musyoka, Timothy Maina Rimu, Vincent Owino (Kenya)

[Note that postgraduate students are not officially icipe staff but are major contributors to icipe's R&D effort.]

Science Departments

Behavioural and Chemical Ecology Department

Ahmed Hassanali, *Principal Scientist and Department Head*
Wilber Lwande, *Senior Scientist and Programme Leader, Applied Bioprospecting*
Peter Njagi, *Consultant*
Yoshida Takao, *Coordinator, icipe-JIRCAS Project***
Nicholas Gikonyo, *Visiting Scientist, University of Nairobi*
Muniru Tsanuo Khamis, *Visiting Scientist, JKUAT*
Mary W. Ndungu, *Visiting Scientist, JKUAT*
Aklilu Seyoum, *Visiting Scientist, Addis Ababa University*
Isaac Mwanzo, *Visiting Scientist, Kenyatta University*
B. Onesmus Kaye Wanyama, *Senior Research Assistant*
Edward Nyandat, *Senior Research Assistant*
Lamberts V. Moreka, *Research Assistant*
Martin Collins Koko, *Technician*
David Mbuvi Mbesi, *Technical Assistant*
Ben Sylvester Olukohe, *Technical Assistant***
Rose Muthoni Marubu, *Technical Assistant****
Charity Waruinu Mwangi, *Secretary*

Mbita Point-based

Zeyaur Rahman Khan, *Principal Scientist and Habitat Management Programme Leader*
Stephen Onyango Osore, *Webdesigner***
Samuel Ezekiel Mokaya, *Technical Assistant/Driver*
Stephen Gwendo Ogechi, *Technical Assistant/Driver***
Elisha Kongere, *Technical Assistant/Driver*
Philip Salim Juma, *Field Attendant/Driver*

Port Sudan Field Station-based

Magzoub Omer Bashir, *Consultant and Scientist-in-Charge, Port Sudan Field Station*

Molecular Biology and Biotechnology Department

Ellie Osir, *Principal Scientist and Unit Head*
Rémy Pasquet, *Principal Scientist**
Daniel Masiga, *Visiting Scientist*
Mathayo Mangwe Chimtawi, *Research Assistant*
James Gitari Kabii, *Research Assistant*
Mark Gacau Kimondo, *Research Assistant*
Violet Jepchumba, *Research Assistant****
Rosekellen N. Njiru, *Data Input Clerk*

Muhaka-based

Athumani Gunia, *Research Assistant*
Beatrice Elesani, *Field Assistant*
George Okoth Nyambach, *Field Assistant****
Masudi Mohamed Koja, *Field Assistant****

Population Ecology and Ecosystems Science Department

Johann Baumgärtner, *Principal Scientist and Department Head*
Getachew Tikubet, *Consultant and Scientist-in-Charge, Ethiopia Country Office***
Gianni Gilioli, *Visiting Scientist*
Melaku Girma, *Consultant, Biovillage Project***

Research Support Units and Services

Arthropod Pathology Unit

Nguya Kalemba Maniania, *Senior Scientist and Unit Head*
Sunday Ekesi, *Research Scientist*
Xiang Xie, *Visiting Scientist, Bt Project*
Elizabeth Awuor Ouna, *Research Assistant*

Biostatistics Unit

Lev V. Nedorezov, *Senior Scientist and Unit Head*
Anthony Kibira Wanjoya, *Senior Research Assistant*

Information Technology and Bioinformatics Unit

Yunlong Xia, *Head, Information Technology and Bioinformatics***
Glenn Mark Sequeira, *Webmaster*
John Mureithi Mwangi, *Network Administrator*
Allan Anthony Kamau, *Programmer/Web Developer***

Mbita Point-based
Fredrick Ochieng Orwa, *EDP Specialist, IT*

Social Science Unit

Achola Pala Okeyo, *Principal Scientist and Unit Head****

Animal Rearing and Containment Unit

James Patrick Ochieng'-Odero, *Senior Scientist and Unit Head*
Francis Omeno Onyango, *Senior Research Assistant/ Coordinator of Insectary Services*
John Wabwire Otsieno, *Technician*
James Henry Ongudha, *Technician***
Matthew Mugweru Miti, *Technical Assistant*
James Henry Ongudha, *Technician***
Alphonse Majanje, *Technical Assistant*
Paul Odawo Wagara, *Technical Assistant*
Raphael Odhiambo Agan, *Technical Assistant***

Mbita Point-based
Amos Gadi Nyangwara, *Technical Assistant*

Technology Transfer Unit

Brigitte Nyambo, *Senior Scientist and Unit Head*
Janet Nguna Maundu, *Research Assistant*

Mwea-based
James Kariuki Kabunyi, *Technical Assistant*

Mbita Point-based
Bernard Mulwa Musee, *Driver/Mechanic (Biovision Project)*

Information and Publications Unit

Annalee Ng'eny-Mengech, *Principal Science Editor and Unit Head; Managing Editor,* International Journal of Tropical Insect Science (IJT)
Jean Claude Nsengimana, *Consultant Science Editor,* International Journal of Tropical Insect Science
Irene A. Ogendo, *Graphics Artist*
Dolorosa Osogo, *Editorial Assistant*
Joseph Mwanthi Malombe, *Printing Technician*
Edward Isaya Mung'aya, *Assistant Print Finisher****
Joshua Mbithi Kisini, *Clerical Assistant*
Gilbert Mwaura Kageche, *Driver*
Annclaire Muthoni Ndungu, *Secretary*

Information Resources Centre
Eddah Wasike, *Library Assistant*
Joash Ada Lago, *Library Assistant*
Wellington Ambaka, *Clerical Assistant*

Administration and Finance

Christopher Geoffrey Hill, *Director, Finance and Administration*

Finance

Accounting

Dinah Wairimu Njoroge, *Financial Controller*
Patrick Ngahu Ndiangui, *Project Accountant*
Cyrus Kimani Watuku, *Systems Analyst*
Eustace Njuma Mbuthia, *Treasury Accountant*
Peter Nyakeri Onsongo, *Management Accountant***
George Muchuku Kiondo, *Assistant Project Accountant*
Peter Ossmy Ngugi, *Assistant Accountant*
Nancy Wangui Mwangi, *Accounts Assistant***
Zeena Adams Ahmed, *Project Assistant****
Alphonse Bubusi, *Mail Clerk*

Mbita Point-based
Henry Victor Ligedere, *Assistant Accountant*
John Muhia Kibera, *Accounts Assistant*

Procurement

Peter Dickson Kamau Ndirangu, *Procurement Supervisor*
Daniel Oduor Owino Olalo, *Storekeeper*
Patrick Matheri Munyui, *Administrative Assistant*
Elias Maikuri Aosa, *Purchasing Officer****
Millicent Wanjiku Mburu, *Data Input Clerk****
Tobias Odongo Oloo, *Purchasing Officer***

Mbita Point-based
John Odongo Gombe, *Purchasing Officer*

Administration

Human Resources

Duduville-based
Willis Harrison Awori, *Human Resources Manager*
Lucy Wangari Macharia, *Specialist/Benefits Compensation*
Purity Ngima Kawelu, *Recruitment Specialist*
Titus Musyoki Kaviti, *Clerical Assistant*
Simprose Oyola Oyugi, *Receptionist/Telephone Supervisor*
Dominic Ogembo Mogeni, *Receptionist/Telephonist*
Josephine Akoth Opiyo, *Receptionist/Telephonist*
Elijah Asami, *Mail Clerk*
Syprine Amolo Abongo, *Janitorial Assistant*
Esinas Jeptum Tirop, *Office Attendant*
George S. K. Kariuki, *Office Attendant*
Benard Mita Okech, *Office Attendant*
Elias Ondeyo, *Office Attendant*
Lucy Wanjiru Mwaura, *Office Attendant*
Phoebe Siva, *Office Attendant*
Richard Musyoki Masaka, *Office Attendant*
Anne Wanjiku Karanja, *Office Attendant*

Muhaka-based
Douglas Charo Kalume, *Office Attendant*

Security

Duduville-based
Isaac Adika Agola, *Security Supervisor****

Mbita Point-based
Mustafa Juma Hamisi, *Security Supervisor****
Samuel Ojako Okumu, *Security Guard*
Peter Otieno Kisaria, *Security Guard*

Nguruman-based
Joseph Saningo ole Soinkei, *Camp Attendant*
Joseph Naata Tanchu, *Camp Security Guard*

Transport Unit

Zakayo Kimathi Mungania, *Fleet Supervisor*
David Marangu Mbui Kimotho, *Transport Assistant*
Umar Ibrahim, *Artisan Assistant*
Donald Mwachoni Nyambu, *Mechanic*
Anastasia Kabura Macharia, *Mechanic*
Walter Kariuki Warui, *Mechanic*
Joseph Raphael Makumi, *Driver/Mechanic*
Henry Njoroge Njachi, *Driver*
John Mweu Mutunga, *Driver*
Richard Muiruri Mugi, *Artisan Assistant***
Daudi Mutua Muumbi, *Assistant Storekeeper****
Josephine Mueni Mayale, *Transport Clerk****

Workshop Services

Abdul Razaq Abdalla, *Workshops Manager*
Patroba Nyachieo, *Senior Artisan*
Andrew Makheti Wanyama, *Artisan/Plumber***
Dominic Owinyo Wanjara, *Artisan/Woodwork*
John Pancras Nyongesa, *Artisan/Carpenter*
Dick Mutisya Kakuku, *Artisan/Metal, Plastic Fabricator*
John Musyoka Mutua, *Electrician*
John Njeri Waweru, *Artisan*
Christopher Bernard Wasike, *Artisan*

Mbita Point-based
Tony Linus Ngutu, *Mechanic*
Robert Mutunga Nzioka, *Artisan Assistant*
Eliud Oguok Ndiao, *Artisan Assistant*

Special Services

Kurt Benjamin Iten, *General Manager, Guest Centres*

Duduville International Guest Centre

Simon Maitethia Aritho, *Assistant Accountant*
Joseph Omari Mukhobi, *Chef*
Ruth Molly Wekesa, *Executive Receptionist*
Petronila Achieng Ocholla, *Executive Housekeeper*
Silas Owiti Ojwang', *Storekeeper*
David Nyaribo, *Receptionist*
Marystella Mutasta Wanjala, *Pastry Cook*
Mary Nyeusi Etuku, *Pastry Cook*
David Otieno Orinda, *Barman/Waiter*
Naomi Mwendwa Stephen, *Waitress*
Tabitha Akeyo Ogongo, *Room Stewardess*
Joan Auma Awich, *Room Stewardess*
Jane Adisa Asaba, *Room Stewardess*
Charles Odera Nyagaya, *Room Steward*
John Nalisi Kipserem, *Laundry Assistant*
Naomi Jfire, *Laundry Assistant*
Moses Kasembeli Wepukhulu, *Kitchen Assistant*

MPFS International Guest Centre

Wilson Mahindu Esirenyi, *Head Cook*
George Gichuru, *Chef*
Johnstone Okal Koyaa, *Catering Officer*
Francis Namoyo Omutsebi, *Laundry Assistant*

Field Stations

icipe-Mbita (Thomas Odhiambo Campus)

Charles Mwendia, *Station Administrator*
Patrick O. Sawa, *Medical Officer*
Peter William K. Nyongesa, *Farm Supervisor*
John Mongare Motaari, *Security Supervisor***
William Nagenda Omino, *Transport Assistant*
Zedekia Boaz Ooko, *Technical Assistant*
Barack Odhiambo Okudo, *Assistant Electrician*
Mohamed Onyango Auma, *Assistant Generator Operator*
Benedict Onyango Juombo, *Tractor Operator*
George Khaemba Khisa, *Telephonist/Receptionist*
Susan Akinyi Akelo, *Clerical Assistant*
Susan Adhiambo Otila, *Cleaner*

Port Sudan Field Station

Magzoub Omer Bashir, *Scientist-in-Charge*

Ethiopia Country Office

Getachew Tikubet, *Scientist-in-Charge***

Republic of Chad

Hassane Mahamat, *Visiting Scientist and Country Representative*

Democratic Republic of Congo (DRC)

Guy d'Ieteren, *Visiting Scientist and Country Representative*

Affiliates

International Journal of Tropical Insect Science (IJT) Secretariat

(IJT is hosted by icipe but has its own independent Editorial Board and policy. It is co-published by icipe and CABI, UK in association with the African Association of Insect Scientists.)
Web Link: http://www.cabi-publishing.org/ijt

Hans R. Herren, *Editor-in-Chief*
Ahmed Hassanali, *Associate Editor*
Annalee Ng'eny-Meng'ech, *Managing Editor*
Jean Claude Nsengimana, *Consultant Science Editor*
Bruno Le Rü, *French Editor*
Charlotte Sanginga, *Secretariat Manager*
Dolorosa Osogo, *Editorial Assistant*
Irene Ogendo, *Graphics Artist*

Southern Environmental and Agricultural Policy Research Institute (SEAPRI)

(SEAPRI focuses on issues ranging from patents, biological material transfer and collaborative agreements to negotiations relating to biological resources. Its projects are based on a 'ground-up', or field-oriented philosophy because SEAPRI believes effective policy and legal systems are developed from a thorough understanding of the field to be regulated, and the needs and aspirations of the intended beneficiary.)

Kent Nnadozie, *Director*
Robert Lewis-Lettington, *Deputy Director*
Peter Munyi, *Chief Legal Officer*

PARTNERS

Institut de Recherche pour Developpement (IRD)

(IRD performs research and manages scientific programmes centred on the relations between humans and their environment in the tropics.)
Web Link: http://www.ird.fr/
(See staff under Environmental Health visiting scientists in icipe main list.)

AfriCert Ltd

(AfriCert is a local certification body assisting and providing non-discriminatory competitive certification services to the agricultural sector to ensure compliance to ISO standards.)
Web Link: http://www.hoquality.com/africert

Ruth Nyagah, *Managing Director/Lead Auditor*
Francis Akivaga, *Quality Director/Auditor*

Bridgeworks

(Bridgeworks is a privately owned Swiss- and Kenya-based enterprise whose mandate is to commercialise all new developments coming out of icipe research at affordable prices to developing country farmers. Bridgeworks is the majority shareholder in BIOP Company Ltd.)
Web Link: http://www.Bridgeworks.ch/

Andreas Schwyn, *Director*
Edi Theiler, *Director*
Martin Lore, *Managing Director*

BIOP Company Ltd

(The mission of BIOP Company Limited is to produce affordable, eco-friendly natural products and promote their use to improve human, animal, plant and environmental health.)
Web Link: http://www.neemkenya.com/

Lucy Muchoki, *Managing Director*

**Left in year 2004
***Joined in year 2004

GOVERNING COUNCIL MEMBERS (2004)

Prof. Peter Esbjerg
Chairman, *icipe* Governing Council and Chairman, Executive Board
Professor, Agricultural Entomology
Royal Veterinary and Agricultural University
(Denmark)

Dr Dunstan Spencer
Dunstan Spencer and Associates (Sierra Leone)

Dr Michael Porter Collinson
Vice-Chairman, *icipe* Governing Council
(UK)

Dr Hiroyasu Aizawa
President
Hiro Research Consultancy Inc. (Japan)

Dr Jorge Soberon
Chairman, Programme Committee
Secreatrio Ejectivo
CONABIO (Mexico)

Ms Nancy Andrews
Chairperson, Audit Committee
President, Low Income Housing Fund (USA)

Dr Shantanu Mathur
Chief Economist
International Fund for Agricultural Development
(Italy)

Prof. W. K. Kilama
AMANET Managing Trustee
Chairman cum Coordinator
African Malaria Network Trust
(Tanzania)

Dr Sylvia Blümel
BFL, Institute of Phytomedicine
(Austria)

Dr Idah Sithole-Niang
University of Zimbabwe
(Zimbabwe)

Mr Donald W. Kaniaru
Environmental Lawyer and Manager
(Kenya)

Prof. David P. S. Wasawo
(Kenya)

Mr Nicholas P. Retsinas
Director, Joint Center for Housing Studies
Harvard University
(USA)

Dr Hans R. Herren
Ex-Officio Member
Director General, *cipe*
(Switzerland)

Appendix 11:

icipe Staff and Governing Council Members
(as at 31st December 2005)

RESEARCH MANAGEMENT

Office of the Director General
Christian Borgemeister, *Director General and CEO, joined on 1/6/05*
Hans R. Herren, *Director General, left on 30/4/05*
Susan Kariuki, *Executive Officer*
Elizabeth N. Ng'ang'a, *Consultant Press Officer*
Enock Kimanzi Nguthu, *Internal Auditor***
Kristine Wambui Karanja, *Receptionist*
Francis Omondi Ujiji, *Driver*
Fredrick Chichi Makhulo, *Office Assistant*

Office of the Director of Research and Partnerships
Onesmo K. ole-MoiYoi, *Director of Research and Partnerships*
Lucy M. Theuri, *Assistant Programme Manager*

Research Divisions

Plant Health

Staple Food Crops
Fritz Schulthess, *Principal Scientist and Coordinator, Biological Control of Cereal Stemborers in Eastern and Southern Africa Project; Divisional Head*
Zeyaur Rahman Khan, *Principal Scientist and Programme Leader, Habitat Management of Stemborers and Striga Project*
Charles Omambia Omwega, *Senior Scientist and Regional Coordinator, Biological Control of Cereal Stemborers in Eastern and Southern Africa Project*
Nanqin Jiang, *Research Scientist*
Laure Weisskopf, *Postdoctoral Fellow*
Isaac Njaci, *Project Documentalist*
Eric Muchugu, *GIS Specialist*
Joseph Owino Ochieng', *Technician*
Gerphas Okuku Ogola, *Technician*
Peter Omolo Owuor, *Technical Assistant*
Andrew Wanyonyi, *Technical Assistant*
Hellen Heya Mwadime, *Technical Assistant***
Julius Obonyo Ochieng, *Technical Assistant*
Charles Wahome Kamonjo, *Technical Assistant****
Jane Wacera Kiarie, *Technical Assistant***
Daniel Kinyanjui Mungai, *Technical Assistant/Driver*
Charles Oyugi, *Field Assistant****
Carolyne Akal, *Project Secretary*

Cameroon-based
Rose Ngeh Ndemah, *Scientist and Regional Coordinator, IPM of Maize Stemborers in Western Africa Project****

Horticultural Crops
Bernhard Löhr, *Principal Scientist and Head, Horticultural Crops Sub-Division; Division Head to June 2005; Diamondback Moth Project Leader*
Slawomir Antoni Lux, *Principal Scientist and African Fruit Fly Initiative Programme Leader***
Markus Knapp, *Scientist and Tomato Red Spider Mite Project Leader*
Sunday Ekesi, *Scientist and African Fruit Fly Programme Leader from 9/05*
Dagmar Mithöfer, *Scientist and Co-ordinator, Economic Impact Assessment, DBM Project****
El-Sayed El-Banhawy, *Visiting Scientist****
Samira Mohamed, *Consultant*
Paul Mbugua, *Visiting Scientist*
Linus Gitonga, *Visiting Scientist****
Gatama Gichini, *Senior Research Assistant*
Ibrahim Macharia, *Research Assistant*
Peterson Wachira Nderitu, *Research Assistant*
Constance Andeyo Muholo, *Research Assistant*
Eddah Makinia Nang'ole, *Research Assistant****
Nicholas Mungula Mwikya, *Technician*
Miriam Mwarania Kungu, *Technician*
Bernard Musembi Muia, *Technician*
Faith Wamurango Nyamu, *Technician*
Gideon Jira Chigunda, *Technician***
John Mbatha Kiilu, *Technical Assistant*
Andrew Wanyonyi, *Technical Assistant***
Judith Mumo Kiluvu, *Technical Assistant***
Raphael Mukiti, *Technical Assistant*
Carlos Maweu, *Technical Assistant*
Emmanuel Fadhili Mlato, *Technical Assistant****
Gladys Kemunto Onyambu, *Technical Assistant***
Everlyne Nafula Wosula, *Technical Assistant*
Emmanuel Fadhili Mlato, *Technical Assistant*
Charles Muchina Kanyi, *Driver/Mechanic*
Geoffrey Gachanja Kinyanjui, *Driver*
Joseph Gachugu Mucheru, *Driver*
Rose Atieno Ogolla, *Secretary***
Beatrice Muthoni Gikaria, *Secretary*
Lucy Mutheu Kiilu, *Administrative Assistant****

Mbita Point-based
George Genga, *Technician*
Pascal Agola Oreng, *Technical Assistant*
Dickens Nyagol, *Technical Assistant*
Nahashon Ogongo Otieno, *Field Assistant/Driver*

Bungoma-Based
Aloice Ouma Ndiege, *Technical Assistant*

Locusts and Migratory Pests
Ahmed Hassanali, *Principal Scientist and Head, Locusts and Migratory Pests Sub-Division*

Port Sudan Field Station-based
Magzoub Omer Bashir, *Consultant and Scientist-in-Charge, Port Sudan Field Station*
Sidi Ould Ely, *Visiting Scientist*
Abdul Rahim W. Bashir, *Technician*
Haidar H. Korena, *Technician*

Animal Health

Rajinder K. Saini, *Principal Scientist and Ag Division Head; Tsetse Research Programme Leader*
John Akiri Andoke, *Research Assistant*
Peter Nthale Muasa, *Technical Assistant*
Richard Ouma Tumba, *Technical Assistant/Driver*
Carolyne Muthoni Muya, *Secretary*

Human Health

John Githure, *Visiting Scientist and Ag Division Head Malaria Vectors Programme Leader*
Josephat Shililu, *Visiting Scientist*
Guiyun Yan, *Visiting Scientist-State University of New York, USA*
Weiner Spitteler, *Visiting Scientist***
Charity Kabutha, *Visiting Scientist*
Lucy Kabuage, *Visiting Scientist*
Violet Kimani, *Visiting Scientist*
Pamela Beatrice Seda, *Research Assistant*
Peter Baraza Wekoyela, *Research Assistant*
Ephantus Juma Muturi, *Research Assistant***
Milcah Gitau, *Technician*
Enock Mpanga, *Technician*
Charles Muriuki, *Technical Assistant*
Nelly Gatwiri Gitonga, *Technical Assistant*
Faith Kyengo, *Secretary*
Nelly Njoki Njeru, *Administrative Assistant*

Mbita Point-based

Richard Mukhabana, *Visiting Scientist*
Robert Ray Jackson, *Visiting Scientist*
David Simon, *Visiting Scientist*
Basilio Ngari Njiru, *Technician*
Jackton Arija, *Technical Assistant*
Lawrence Omukuba, *Technical Assistant***

Kisii-based

François Omlin, *Visiting Scientist, Cape Town University, RSA*
Annabel Howard, *Visiting Scientist****
Emmanuel Mushinzimana, *Consultant***
Samson Kiriri Gichia, *Research Assistant*
Wycliffe Lumumba Migiro, *Technician*
Jared Kaunda Aroko, *Driver/Mechanic*
Abel Omari Mainya, *Driver*
Eric Olielo Odhiambo, *Field Assistant*

Kilifi-based

Charles Mbogo, *Visiting Scientist*

Mwea-based

Ephantus Juma Muturi, *Research Assistant*
Peter Barasa Wekoyela, *Technical Assistant*
Nicholas Gachiki Kamari, *Field Assistant*
Martin Ngigi Njigoya, *Field Assistant*
Charles Chomba Kiura, *Field Assistant*
Susan Wanjiku Mugo, *Field Assistant*
Christine Wangari Maina, *Field Assistant*
Nelson Muchiri Maingi, *Field Assistant*
Isabel Wanjiku Marui, *Field Assistant*
Peter Muriuki Mutiga, *Field Assistant*
William Waweru Michiri, *Field Assistant*
Paul Kibuchi Mwangi, *Field Assistant*
Irene Kamau, *Field Assistant****
Naftaly Gichuku Manegene, *Field Assistant****
Gladys Muthoni Karimi, *Field Assistant****
Julius Murimi Muthike, *Field Assistant****
James Ogaa Wauna, *Driver****

Environmental Health

Ian Gordon, *Principal Scientist and Division Head*
Suresh Kumar Raina, *Principal Scientist and Commercial Insects Programme Leader*
Wilber Lwande, *Senior Scientist and Programme Leader Kakamega/Echuya Forests Conservation Projects*
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Appendix 12:

Acronyms and Abbreviations

AFESD Arab Fund for Economic and Social Development
AGRIS The international information system for the agricultural sciences and technology, created by the Food and Agriculture Organization of the United Nations (FAO)
AREU Agricultural Research and Extension Unit (Mauritius)
ARPPIS African Regional Postgraduate Programme in Insect Science (*icipe*)
ASARECA Association for Strengthening Agricultural Research in Eastern and Central Africa (Uganda)
ASFCMP Arabuko-Sokoke Forest Management and Conservation Plan
ASFMT Arabuko-Sokoke Forest Management Team
AU African Union (Ethiopia)
BBSRC Biotechnology and Biological Sciences Research Council (UK)
BEAF Advisory Service on Agricultural Research for Development
BMZ Bundesministerium für Wirtschaftliche Zusammenarbeit (Germany) [Federal Ministry of Economic Cooperation and Development]
Bs *Bacillus sphaericus*
BSMDP Business Services Market Development Project
Bti *Bacillus thuringiensis israelensis*
CAAS Chinese Academy of Agricultural Sciences
CABI Commonwealth Agricultural Bureaux International (UK)
CDM clean development mechanism
CEES The Centre for Ecological and Evolutionary Synthesis (Norway)
CEPF Critical Ecosystem Partnership Fund (of Conservation International, CI)
CGIAR Consultative Group on International Agricultural Research
CIAT/TSBF Centro Internacional de Agricultura Tropical/Tropical Soil Biology and Fertility Programme (Kenya)
CNRS Centre National de la Recherche Scientifique (France)
COLEACP-PIP Europe/Africa–Caribbean–Pacific Liaison Committee Pesticide Initiative Programme
CP/IPM crop production and integrated pest management
CTA Technical Centre for Agricultural and Rural Cooperation (the Netherlands)
CSIRO Commonwealth Scientific and Industrial Research Organisation (Australia)
DAAD German Academic Exchange Service
DBM diamondback moth
DED German Development Service
DFID Department for International Development (UK)
DGIS Directorate General for International Cooperation (the Netherlands)
DRIP Dissertation Research Internship Programme (*icipe*)
DSO Direct Support to Training Institutions in Developing Countries Programme
EU MRLs European Union's maximum residue levels
EurepGAP European Retailers Programme on Good Agricultural Practices
FAO-EMPRES/CR Food and Agriculture Organization of the United Nations-Emergency Prevention System/Central Region Programme
FAO-TCP Food and Agriculture Organization of the United Nations-Technical Cooperation Programme
FD Forest Department
FFS Farmers' Field School
FPEAK Fresh Produce Exporters Association (Kenya)
GEF Global Environment Facility
GIS geographic information system
GMO genetically modified organism
GPS global positioning system
GTZ Gesellschaft für Technische Zusammenarbeit (Germany)
HACCP hazard analysis critical control point
HH households
IACR Institute of Arable Crops Research (UK)
IAEA International Atomic Energy Agency (Austria)
ICRAF World Agroforestry Centre (Kenya)
ICRISAT International Crops Research Institute for the Semi-Arid Tropics (India)
ICSC International Centre for Scientific Culture-World Laboratory (Switzerland)
IDRC International Development Research Centre (Canada)
IER Institut d'Economie Rurale (Mali)
IFAD TAG International Fund for Agricultural Development (Italy) technical assistance grant
IFS International Foundation for Science (Sweden)
IITA International Institute of Tropical Agriculture
ILRI International Livestock Research Institute (Kenya)
INASP-PERI International Network for the Availability of Scientific Publications—Programme for the Enhancement of Research Information (UK)
INERA/CREAF Laboratoire d'Entomologie Agricole de Kamboinsé (Burkina Faso)
INRA Institut National de la Recherche Agronomique (France)
IPGRI International Plant Genetics Research Institute
IPVM integrated pest and vector management

IRD Institut de Recherche pour le Développement (France)
ISAR Institut des Sciences Agronomiques du Rwanda
IsDB Islamic Development Bank
ITN insecticide-treated net
IVM integrated vector management
IWMI International Water Management Institute (Colombo)
JIRCAS Japan International Research Centre for Agricultural Sciences
JKUAT Jomo Kenyatta University of Agriculture and Technology (Kenya)
JSPS Japan Society for the Promotion of Science
KARI Kenya Agricultural Research Institute
KEFRI Kenya Forestry Research Institute
KEMRI Kenya Medical Research Institute
KETRI Kenya Trypanosomiasis Research Institute
KFAED Kuwait Fund for Arab Economic Development
MDGs millennium development goals
NARS national agricultural research systems
NARES national agricultural research and extension systems
NEMA National Environmental Management Authority (Kenya)
NGO non-governmental organsiation
NIH/ICIDR National Institutes of Health/ International Collaboration in Infectious Disease Research program (USA)
NIH/NIAID National Institutes of Health/National Institute of Allergy and Infectious Diseases (USA)
NRES national research extension and education systems
NRI Natural Resources Institute (UK)
NPB nymphal pheromone blend
OPEC Organisation of the Petroleum Exporting Countries
PATTEC Pan African Tsetse and Trypanosomosis Eradication Campaign (approved by the African Union under the NEPAD Initiative)
PBARC US Pacific Basin Agricultural Research Centre (Hawaii)
PLPA Projet de Lutte Preventive Antiacridienne (Madagascar)
R&D research and development
SFML Sustainable Forest Management Limited (UK)
SIDA/SAREC Swedish International Development Cooperation Agency/Department for Research Co-operation
SIMA Systemwide Initiative on Malaria and Agriculture
TARDA Tana and Athi River Development Authority (Kenya)
TDIP Tana Delta Irrigation Project (Kenya)
TRNPR Tana River National Primate Reserve (Kenya)
TWAS Third World Academy of Sciences
TWOWS Third World Organization for Women in Science
UNDP United Nations Development Programme
UNEP United Nations Environment Programme (Kenya)
UNESCO United Nations Educational, Scientific and Cultural Organization
UNICEF United Nations Children's Fund (USA)
USAID/AELGA United States Agency for International Development/Assistance for Emergency Locust/Grasshopper Abatement (USA)
USDA-ARS United States Department of Agriculture-Agricultural Research Station
WAU Wageningen Agricultural University (The Netherlands)
WHO/AFRO World Health Organization/Regional Office for Africa
WHO/MIM World Health Organization/Multilateral Initiative on Malaria Research in Africa
WHO/TDR World Health Organization/Special Programme for Research and Training in Tropical Diseases Research
WWF World Wide Fund for Nature

icipe is a unique and advanced research and training organisation working to improve the lives and livelihoods of people in Africa. Because insects and other arthropods have a major impact in almost every area of their physical well-being and prosperity, ***icipe*** is making its contribution by continuing to improve the plant, animal, human and environmental health of, primarily, smallholder farmers and disadvantaged urban dwellers in Africa.

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