

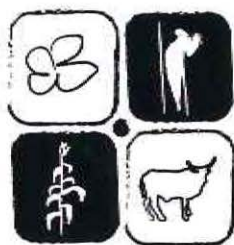


icipe

African Insect Science for Food and Health



**biennial
scientific report
2006–2007**



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Cover photo of children playing near a temporary pond in Ethiopia,
courtesy of Getachew Tikubet

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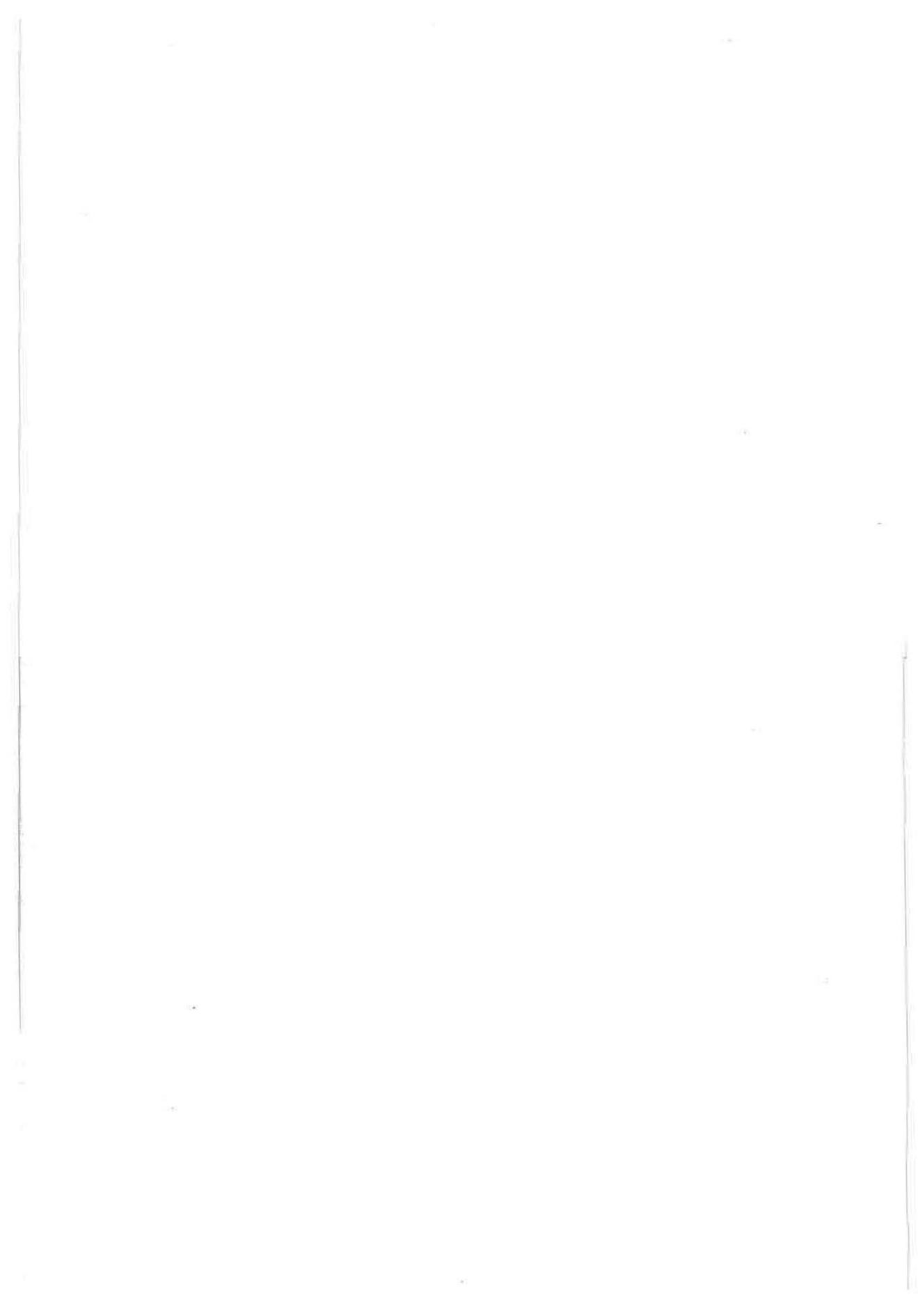
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MESSAGE FROM THE DIRECTOR GENERAL

Why do mosquitoes feed on plants, and why do they prefer certain species and avoid others? What are the effects of plant feeding on their life history, and more so on the malaria pathogen the female mosquitoes are transmitting? How do we control the ever-increasing number of alien invasive species in Africa that threaten agricultural production and international trade? Biodiversity is vanishing at an incredible pace in Africa. What can we do to conserve it? Are there ways to empower communities living adjacent to biodiversity-rich forests and other ecosystems to exploit their environments in a sustainable and at the same commercially valid way? How can we measure the impact of interventions at the beneficiary level? Can we manipulate the behaviour of insect pests and disease vectors for control or monitoring purposes? Can we contribute to the training of young scientists in Africa?

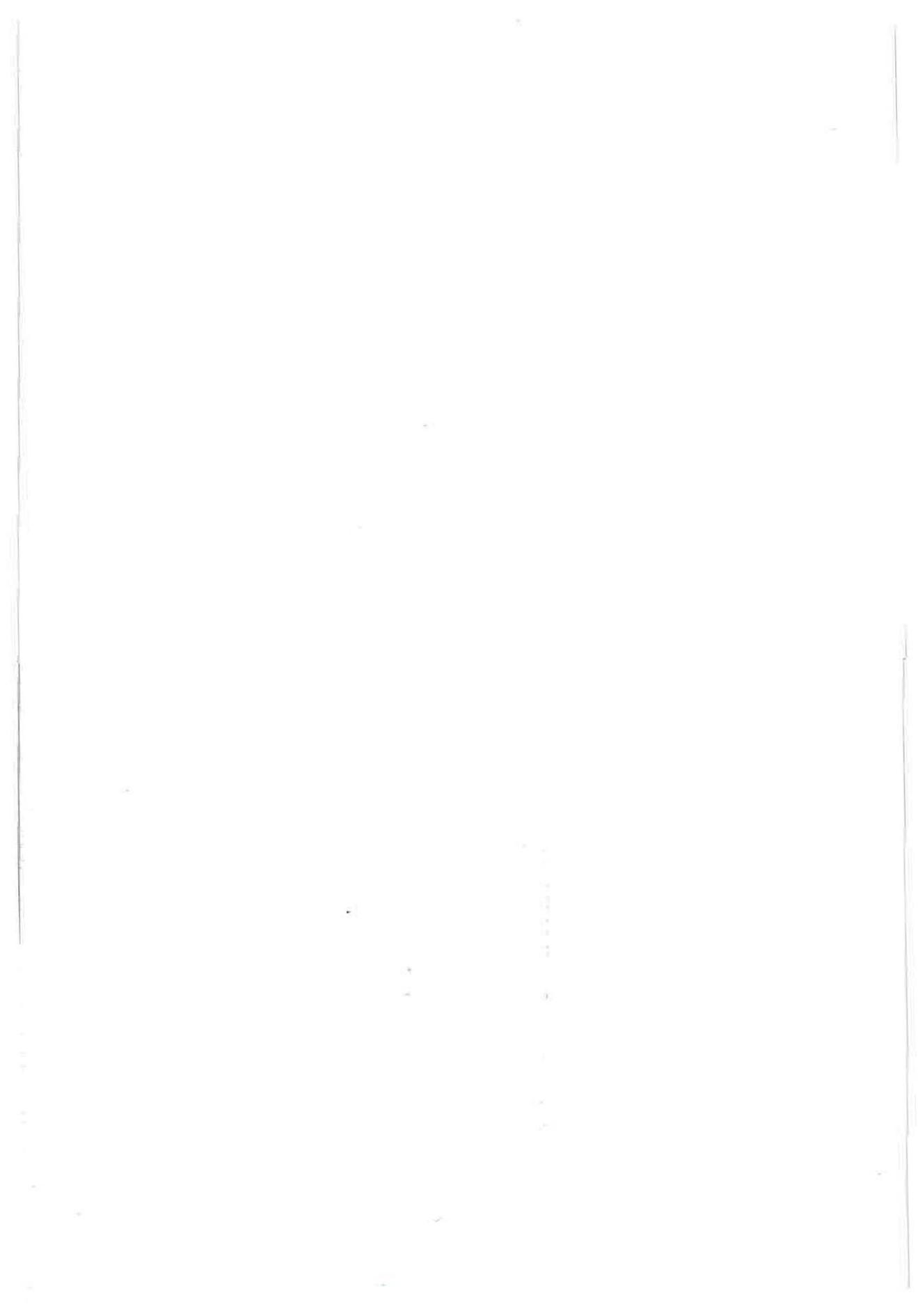


*Prof. Christian Borgemeister,
Director General, icipe*

These and other interesting and challenging questions are addressed in this biennial scientific report of *icipe*. The results reflect the collaborative effort of our Centre scientists, the numerous postgraduate students from Africa and elsewhere, and our many collaborators from Africa and the other four continents.

I hope you will enjoy this scientific compilation of two years of *icipe*'s R&D work. More information can be found on our website (www.icipe.org). Let me finish by thanking all the contributors to this document, as well as the many donors of our Centre.

A handwritten signature in black ink that reads "Christian Borgemeister". The signature is written in a cursive, flowing style.





HUMAN HEALTH RESEARCH

Overview

Malaria is the tropics' most serious infectious disease. It affects more than 500 million people yearly, 3 million of whom die from the disease. Its effective and sustainable control in most parts of the tropics cannot be realistically accomplished without new tools and approaches for fighting both the parasite and the mosquito vector.

Vector control and treatment methods previously effective in controlling malaria are now largely ineffective due to the growing prevalence of insecticide-resistant mosquitoes and drug-resistant parasites. Resistance to anti-malarial drugs is emerging and spreading faster than new drugs are being developed and deployed.

The overall goal of *icipe's* research in human health is to contribute to the reduction of malaria (and neglected tropical diseases as well as emerging infectious ones). In malaria research, the focus is on mosquito ecology, mosquito behaviour and malaria transmission, with emphasis on developing new tools for integrated malaria control, which go beyond bednets and traditional insecticide-based approaches. Attention focuses on changes in malaria trends due to global warming, insecticide resistance and land use, among other factors.

The adaptive IVM malaria projects are embedded in operational research on the ecology and behaviour of anopheline mosquitoes and aim to:

- Perform research on the ecology and behaviour of mosquitoes, so as to contribute to the efforts of the national malaria control programmes in Africa;
- Strengthen linkages and networks with national research and teaching institutions in Africa;
- Develop integrated vector management strategies for use in different ecological settings in Africa, in collaboration with the WHO/Africa Regional Office.

Relevant outputs require the adaptive management of mosquito populations, by establishing a system of continuous monitoring, data analysis and decision-support for precision target interventions and control on the basis of epidemiological knowledge. The outputs contribute significantly to a sound adaptive IVM of malaria by delivering decision-support tools and early warning system methods.

MALARIA VECTORS RESEARCH PROGRAMME

Mosquito Ecology: Integrated Vector Management for Malaria Control in Africa

General Background

Malaria remains one of the most significant health problems in Africa where more than one million children die from the disease every year. The cycle of poverty and malaria is the main obstacle for Africa's development. While the economic cost of malaria is estimated at US\$ 12 billion per year, only a fraction of this amount is needed to put the disease under control and improve the lifestyle of African communities. Reliance on curative services has become more problematic with the increasing spread of multi-drug resistant malaria and weak health delivery systems, thus highlighting the importance of transmission reduction. While a vaccine is years away from being widely available, vector control remains the most viable prevention strategy.

As already demonstrated by mosquito abatement districts in the developed countries, an understanding of mosquito ecology and behaviour combined with the use of integrated approaches for mosquito control allows for a significant reduction in the use of insecticides, reduces negative environmental impacts and has lower overall costs. During the 1920s and 1930s, malaria was successfully controlled in parts of Africa by using such techniques as environmental management, larval control and indoor residual spraying. However, such interventions will only be successful and sustainable by understanding and working with local communities and including them in solving their public health problems.

icipe in collaboration with KEMRI, Ministry of Health, WHO/AFRO and other partners has ongoing projects that implement a series of malaria control demonstration projects in the Lake Victoria region, western Kenya highlands, central Kenya, the coastal region of Kenya, as well as in Eritrea and which address the following areas:

- Field evaluation of the ecology, behaviour and transmission potential of mosquitoes;
- Semi-field testing of new approaches to mosquito control including gene flow in screen houses;
- Environmental and habitat management;
- Establishment of surveillance mechanism;
- Assessment of socioeconomic activities;
- Training of organised community groups;
- Institutional capacity building and development of technical staff for operational and community-based control programmes.

Progress Report and Outlook

A. Microbial Control of Immature Stages of *Anopheles* Mosquitoes in Rice Ecosystems

The ecological complexity of rice agroecosystems and the key components that drive malaria vector production, distribution and composition formed the basis of this research. Only isolated data exist on the bionomics of *Anopheles* vector species in rice agroecosystems. The research involved the development and implementation of an integrated vector management (IVM) that focused on the immature stages of *Anopheles* species to reduce the transmission of malaria in rice-village complexes in Mwea, Kenya.

The objectives of the study were to:

- Determine the spatial/temporal distribution and abundance of *Anopheles* larval habitats and their adult productivity in irrigated rice-village complexes;
- Determine the key environmental, agricultural and ecological factors that regulate vector productivity and non-target abundance, and diversity in the larval habitats.

Adult mosquitoes were sampled weekly both indoors and outdoors in 4 villages representing different rice cropping regimens and coverage. The mosquito specimens were identified morphologically and 25 species belonging to five genera were observed. The entomological results showed that irrigation systems had a marked effect on the mosquito diversity and abundance in Mwea with 17 species collected in the planned rice growing village, 22 species in the unplanned rice growing site and 20 species in the non-rice growing village. 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). It was also observed that the prevalence of the major anopheline species during the rice growing cycle followed a pattern closely linked to rice stage. Our results show that although *Anopheles arabiensis* larval production is sustained throughout the rice cropping cycle (≈ 3 months per cycle), high densities are observed only during early vegetative stages (3 weeks post transplanting).

Different levels of habitat disturbance with regard to rice cultivation have variable effects on mosquito diversity. This information is critical in understanding the mosquito community structure and targeting control strategies in rice agroecosystems where the vector species is predominant.

The transplanting stage is favourable for growth of immature stages of *A. arabiensis* and application of larvicides should target this narrow larval developmental window in rice agroecosystems, demonstrating the need for time-dependent and species-specific mosquito control operations. Habitat diversity and productivity of immature stages of *A. arabiensis* based on rice



Rice paddy in Mwea (Kenya)

husbandry and water management practices may be utilised for developing targeted larval control strategies for rice agroecosystems.

The research project has provided an opportunity for training of 3 PhD students. As well stakeholder workshops and village meetings in each of the study villages have contributed immensely in creating awareness on malaria control among the communities.

The Project comes to an end in May 2008.

B. Community-based Integrated Malaria Vector Control in Mwea Irrigation Scheme, Kenya

The Global Fund Project is implemented also in the Mwea Rice Irrigation Scheme. The project is based on the premise that success and sustainability of malaria control strategies relies on effective incorporation of communities in control projects through effective education and communication. The overall objective of the project is to build capacity for vector control through community participation. The project aims at implementing vector control by involving communities in designing, planning, monitoring and evaluating sustainable methods adaptable to the local situation. This is achieved through formation of active partnerships between the community members, health workers, research teams and other stakeholders.

Community-based planning meetings were conducted to develop, discuss and plan training programmes and initiate sustainable and active partnerships between the community members and the project team. Village maps indicating location of homesteads, households, water points, rice paddies, canals and other aquatic habitats were developed. A baseline household census was conducted by use of a structured questionnaire in all the study villages to collect household socio-demographic information which later served as a framework for sample selection in subsequent vector control questionnaire administered to a third of the households in each village. Entomological surveillance was conducted by sampling indoor-resting adult mosquitoes in 10 randomly selected houses by pyrethrum spray collection and larval sampling.

The results of the demographic surveys indicated that at least 77% of the respondents related malaria to mosquito bites although a few pointed to some non-biological causes. At least 87% of the respondents applied at least one vector control method. In total, among the vector control methods applied, use of bednets (treated or untreated) was reported by over 95% of the respondents. The socio-demographic survey further showed that some 88% of the households owned at least a bednet (n=1798). The baseline survey provides relevant information to be considered and integrated in the design and implementation of malaria vector control strategies.

A total of 131 community members have been trained as ToTs on vector control strategies and as larval control spray operators. They have subsequently conducted awareness campaigns involving up to 11,523 persons in the study villages. A training curriculum for use by the ToTs has been developed.

This first phase of the Global Project Fund (2006–2008) has generated critical baseline information that will guide the second implementation phase (2008–2010). This phase will have three major components: (1) larval management including application of biolarvicides (*Bacillus thuringiensis* var *israelensis*) and environmental management; (2) impact of larval control on malaria management as a basis for informing vector control decisions; and (3) scale up of community training through ToTs as a strategy for sustainability and improving community participation in malaria control actions.

In the next review period, three strategies will be pursued. These are:

- Entomological surveillance through adult and larval mosquito monitoring.
- Assessment of the impact of larval control through malaria morbidity monitoring in health facilities within the catchment area of the study villages.
- Facilitation of ToTs and other IEC channels for training of communities on malaria control.

Participating Scientists: J. Githure, J. Shililu and P. Ng'ang'a (icipe, Kenya)

Key Collaborators: Kenya Medical Research Institute (Kenya), and University of Alabama and Valent BioSciences Corporation (USA)

Main Donor: Ministry of Health (Kenya)

Community-based Malaria Control in Urban and Rural Malindi, Kenya Coast

General Background

Through past collaborations with the local government authorities responsible for mosquito control in Kenya, and with community action groups in Malindi, we have learned that there is a tremendous need for sound biological-based malaria control programmes. We noted early in 2004 that the government-sponsored mosquito control activities were very limited in Malindi due to lack of designated funding, and policies that only emphasised personal protective measures such as insecticide treated nets. As well, the local government was using used engine oil to treat water sources, and they were not targeting habitats that specifically produce malaria vectors. Through our work funded by the NIH and EHP since 2002 and our collaboration with 19 community organisations that are engaged in various types of environmental management and mosquito control programmes in Malindi, we have found that there is much more that local government and community organisations could be doing in terms of more appropriate vector management given better information and guidance. The entry of Biovision Foundation in 2005 helped us to continue working in the same communities and developing a community-based adaptive management intervention for reducing malaria incidence in children, and malaria transmission intensity in general, and thereby achieving improvement of human health.

Community participation and mobilisation, which is an important part of the overall malaria control activities in the District, 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 this project, we have begun training community group members (mosquito scouts) in larval control, environmental management techniques and scaling up of long-lasting insecticide nets (LLINs). 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, will be used for larval control. 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 be used to train community members in the proposed extension of the project to cover a wide area within Malindi District.

Progress Report and Outlook

A. Combating Malaria in Urban Malindi

Human health improvement through integrated malaria vector 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.

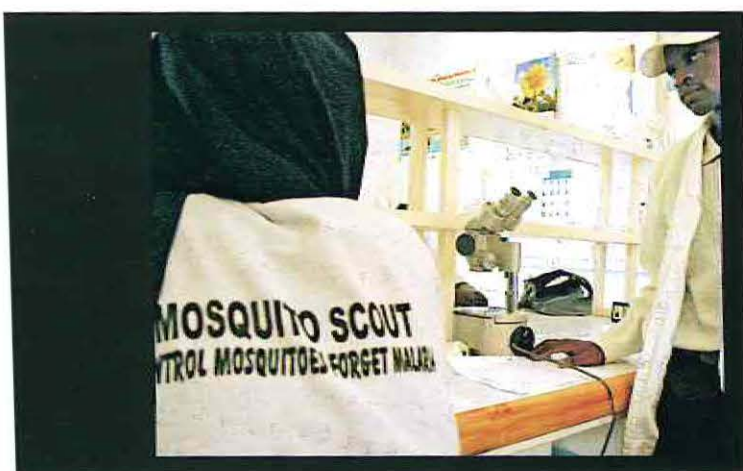
The objectives of this study are to:

- Develop and implement adaptive mosquito population management for human health improvement;
- Determine the feasibility and sustainability 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; and
- Build the capacity of the community for malaria vector control.

The burden of malaria remains a significant problem in both urban and peri-urban areas, where high proportions of the population lack natural immunity to the disease. The lack of acquired immunity in urban populations, the unstable nature of malaria transmission, and the heterogeneous nature of malaria risk in urban environments, require the development of novel tools and methods for preventing the emergence or resurgence of malaria within such environments. The objective of this study is to reduce the burden of malaria in urban environments through the use of sustainable, community-based adaptive vector management tools and thus improve human health. The study was carried out in urban Malindi in which entomological surveys and community mobilisation and education were carried out. Larval sampling was done in habitats within a 1 km² grid.

Mosquito scouts were trained on entomological field sampling techniques and consequently were involved in field sampling. Action was taken on positive habitats for mosquito

larvae which involved using Bti larvicides or environmental management. Adult sampling using CDC light traps was used as a proxy of effectiveness of the larval management. A total of 65,648 adult mosquitoes were collected between June 2006 and December 2007 across all the 16 grid cells. Of these, 98.95% ($n = 66,533$) were *Culex*, 0.39% ($n = 259$) *Anopheles*, 0.41% ($n = 278$) *Mansonia* and 0.28% ($n = 188$) *Aedes*. June and November 2006 recorded most of the adult mosquitoes collected, while September recorded the lowest number. The mosquito species



Mosquito scout from a grassroot organisation in Malindi, Kenya.

composition included *Ae. dalzielii* (0.13%), *Ae. aegypti* (1.96%), *Ae. metallicus* (0.02%), *Ae. sudanensis* (0.01%), *Ae. tricholabis* (0.14%), *An. funestus* (0.08%), *An. gambiae* (1.53%), *An. nilli* (0.02%), *Cx. azurites* (0.02%), *Cx. tritaeniorhynchus* (0.10%), *Cx. quinquefasciatus* (92.71%), *Cx. sitiens* (0.02%), *Cx. thalassius* (0.18%), *Eretmapodites melanopus* (0.0001%), *Ma. africanus* (0.63%) and *Ma. uniformis* (2.42%). *Culex quinquefasciatus* was the most abundant species accounting for 92.71% of the total identified species. A total of 307,020 immature mosquitoes were recorded across all the 16 grid cells from June 2006 to December 2007. Culicine larvae were most abundant in all cells accounting for 87.54% (n = 268,796) and anophelines only accounted for 1.20% (n = 3682) of the larvae collected. The pupal abundance was 11.25% (n = 34,552) during the sampling period. Nineteen different habitat types were sampled in Malindi during the sampling period. These habitat types included abandoned boats, car tracks, assorted containers, ditches, dug ponds, fish ponds, house drainages, manholes, ponds, puddles, roadside drainages, septic tanks, swamps, swimming pools, tyres, water fountains, water tanks, water troughs and wells. Most of the culicines were collected from house drainages, manholes, septic tanks, swimming pools and water tanks.

Anopheles larvae were collected mostly from swimming pools, swamps, water tanks and house drainages, with 71.26% of larvae occurring in these habitats. Most pupae were collected from house drainages, manholes, septic tanks and water tanks. Treatment of unused swimming pools with Vectobac DT and CulinexCombi showed that both biolarvicides were effective against late instar larvae reducing their population by over 97% within 24 hours post-treatment. Through the integrated vector management approach we will be able to substantially reduce the burden of vector-borne diseases (including malaria) in urban Malindi to very low or to manageable levels.

Community and stakeholders in Malindi were involved from the initiation of this project. Community groups were trained on mosquito control activities and played a key role in community mobilisation for mosquito control actions. 'Punguza Mbu' (PUMMA), the mosquito and malaria control association, which is an umbrella body for all community-based organisations, mobilised the community groups for the dissemination of information, education and communication materials. Over 10,000 long-lasting insecticide-treated bednets (LLINs) were distributed through PUMMA, either through sales using a voucher system or free of charge. The rural community received the free bednets while the population in the urban and peri-urban areas bought them. The KEMRI-*icipe* malaria team facilitated the distribution of the two sets of LLINs to the community. The stakeholders including Ministry of Health, Municipal Council, Green Town Movement, hoteliers, and cottages and apartment owners were involved in holding key meetings, which mapped the strategies for mosquito control. The stakeholder meetings were organised through the Malindi District Medical Officer of Health (DMoH).

Adaptive management principles stipulate active participation of the communities. The cornerstone of adaptive management is decision support for the people through participation in integrated and sustainable problem solving processes. This project advocated 'learning by doing' with a need to develop, plan and implement an evidence-based integrated vector management (IVM) strategy using a range of interventions selectively to control vector-borne diseases. Besides promoting ITN use, the programme involved the use of ecological biocides to treat the water bodies containing mosquito larvae, removal of mosquito larval habitats, educating the communities and other stakeholders in decision making process and taking action. Emphasis is being put on local level involvement through community and/or inter-sectoral participation. The integrated vector management approach in this study would help reduce the burden of vector-borne diseases including malaria in urban Malindi, which would be adapted in other cities within the region.

In the next review period, one main strategy will be pursued:

- To put all the structures required for the implementation of IVM strategies, we need to address the challenges the Ministry of Health (MoH) continues to face that seriously constrain the implementation of effective malaria vector control. The MoH has limited infrastructures, human resources and also lacks the technical skills to generate and analyse entomological information for selecting, planning, monitoring and evaluating vector control interventions, including resistance management. Since 2006, we have been promoting IVM as the new strategic approach to vector control at the community level in Malindi but did not build capacity at the district level to provide the much-needed technical support. We, therefore, propose to build and strengthen technical support and capacity at the MoH with the following objectives pertinent to IVM as follows: (1) reduce malaria transmission in urban Malindi through increasing access and availability of LLINs, (2) expanding environmental management and larviciding, (3) strengthening coordination and partnership development for malaria prevention and control, and (4) improving capacity for monitoring and evaluation.

B. Community-based Malaria Control in Rural Malindi, Kenya

We extended the above study to the rural areas of Malindi District with the aim of involving the rural communities in integrated vector management. We have now collected baseline entomological, epidemiological and demographic information from 20 selected villages in the 3 Divisions of Malindi District. We have successfully trained over 150 community members including 30 community liaison officers, 6 field assistants and 14 public health technicians from the MoH.

Community participation is an essential element of adaptive management and the project will rely on community participation and support. To enhance this strategy, more community members will be trained in mosquito monitoring and control operations for sustainability and decision making as well as in programme management and leadership.

icipe considers the establishment of strong collaborative linkages with local research institutions to be critical for enriching its research work and impact, as well as expanding the geographical coverage and sustainability of its programmes. The collaborative linkages with researchers from the Kenya Medical Research Institute (KEMRI), the Ministry of Health (MoH) and Municipal Council of Malindi have facilitated implementation of research activities in Kenya and we are planning to establish new collaboration with other stakeholders and strengthen participation in these partnerships.

Over the next two years, *icipe* expects to receive continued support from the Biovision Foundation. *icipe* has received funding from the Global Fund to facilitate collaborative linkages with the Ministry of Health and the Pyrethrum Board of Kenya to continue research on larval control at the coast, central and western highlands of Kenya. This new funding will synergise Biovision's current support in enabling the communities to adopt the adaptive management structure while also broadening the revenue base either from the government, stakeholders and/or well wishers. To sustain this strategy, researchers are encouraged to work with the communities to remove the bottlenecks that hinder community participation in malaria control and motivate them to engage in income generating activities.

icipe is keen to transfer technology on mosquito and malaria control to the communities and the stakeholders.

In the next review period, eight strategies will be pursued. These are:

- Capacity building and partnerships with civil society in the study sites to provide the necessary capacity required for malaria control at the district level.
- Encourage the communities to engage in income-generating operations so that the IVM activities can be sustained through their participation.
- Provide technical assistance for community organisations such as 'Punguza Mbu' (PUMMA).
- Carry out malaria prevention and control involving the business community.
- Malaria education imparted to schoolchildren by encouraging their participation through poems, drama and song.
- Assist in the facilitation of more available and affordable larvicides and nets.
- Effect the establishment of a rapid response community spray team.
- Support to communities to write proposals and tap into the Constituencies Development and Youth funds provided by the Government for each Division by encouraging them to develop malaria-related projects and IGA. This will help them become active partners in malaria control.

Participating Scientists: C. Mbogo, L. Kibe, J. Mwangangi, J. Nzovu, S. Kahindi, C. Nyundo and J. Githure (*icipe*, Kenya)

Key Collaborators: Swiss Federal Institute of Technology and Swiss Mosquito Control Agency (Switzerland), and Kenya Medical Research Institute (Kenya)

Main Donors: Global Fund to Fight AIDS, Tuberculosis and Malaria (Switzerland), and KEMRI and *icipe* (Kenya)

Anticholinesterase for Mosquito Control

General Background

Insecticide treated nets (ITNs) are being strongly promoted as a malaria control tool in Africa by the World Health Organization and other international agencies. Their efficacy in reducing man-vector contact, malaria morbidity and mortality has been demonstrated in various epidemiological situations. Pyrethroids are the only group of compounds currently recommended for use on nets. However, with current use of pyrethroids in agriculture and increasing scale of ITNs coverage, selective pressure for pyrethroid resistance in mosquitoes is expected to increase. In recent years, pyrethroid resistance has become widespread among anopheline mosquitoes, the filariasis vector and *Culex* species in western Africa, and has also arisen in eastern and southern Africa. There is concern that continued and/or increased use of these compounds may result in increased resistance that would threaten the sustainability of this vector control strategy. Finding an alternative to pyrethroids that could be effective on nets but with a different mode of action has, therefore, become a priority. This research aimed to test new anticholinesterase compounds (classified as members of an earlier generation of insecticides, i.e. carbamates) for their potential as bednet treatment (ITN) or indoor residual spray (IRS) on malaria vectors.

Progress Report and Outlook

A. Experimental Hut Trials

During the review period, the first objective was to construct, calibrate and optimise experimental huts system for testing the efficacy of compounds on the mortality and behaviour of free flying *Anopheles* mosquitoes under well controlled semi-field conditions

that simulated the natural conditions of adult mosquitoes. Deltamethrin-impregnated bednets (the currently used ITNs in Kenya) against untreated bednets were used to calibrate and optimise the experimental huts so as to increase entry rates of mosquitoes in the experimental huts, increase recovery rates within the semi-field system and reduce mortality in the control. Before testing the efficacy of the new anticholinesterase compound (PRC 331) on *Anopheles* mosquitoes in experimental huts, a laboratory bioassay was carried out to test *An. gambiae* s.s. susceptibility to pieces of netting material impregnated with various concentrations of PRC 331 in the laboratory. The objective was to determine the lowest concentration of this compound on netting material that gives the highest mortality of mosquitoes when they are exposed to a freshly treated net. The laboratory bioassay data showed that the percentage of mosquito knockdown (within 1 hour after exposure of mosquitoes to the treated net) was almost equal to the percentage of dead mosquitoes (24 h later). This means that PRC 331 is a fast acting compound as knocked down mosquitoes never recovered. The lowest concentration of PRC 331 that gave 80–100% mosquito mortality on net bioassay after 20 replicates was 222 mg/m². This is the mortality required to take a given concentration to the experimental hut trials. These experiments were performed in a bioassay room with optimum temperature (24–28 °C) and relative humidity (70–90%) conditions for mosquito survival. Based on this, we chose the 111-mg/m² concentrations as first trial for the experimental hut studies.

The objective was to measure the efficacy of PRC 331 treated bednets on free-flying *An. gambiae* s.s. under well-controlled semi-field conditions with fluctuating ambient temperature and relative humidity. The data from the experimental huts show that PRC 331 at 111 mg/m² is not a spatial repellent, but seems to be a contact irritant insecticide when freshly applied on the net. At that concentration, and up to 2 months post-treatment, it kills 100% mosquitoes within 48 h post exposure, with almost all of them dying within 24 h from exposure. These data are encouraging and prove that PRC 331 at this concentration is indeed toxic to *An. gambiae* in a semi-field condition with fluctuating ambient temperature and humidity, and has some good residual effects.

There is currently no alternative to pyrethroids for ITNs. The results of this study indicate that there is some hope of finding new compounds (with different mode of action than pyrethroids) that can effectively be used in ITNs. This will assist in the management of resistance to sustain this vector control strategy.

In the next review period, five strategies will be pursued. These are:

- Experimental hut trials with PRC 331 treated bednet (111 mg/m²) to determine its complete residual effect.
- Testing a lower concentration (55 mg/m²).
- Laboratory bioassays and semi-field testing of the efficacy of various concentrations of PRC 331 on *An. arabiensis*.
- Comparison of PRC 331 treated bednet with deltamethrin hand treated bednet.
- Experimental hut trials with new compounds obtained from our collaborators at Virginia Tech University (USA).



Collecting mosquitoes from residential homes in Kenya

Participating Scientists: H. Manda and J. Githure (icipe, Kenya)

Key Collaborators: Virginia Tech University (USA)

Main Donor: Foundation for the National Institutes of Health (USA)

Mosquito Nutritional Ecology

General Background

Integrated vector management is currently an important approach to control malaria and improve human health. However, its success lies on the effective implementation of available control tools and the development of new approaches of vector control based on aspects of their biology, ecology and behaviour. The Mosquito Nutritional Ecology project undertook to study the nutritional ecology of *Anopheles* mosquitoes with regard to plant feeding (an aspect of mosquito behaviour that is still poorly understood) in malaria endemic areas of Kenya. The study aimed to determine if plant-sugar feeding is a significant feature of the natural biology of Africa's major malaria vectors, because earlier expression of doubt that plant feeding plays a role in the biology of *An. gambiae* and other anopheline vectors of malaria in sub-Saharan Africa appears to be unwarranted.

Progress Report and Outlook

A. Plant-feeding Frequency and Identification of Mosquito Host Plant Species in Nature

Adult mosquitoes in two behavioural states (resting and host-seeking) were sampled once a week from February 2006 to May 2007 in Mbita (dry, semi-arid malaria endemic area of western Kenya, with modest plant diversity), and during a collection visit in Kilifi in the Kenyan coast, a malaria endemic area with a radically different climate and plant community (warm, humid, high rainfall). All mosquitoes collected were identified to species and then tested for detection of undigested plant sugar in their abdomen. This infers the likelihood of sugar feeding. A total of 23,866 adult mosquitoes, about 40% being *Anopheles* representing 4 species were collected over the study period in Mbita. *Anopheles arabiensis* was the predominant species, followed by *An. funestus*, *An. gambiae* s.s. and *An. coustani*. A total of 2892 mosquitoes were collected in Kilifi, 88% being *Anopheles*. *Anopheles funestus* was the dominant vector, followed by *An. arabiensis*. Other species of *Anopheles* collected included *An. pretoriensis*, *An. rufipes*, *An. coustani*, *An. pharoensis*, *An. maculipalpis* and *An. jebudensis*. In Mbita area, about 12% females and 45% males of *Anopheles* were positive for plant sugar at the time of collection. The feeding rates were similar for all *Anopheles* species collected. The propensity of feeding on plants was 40% higher when females were young (nulliparous) than when older (parous). Between morning and evening, about 50% of mosquitoes had completely digested the sugar in their crop, and digestion took place independently of the sex and physiological status of the mosquitoes. This rapid digestion of plant sugar by mosquitoes in nature indicates frequent feeding. In Kilifi, where plant diversity is higher than in Mbita, sugar feeding was 2–4 times more common in both sexes. These results indicate that plant utilisation by *Anopheles* vectors can be even higher in the wet tropics of Africa. The sugar sources of wild-caught sugar-positive mosquitoes were identified using chromatographic techniques. The pattern that emerged from analyses of 66 field-caught mosquitoes was that both sexes of *An. gambiae* s.l. feed on the same 5 genera of plants. Three of the host plant species identified have been confirmed by direct observation in the field.

This study has shown that, contrary to previous belief that plant feeding is trivial and uncommon in *Anopheles*, there is now convincing field and experimental evidence that plants play a vital role in the biology of *Anopheles* vectors of malaria.

Future activities shall include:

- Assessment of the impact of the availability of specific host plant species of *An. gambiae* mosquitoes on its developmental timeline and reproductive capacity in simulated natural physical conditions in western Kenya.
- Estimation of (and also quantify) the impact of these plants on *An. gambiae* vectorial capacity, and hence malaria transmission.

Participating Scientists: H. Manda, J. Githure, B. Torto and A. Hassanali (*icipe*, Kenya)

Key Collaborators: Ohio State University (USA) and Simon Fraser University (Canada)

Main Donor: National Institutes of Health (USA)

MOLECULAR BIOLOGY AND BIOTECHNOLOGY DEPARTMENT

Characterisation of Mosquito Samples to Species Level by PCR Technique and Monitoring of Resistance to Pyrethroid Insecticides in Mosquitoes

General Background

Field-based vector control methods rely heavily on sampling of both adult and immature mosquitoes. The *Anopheles gambiae* complex consists of 6 morphologically similar, yet genetically distinct sibling species of mosquitoes, whose vectorial capacity and behaviour vary. It is, therefore, important to characterise mosquitoes beyond the morphological level, using PCR techniques. The mosquito genotyping laboratory used PCR-based mosquito taxonomy technique to genotype the mosquito species. The PCR technique is developed based on conserved and species-specific sequences in the intergenic spacer (IGS) of the ribosomal DNA. The conserved and species-specific regions have been used to generate universal and species-specific primers, whose PCR products vary in mobility upon electrophoresis on an agarose gel. The mosquito taxonomy laboratory was also involved in providing species ID services for universities in Kenya on a contractual basis. The levels of monooxygenase activity and *kdr* allele frequency are useful biochemical and molecular indices that indicate extent of mosquito resistance to pyrethroids. Apart from species ID, the laboratory was also involved in screening for spread of resistance to pyrethroids in mosquito populations across the country. Monitoring of spread of resistance is important in ensuring success of chemical control methods such as insecticide treated nets (ITNs) and indoor residual spraying (IRS) of synthetic pyrethroids. This helps to minimise control failures in areas where resistance has developed, which may result to increased incidence of disease despite vector control efforts.

Progress Report and Outlook

A. Characterisation of Mosquito Samples to Species Level by PCR

Mosquito samples are received from the field or from other universities as adults or larvae preserved in ethanol. Prior to preservation, samples are identified by morphology

to ensure that they belong to the *An. gambiae* complex, using morphological characters/keys. Total DNA is extracted by ethanol precipitation method and suspended in DNA buffer awaiting further analysis. Usually a small portion of the DNA is used for species ID and the remaining portion preserved at -20°C for any other molecular characterisation purposes. The PCR technique uses a cocktail of four species-specific primers and one pair of universal primers. The universal primer recognises a conserved sequence in the rDNA IGS of all members of the *An. gambiae* complex. AG, AA, AM and AQ are species-specific primers and amplify *An. gambiae* s.s, *An. arabiensis*, *An. merus* and *An. quadriannulatus*, respectively. Discrimination of sibling species is achieved by agarose gel electrophoresis, with observation of size variations that are diagnostic by the differential mobility of PCR products. The species ID is scored on sample identification database which is provided to the scientists who supplied the samples for genotyping. The laboratory screens approximately 6000 samples on average annually, and provides training to university students through field visits, attachments and postgraduate internships. It is hoped that the laboratory will develop capacity to characterise single species belonging to the *An. funestus* complex.

B. Evaluation of Monoxygenase Levels and Knockdown Resistance (*kdr*) Allele Frequencies in *Anopheles gambiae* and *Anopheles arabiensis* Mosquitoes

A baseline survey of *kdr* allele frequencies and monoxygenase levels was conducted in mosquitoes from the western Kenya region, the Great Rift Valley, Central Kenya region and the Kenya Coast. A total of 1990 mosquitoes was collected using IRS and also larval collection by standard daps. The mosquitoes represent 12 *Anopheles gambiae* and 22 *An. arabiensis* populations that are representative of 34 populations in the three geographically distinct regions (Western, Central and Coastal Kenya). Collected immatures were reared in the insectary to adult stage prior to further analysis, and compared to the susceptible Kisumu *An. gambiae*, as a reference strain. All samples were analysed for *kdr* allele by PCR and the levels of monoxygenase activity detected by biochemical analysis. Monoxygenase levels varied significantly with mosquito age in both the sugar- and blood-fed individuals in the Kisumu strain. Monoxygenase activity in field-collected sugar-fed 7–10-day-old adult females varied considerably within populations. The large within-population variability contrasts with the Kisumu reference strain. Both *An. gambiae* and *An. arabiensis* showed significant among-site variations in monoxygenase activity (details of each site/populations are in press). *Anopheles gambiae* mosquitoes from all the 34 sites except 2 (Mumias and Malindi) had significantly higher monoxygenase activity compared to the Kisumu reference strain. In *An. arabiensis* mosquitoes, monoxygenase activity was significantly different across regions and was highest in coastal Kenya, followed by Central, Rift Valley and western Kenya regions, in that order. The L1014S *kdr* mutation was detected in three *An. gambiae* populations (Bondo, Mumias and Stendmwako) and only one *An. arabiensis* population (Ahero). The *kdr* alleles were all heterozygotes, indicating that detection by physiological methods such as bioassays may have been difficult. *Anopheles gambiae* had significantly higher *kdr* allele frequency than *An. arabiensis* ($\chi^2 = 10.22$, $df = 1$, $P < 0.01$). We did not detect the L1014F mutation in any population; this allele is found in West Africa. Overall, the low *kdr* frequencies in multiple sites suggest that the selection pressure due to previous or ongoing use of insecticides has not led to a high *kdr* allele frequency in *An. gambiae* and *An. arabiensis* populations in Kenya. We also reported for the first time *An. arabiensis* mosquitoes living in the highest elevation in the slopes of Mount Kenya. Malaria cases in the Mount Kenya region have been on the increase in the last 20 years and it was not clear whether the cases were imported or were due to indigenous active transmission by mosquitoes. We collected larvae from

31 sampling sites on the slopes of Mount Kenya at elevations of 1720–1921 masl. The species were identified by morphological and molecular techniques, and were found to be *An. arabiensis*, which is the prominent malaria vector in the surrounding Mwea lowlands. These mosquitoes are responsible for active indigenous malaria transmission as observed in mortality and morbidity cases of young children who had not travelled to malaria endemic regions. The indigenous transmission is likely to cause malaria epidemics with young children and pregnant women as more vulnerable groups.

Two areas to be investigated are:

- Assessment of other mechanisms of mosquito resistance to organophosphate and carbamate insecticides, which are widely used in agriculture, using both molecular and biochemical techniques. We further propose to conduct periodic surveys of *kdr* and monooxygenase levels to assess the changes in the threshold of allele frequencies.
- Based on the new records of *An. arabiensis* on the slopes of Mount Kenya, we will investigate further the temporal and spatial abundance of *An. arabiensis* with consideration to land use patterns, land cover changes and vector population dynamics, and with focus on their contribution to highland malaria transmission in the region.

Participating Scientist: J. Githure (*icipe*, Kenya)

Key Collaborator: University of California at Irvine (USA)

Main Donors: National Institutes of Health (USA)

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OUTPUT

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PLANT HEALTH RESEARCH

Overview

The work of *icipe* in plant health contributes to improving sustainable food security and environmental health through developing IPM options for pre- and post-harvest pests, and for parasitic weeds, such as striga, and biological control (BC) using arthropods. All technology development involves farmer participation to ensure farmers' needs are met. The agenda of plant health research covers three domains: **Staple Food Crop Pests**, which deals with the management of cereal pests and parasitic weeds under the 'Push-pull' and other *Habitat Management Strategies (HMS)* and *Biological Control (BC) of Cereal Pests* programmes. The latter is also linked with the *Noctuid Stemborers Biodiversity Programme* (in collaboration with IRD); **Horticultural Crop Pests**, which deals with *vegetable and fruit fly research*; and **Locust and Other Pests**, which deals with the *African and Madagascar migratory locusts*, and the *armyworm*.

Wherever possible, priority is given to solutions that minimise the impact on the environment and human health, such as BC (classical and augmentative BC), use of baiting stations and habitat management. *icipe* is the only international institution in Africa that has internationally accredited quarantine facilities. The facilities enable it to import and maintain exotic natural enemies once the Kenyan authorities have approved their importation. For more intractable problems, an in-depth understanding of the interactions between soil, plant, pests and natural enemies in their cultivated and natural habitats is required. Such multi-trophic level studies often result in novel pest management technologies.

To overcome the threat posed by climate-driven changes, the Plant Health Division, in close collaboration with the Environment Health Division, is generating the knowledge base and tool sets to empower and assist growers and policy makers to cope with these changes to enhance agricultural development and food security.

Further activities in the Plant Health Division analyse the economic impact of the developed technologies and assess factors associated with their success/failure. Finally, the economic impact of good agricultural practices and international standards on export crop production is assessed as well as the dynamics in farmer training and technology transfer.

STAPLE FOOD CROP PESTS GROUP

BIOLOGICAL CONTROL OF CEREAL PESTS PROGRAMME

Integrated Pest Management of Cereal Stem and Cob Borers in Western Africa

General Background

Lepidopterous stem- and cob-boring pests limit both the yield and stability of maize production in sub-Saharan Africa (SSA). The problem is particularly acute in the small-scale, resource-poor systems under which maize is typically grown. Yield losses in areas with chronic borer problems vary between 10–50%. In the past 10 years, the search for control of stemborers by IARCs has yielded various novel control options and strategies focused mainly on three broad avenues: biological control (BC), habitat management (HM) and use of pesticides such as botanicals.

Strong BC and HM implementation programmes exist in eastern Africa. In contrast, little IPM activities on maize are ongoing in western Africa. Furthermore, most technologies have been tested under a limited range of socio-economic and ecological conditions, which does not allow for prediction of their efficiency and adaptability in different environments.

Thus, the goal of this project is two-fold: (1) based on technologies identified by *icipe* and other IARCs to develop, test and adapt IPM packages to reduce quantitative and qualitative yield losses of maize in western Africa under a range of socio-economic and ecological conditions; and (2) to investigate the efficacy of new association and redistribution BC approaches in western Africa, using parasitoid species reared at *icipe*.

Progress Report and Outlook

*A. Identifying, Rearing and Releasing Three Kenyan Strains of the Braconid Larval Parasitoid *Cotesia sesamiae**

In both the western highlands and forest zones of Cameroon, the project focused on identifying, rearing and releasing three Kenyan strains (Kitale, Meru and their hybrids) of the braconid larval parasitoid *Cotesia sesamiae* that successfully develops on *Busseola fusca*, the main pest across all ecozones. Habitat management technologies that substantially reduce pest infestations and increase maize yields such as improving soil fertility by rotating maize with grain or cover crop legumes, or using synthetic fertilisers or mixed cropping maize with non-host companion crops, were also investigated in the western highlands.

In post-release samplings, all three strains of the parasitoid were recovered in both ecozones. Nitrogen and phosphorus, either singly or in combination, significantly reduced stem tunneling, thereby augmenting yields, with a considerable synergistic effect when used in combination. Maize/Irish potatoes and maize/beans were the best crop mixtures with lowest pest incidence and severity.

In the next review period, two strategies will be pursued. These are:

- Post-release monitoring for permanent establishment, and impact of the parasitoid on pest abundance, damage and yield.
- Evaluation of the best HM practices in other Central African countries (along with strengthening the practices in Cameroon), so that an optimum number of farmers benefit.

Participating Scientist: *B. Le Ru (IRD-icipe, Kenya)*

Key Collaborators: *IITA, IRAD, University of Buea and University of Dschang (Cameroon), IITA (Benin), North West University and Sugar Research Institute (South Africa), University of Hanover and Staatliche Naturhistorische Sammlungen (Germany), and IRD (France)*

Main Donors: *Ministry for Economic Cooperation and Development (Germany)*

THE 'PUSH-PULL' AND OTHER HABITAT MANAGEMENT STRATEGIES PROGRAMME

'Push-pull' Habitat Management Strategy—Addressing Second-generation Research Questions and Defining Optimum Technology Diffusion Pathways

General Background

At least four species of stemborers infest maize and sorghum crops in the eastern African region, causing reported yield losses of 20–40%. On the other hand, parasitic weeds in the genus *Striga* threaten the lives of over 30 million people in eastern Africa and infest 40% of arable land in the savanna region, causing an estimated annual loss of US\$1.5 billion. *icipe's* intervention is based on a stimulo-deterrent diversionary strategy, called 'push-pull' that uses trap- and repellent plants for management of stemborers of cereal-based farming systems in Africa. 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 stemborer repellent 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. The intercrop plants also improve soil fertility by fixing nitrogen and preventing soil erosion.

The strategic goal of the 'push-pull' habitat management programme in 2006–2007 was to address smallholder cereal production constraints in eastern Africa, namely striga weeds, stemborers and low soil fertility, through the strategic expansion of the 'push-

'pull' technology. Related research was undertaken to evaluate the effectiveness of new companion plants, developing strategies for control of phytoplasma disease of Napier grass, and development of push-pull strategies for sorghum and millet farming systems in addition to further evaluation of the technology on maize productivity in western Kenya.

Progress Report and Outlook

A. Strategic Expansion of the Push-pull Strategies in Eastern Africa

We focused on scaling up and out of the technology, defining optimum diffusion pathways and capacity development. The push-pull technology has now been adopted by over 15,000 farmers in western Kenya, mainly driven by the need to control striga and stemborer pests, and to produce more fodder for livestock. The scaling up was facilitated through direct extension by project field staff, farmer teachers, farmer field schools,



Push-pull farmer from western Kenya

field days and public meetings, mass media and the National Agriculture and Livestock Extension Programme (NALEP) in Kenya. Similar efforts have been initiated in Tanzania and Uganda that brings on board strategic partners for efficient dissemination of the technology.

Dissemination pathways play different roles in the technology adoption chain. We sought to establish the effectiveness of the pathways shown above and to evaluate the gender component of the same. The effectiveness of the pathways varied from district to district, but they all

served as important communication channels for dissemination of the technology. More importantly, our studies showed that while there was an overall gender balance with regards to some of the channels through which farmers obtained information on the technology, others like 'fellow farmers' were male-biased while others like 'farmer teachers' and 'farmer groups' were female-biased. This is useful in designing dissemination information packages for target groups in the various target communities.

B. Desmodium Seed Production and Marketing

Desmodium seed availability is often cited as a factor limiting the scaling up of the push-pull technology. A key objective is to develop a small-scale farmer-driven market for desmodium seed in eastern Africa as a means to sustain demand-driven technology diffusion among smallholder farmers. *icipe* collaborated with the Western Seed Company in Kenya to establish a community-based desmodium seed multiplication programme, and established a buy-back guarantee to purchase unsold seed that has been distributed in the open market—up to 3 tons per annum. Western Seed produced desmodium seed and distributed it through a network of agrostockists in western Kenya. In addition to this partnership, we continued with on-station studies and collection of panel data on the cost-efficiency of planting push-pull using desmodium seed vis-à-vis vegetative methods using desmodium vines.

C. Capacity Development

Capacity development of partner national institutions was achieved through trainings on the technology through field staff, the national extension systems, NGOs and CBOs, and technical field staff of partner NGOs like Africa Now, Heifer International and Plan International. In addition, the project scientists continue to develop expertise in disciplines related to the technology, in collaboration with universities. The project scientists are supervising the work of the six PhD and six MSc students in the Programme.

D. Towards Identifying New Companion Plants

With the emerging phytoplasma disease of Napier grass and the need for developing push-pull strategies for sorghum and millet for drier areas of Africa, we are evaluating new companion plants for controlling these pests. A GEF-funded grass project identified several potential trap plants for stemborers. These included *Panicum maximum* and *Hyparrhenia rufa*. Our studies showed that *P. maximum*, when used as a border crop, supports a higher abundance of stemborer predators such as earwigs and spiders while acting as a sink for *Chilo partellus*. We have incorporated *Bracharia* sp. in our assessments because of its forage value. Bioassay results show that *Bracharia* sp. is significantly more preferred to maize for oviposition by *C. partellus* moths, with over 60% of the eggs being oviposited on the grass in two-choice tests. We are carrying out further tests to establish its role as a trap plant.

Our studies at Wad Medani, Sudan to evaluate the drought-tolerant *Desmodium* spp. for control of *Striga* and *Orobanche* weeds are ongoing. In laboratory studies, we are assessing the effect of *Desmodium* spp. on *Striga hermonthica* parasitism. We have observed that in the absence of GR 24, *Striga* displays 11 and 18% attachment to sorghum roots 7 and 14 days after transfer, respectively. In presence of *Desmodium dichotomum*, attachment seems to reduce to 0–7%. In the absence of GR 24, *Striga* seems to display 6 and 12% attachment 7 and 14 days after transfer, respectively. In presence of *D. uncinatum*, *Striga* attachment reduces to 0%. Intercropping *D. dichotomum* with tomato in different planting arrangements, hand-drilled 10 cm behind the tomato holes, in the same hole with tomato and between holes, reduced *Orobanche ramosa* infestation by 13, 41 and 29% respectively. *Desmodium uncinatum* on the other hand reduced infestation by 20, 42 and 23%, respectively, increasing tomato yields by up to 86%.

E. Development of Push-pull Strategies for Sorghum and Millets

We have developed a push-pull strategy for sorghum which we are currently testing on-farm in Rachuonyo district of western Kenya (Khan et al., 2006). In the period under review, each farmer had two plots, one planted to sorghum alone while the other to an intercrop of sorghum and the drought-tolerant greenleaf desmodium, *D. intortum*. Data collected from the farmers' fields show that intercropping with *D. intortum* effectively controls striga (striga counts: 39/100 sorghum plants and 181/100 plants in the intercrop and monocrop respectively) and stemborers (10 and 19% sorghum plants damaged by stemborers in the intercrop and monocrop respectively) resulting in higher yields (2.4 and 1.9 t/ha in the intercrop and monocrop respectively). Additionally, we are developing similar strategies for millets. In an on-station study, results show that intercropping finger millet with *D. intortum* effectively suppresses both striga (striga counts: 46 and 552/100 millet plants in the intercrop and monocrop respectively) and stemborers (stemborer damaged plants: 0.1 and 2.7% in the intercrop and monocrop respectively) resulting in higher grain yields (4 and 2.1 t/ha in the intercrop and monocrop respectively). On-farm testing will follow before the technology is disseminated to the farmers.

F. Napier Stunt Disease Research

The Napier stunt disease is caused by phytoplasma and is transmitted by leaf-/planthopper vectors and cloning propagation of infected materials. In our efforts to identify the vector(s), we have confirmed the identity of the phytoplasma and sampled potential vectors from Napier grass fields that will be used in transmission studies. Phytoplasma that cause plant diseases are often transmitted and spread by phloem-feeding insects. We found that four of the 12 leafhopper species collected from the Napier fields fed mostly on the phloem while the rest showed both xylem and phloem feeding, though all the planthoppers sucked the phloem sap exclusively. From these findings, we have selected species for further testing to identify the putative vectors of the disease. We have also carried out studies to understand better the Napier stunt disease and to develop appropriate pathogen detection procedures for our subsequent studies. We verified the classification of Napier grass stunt phytoplasma (Ngs-phytoplasma) in the 16SrXI (Rice yellow dwarf group) by enzymatic restriction fragment length polymorphism (RFLP) analysis of ribosomal DNA (rDNA), using *AluI* and *RsaI* (New England Biolabs) restriction endonucleases. The RFLP profile was electrophoresed on a 1.5% agarose gel, stained with ethidium bromide, visualised with an UV transilluminator and photographed. We then determined the group affiliation by comparing the restricted fragments with *AluI* and *RsaI* virtual digestion site maps of Ngs-phytoplasma 16SrXI genome (GenBank acc. No. AY377876). Phylogenetic analysis of Ngs-phytoplasma showed that its closest relatives are rice yellow dwarf (RYD), sugarcane white leaf (SCWL), sugarcane grassy shoot (SCGS), annual blue grass white leaf (ABGWL), Bermuda grass white leaf (BGWL) and *Brachiaria* grass white leaf (BraWL) phytoplasmas. Due to technical inadequacy of PCR, we developed a nucleic acid based detection technique termed loop mediated isothermal amplification of DNA (LAMP). LAMP did not require thermal cyclers and was able to yield detectable copies of target DNA in only 60 min, and the DNA amplification was highly robust. Nevertheless, the assay had 10-fold higher analytical sensitivity than did the nested PCR analysis (1×10^{-2} versus 1×10^{-3}). The general agreement between LAMP and nested PCR was found to be excellent, at 80%.

In the next review period, eight strategies will be pursued. These are:

- Up- and out-scaling of the 'push-pull' technology and defining optimum diffusion pathways.
- Evaluation of the cost-effectiveness of the different dissemination channels while determining the role of gender in the technology diffusion.
- Development, testing, and dissemination of appropriate push-pull strategies for sorghum and millets for the drier areas.
- Elucidating the chemical ecology of the current and potential companion plants for their proper deployment.
- Identification of vectors of the Napier stunt disease and screening of Napier grass cultivars for resistance to the disease.
- Assessment of the potential role of early herbivory in the wild host plants that can be exploited for maize protection.
- Identification of the genetic basis of the allelopathy in desmodium root exudates that will eventually lead to breeding of legumes with such strong striga-inhibition traits.
- Development of protocols to assess the long-term impact of the 'push-pull' system on stemborers, their natural enemies and the striga weed since IPM systems sometimes exert selection pressures on the target pests leading to resistance development.

Participating Scientists: Z. R. Khan, D. Amudavi, C. Midega, J. Pittchar and D. Masiga (icipe, Kenya)

Key Collaborators: Rothamsted Research (UK), KARI and Heifer International (Kenya), NARO and Africa 2000 (Uganda), and Ministries of Agriculture in Kenya/Uganda/Tanzania

Main Donors: Kilimo Trust (East Africa) and Biovision (Switzerland)

NOCTUID STEM BORERS BIODIVERSITY PROGRAMME

Biodiversity and Chemical Ecology of Gramineous Noctuid Stem Borers in Sub-Saharan Africa

General Background

In sub-Saharan Africa, the economic importance of stem borers and associated parasitoids varies with the phytogeographic characteristics and ecoregions. The reasons are not well understood in spite of extensive research in the past 50 years. Currently, the hypotheses put forward centre around the existence of biogeographic races, the vicinity of the natural habitats and alternate insect and plant hosts, and the inefficiency of natural enemies (mainly parasitoids) to control stem borers in crop fields.

Progress Report and Outlook

A. Ecology and Distribution of Noctuid Stem Borers and their Larval Parasitoids in Natural Habitats Surrounding Cereal Crops

The IRD project on Noctuid Stem Borer Biodiversity (NSBB) initiated in 2001 focuses on assessing the genetic variation in populations of stem borer noctuid pest species and their main larval parasitoids, capturing the biodiversity of lepidopteran stem borers and their natural enemies in natural habitats surrounding the cereal crops, and understanding the role of natural habitats in the turnover of stem borer pests and their natural enemies in the cereal plots. An effective assessment of the genetic variation in stem borer populations and their larval parasitoids requires also a good understanding of the host selection and acceptance processes of the stem borers and their larval parasitoids. Such understanding was done on *Busseola fusca* and its main larval parasitoid *Cotesia sesamiae*.

The main result of our studies on the genetic structure of the noctuid pests seems to be the maintenance of the ancestral genetic structure. The shift on cereal crops happened independently several times, fast and in several sub-Saharan sub-regions whatever the noctuid pest species. The adaptation to a new host plant is not a rare and slow event for the noctuid species studied. Our results provide new insights on the largely incomplete knowledge of the bio- and phylo-geography of African insects and are putting forward a hypothesis on the origin of the current genetic structures.

Extensive surveys carried out since 2003 in 12 countries of sub-Saharan Africa provide for the first time an overview of the biodiversity of lepidopteran stem borers (171 species with more than 30 new noctuid species), their host plant range (156 species) and natural enemies. They show that stem borer diversity is much higher than reported before and that most species are specialised and localised. Among these pests only *Sesamia calamistis* and *Eldana saccharina* are polyphagous. In addition, our results show that most stem borer species inhabit the wet ecozones (swamps, riverbanks, forest edges).

These results have opened up new research areas in terms of community functioning and stemborer host plant recognition, and led us to reconsider the current hypothesis on the utility of fallow lands in stemborer pest management.

During the next two years surveys will be carried out and extended to the sub-Saharan countries and regions not yet investigated. With the material and data recovered we shall develop our research activities in two areas—systematics and biogeography—of the noctuid stemborers.

The systematics of noctuid stemborers is confusing at both species and genus level. The great similarity of habitus between taxa makes identification difficult. By combining morphological characters and molecular markers we started the revision of the different genera and the phylogeny of all the groups will be reconstructed.

Our recent findings expanded our knowledge on ecology and distribution of noctuid stemborers at a regional spatial scale. Combined with the availability of good climate and mathematical models these data now allow us to predict areas with high potential for diversity and also to infer how global changes will modify stemborer distribution and diversity.

In the next review period, one main strategy will be pursued. This is:

- Investigations to explain the host selection and acceptance processes of the stemborer species studied.

Participating Scientists: B. P. Le Ru and P.-A. Calatayud (IRD/icipe, Kenya), A. Hassanali, P. C. Njagi, C. Omwega and F. Schulthess (icipe, Kenya), and R. Ndemah (icipe, Cameroon)

Key Collaborators: IRD/CNRS, INRA and Muséum national d'Histoire naturelle (France), IITA (Benin), Transvaal Museum, University of Natal and North-West University (South Africa), Wagga Wagga Agricultural Institute (Australia), Institut de Recherche Agricole pour le Développement (Cameroon), National Agricultural Research Organisation (Uganda), Ministry of Agriculture-Zanzibar and Biocontrol Programme (Tanzania), Ethiopian Agricultural Research Centre (Ethiopia), Eduardo Mondlane University (Mozambique), and Centre de Recherche Agronomique de Loudima (Congo)

Main Donors: IRD (France) and icipe (Kenya)

HORTICULTURAL CROP PESTS GROUP

TOMATO RED SPIDER MITE PROGRAMME

Development of Environmentally Friendly Management Methods for Red Spider Mites in Smallholder Tomato Production Systems in Eastern and Southern Africa

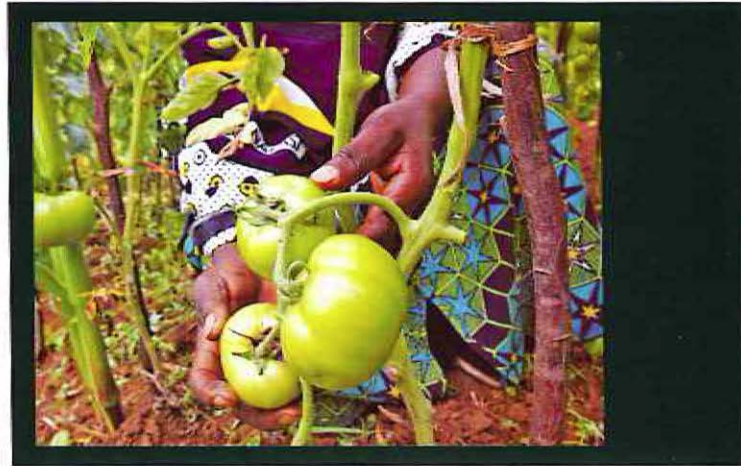
General Background

Tomato production in eastern and southern Africa is affected by a large number of pests and diseases, and consequently pesticide use is high. Therefore, the success of classical biological control is highly dependant on an IPM system that includes biocontrol-compatible control options for all other pests and diseases affecting tomato production. Some IPM components being developed at icipe are listed below.

Progress Report and Outlook

A. Host Plant Resistance

Experiments with crosses between the commercial tomato variety Money Maker and the spider mite resistant wild tomato *Lycopersicon hirsutum* accession LA 2204 indicated that both species hybridise easily and resistance to *T. evansi* is inherited by the progeny. Fecundity and longevity of *T. evansi* were highest in Money Maker, lowest in LA 2204 and intermediate in the crosses. Density of type IV trichomes was negatively and type V trichomes positively correlated with mite fecundity and repellence.



Healthy tomatoes grown in the Usambara mountain ranges of Tanzania

B. Introduction of Predatory Mite *Phytoseiulus longipes* into Kenya

A permit for the release of *P. longipes* was applied for in January 2006 and was granted in December 2006 by the Kenya Standing Committee on Imports and Exports (KSTCIE) after complying with the quarantine requirements and following results from the greenhouse. A release experiment was conducted in a farmer's field between February and May 2007. However, the predatory mites did not establish in the field and had no control effect on the pest despite being present at low densities throughout the experiment. This was probably due to negative effects of pesticides used to control other pests and diseases.

C. Biodiversity of Tetranychid Mites in Kenya

Thirteen tetranychid species have been reported for the first time in Kenya bringing the total number of Tetranychidae found in Kenya to 23 up from 10 before this study. The genus *Tetranychus* is most abundant in Kenya with *T. evansi* and *T. urticae* being the most important species in horticulture. Molecular characterisation of *T. evansi* from Kenya and Tanzania using mitochondrial COI gene and microsatellites analysis has resulted in an identical sequence and alleles for these countries, indicating that there was a single introduction of this pest into this part of East Africa.

D. Inundative Biological Control

The effectiveness of *Metarhizium anisopliae* ICIP78 on the population density of *T. evansi* infesting tomato plants was evaluated in the field. Tomato plants were artificially infested with *T. evansi* and treated with an aqueous or emulsifiable formulation of the fungus. The synthetic acaricide abamectin was included as a check. Treatments were applied 3 times after every 10 days. Mite density was evaluated two days before spraying and weekly post-spraying. There were no significant differences in *T. evansi* population density between the treatments before spraying. Application of the two formulations of the fungus and acaricide resulted in significant reduction of the population density of mites as compared to the controls. However, the reduction was significantly higher

in the emulsifiable and acaricide than in the aqueous formulation. There were no significant differences in number of tomatoes/plant, but the weight of tomatoes/ha was higher in the treated plots than in the controls.

E. Biological Performance and Population Dynamics of Tetranychus evansi as Influenced by Different African Nightshade Species

Studies have shown that developmental time of immature stages of *T. evansi* varies among nightshade species and population growth parameters are influenced by nightshade species. Trichome types and density vary among nightshade species and fecundity and response of *T. evansi* is influenced by presence of trichomes.

In the next review period, four strategies will be pursued. These are:

- Getting reliable information on the establishment of *P. longipes*. Therefore, repeated release experiments have to be conducted in different agroecological zones of East and southern Africa
- Identification of synthetic chemical pesticides that are compatible with the adult predatory mite *P. longipes*, since a number of pesticides show toxicity against it.
- Large-scale field trials to validate the field results obtained with inundative application of *M. anisopliae*.
- Investigations on the effect of *M. anisopliae* fungus on the predatory mite, *P. longipes*.

Participating Scientists: M. Knapp (PI) and N.K. Maniania (icipe, Kenya)

Key Collaborators: Plant Protection Research Institute (Zimbabwe), Universidade de Sao Paulo, Universidade Federal Rural de Pernambuco, Universidade Regional do Cariri and Universidade de Lavras (Brazil), and Ecole Nationale Supérieure Agronomique (France)

Main Donors: GTZ (Germany) and icipe (Kenya)

BIOLOGICAL CONTROL OF THE DIAMONDBACK MOTH PROGRAMME

Expanding Biological Control of the Diamondback Moth (*Plutella xylostella* L.) in Eastern and Southern Africa

General Background

Production of cruciferous vegetables in eastern and southern Africa is seriously affected by the diamondback moth (DBM) *Plutella xylostella* (L.). Chemical insecticides were largely used for the management of this pest, which has gained resistance against many commonly used insecticides resulting in environmental contamination and increased production cost. To develop sustainable pest management techniques against this pest, icipe initiated a biological control project covering Kenya, Uganda, Tanzania and Ethiopia in collaboration with the World Vegetable Centre (AVRDC, Taiwan), University of Hanover, Germany and national agricultural research and extension system partners in the target countries. Since the average natural parasitism rates by the native natural enemies were insufficient to check the pest population, efforts to identify potential natural enemies outside Kenya were initiated. A larval parasitoid, *Diadegma semiclausum*,

used widely and successfully in Southeast Asia, was introduced to Kenya in October 2001. Field releases were made in pilot sites in Kenya and Tanzania. Establishment was recorded from all the sites and parasitism rates by this larval parasitoid surpassed the combined rate of all the indigenous parasitoids. An ex-ante impact assessment predicted a return of 31:1 on the investment in Kenya alone and the number of insecticide sprays on cruciferous crops decreased from 12 sprays to none per season. Subsequently, parasitoids suited to other agroecological zones (like *Cotesia plutellae* from South Africa, which is suited for semi-arid regions of Kenya) were introduced. Based on the success in Kenya, biological control efforts were expanded to other African countries like Ethiopia, Tanzania and Cameroon.

Progress Report and Outlook

A. Release and Impact of *Cotesia plutellae* for DBM Control

Eastern Africa. *Diadegma semiclausum*, the DBM parasitoid, was released in western Usambara, Northeastern Tanzania in August/September 2006 and in the Central and Southern Highlands in 2007 using parasitoids reared at *icipe*. The parasitoids established well and spread to other parts with effective control of DBM in all the release areas. The Ethiopian government gave an import permit to facilitate introduction of *D. semiclausum* to Ethiopia. The long-term observations of the impact of *D. semiclausum* on DBM populations, damage and indigenous natural enemies were concluded after four years of data collection at two pilot sites. The same data set was being used for mathematical modelling of DBM populations. The release campaign for *Cotesia plutellae* in Kitui, Kibwezi, Machakos and Loitokitok districts, Eastern Province, Kenya was completed. KARI started with monitoring surveys for establishment of the parasitoid on all sites in June 2007. The parasitoid was recovered on a few of the release sites but its impact on DBM populations was insignificant. After-release impact studies of *C. plutellae* were continued for the second year at Athi River and Yatta pilot release areas in Kenya. Whereas there are continuous recoveries of the species at Athi River, recoveries at Yatta are erratic. However, at both places, the parasitoid has not managed to increase in numbers as observed in Uganda and this did not change after a re-release of both parasitised larvae and adult parasitoids at Yatta. *Diadegma semiclausum* has become the most important parasitoid at both pilot sites, in spite of its alleged sensitivity to high temperature. We believe that strong competition from this species is responsible for the failure of *C. plutellae* to take over and we have started investigating the factors affecting the outcome of intraspecific competition between the two species. In addition, the situation that was stable until the beginning of December 2006, with *D. semiclausum* in control of the DBM problem, was disturbed by the unexpected outbreak of a very unusual pest problem—the painted bug (*Bagrada cruciferarum*). Massive outbreak of this pest on cabbage, hitherto unknown to the farmers and extension workers, forced farmers to apply a wide range of pesticides to control it. The spraying interfered with the DBM parasitoids and resulted in a huge resurgence of DBM once the bagrada bug problem had subsided.

Western Africa. In an effort to expand DBM biocontrol to countries beyond the immediate project partners, two shipments of *D. semiclausum* were made to Cameroon in July and November 2007 for direct field releases.

B. Studies on the Role of Wild Crucifers for the Cultivated Species

Studies on the role of wild crucifers for the cultivated species were concluded. The aim of this work was to assess the consequences of pesticide applications for pests other than DBM in the system for the introduced biocontrol agents and the role wild crucifers could

play as refugia for parasitoids. Seasonal variation of the diversity and abundance of wild crucifers and the associated cabbage pests and their natural enemies was studied in survey-like assessments for two years at four sites in Kenya, two each in the highlands and two in mid-altitude semi-arid conditions. Whereas crucifer diversity and numbers were high and several species are permanent in the highlands, only two seasonal species were observed in semi-arid areas. The diamondback moth and its parasitoids were found on most wild crucifers in the highlands. In semi-arid areas, parasitoid species diversity was higher but the numbers were much lower than in the highlands. Nevertheless, we conclude that wild crucifers play a role as refugia for parasitoids in case of extinction through the application of broad-spectrum pesticides for the control of aphids or other insect pests.

C. Studies on the Changes in the Behavioural Characteristics of DBM Adults and Larvae During Adaptation

Efforts to study the changes in the behavioural characteristics of the adults and larvae of the DBM during adaptation were conducted in 2007. The ability of adult insects to oviposit on pea also increased with selection for survival on pea. Studies with two populations of DBM indicated no difference at population level for adaptation to pea.

D. Collections of DBM and Its Parasitoids in Romania and Syria

Several collections of DBM and its parasitoids were made in the Black Sea area of Romania in 2006. Additional collections of DBM and its parasitoids were made in the Deir Ezzor and Homs (*D. semiclausum*), Homs (*C. plutellae*) and Deir Ezzor (*Diadromus collaris*) areas of Syria in June 2007 where the day temperatures are above 40 °C. No new DBM parasitoids were discovered.

In the next review period, one main strategy will be pursued. This is:

- Biocontrol of DBM in southern and Central Africa.

Participating Scientists: B. Löhr (PI), B. Nyambo and S. Sevgan (icipe, Kenya)

Key Collaborators: AVRDC (Taiwan) and University of Hanover (Germany)

Main Donors: BMZ (Germany)

DIAMONDBACK MOTH BIOCONTROL IMPACT ASSESSMENT PROGRAMME

Economic Impact Assessment of Biological Control of the Diamondback Moth in Crucifers in East Africa

General Background

This project is part of a larger project on the biological control of the diamondback moth (DBM) (*Plutella xylostella*), in East Africa, which icipe embarked on in 2000. The diamondback moth is the most important pest of crucifers worldwide. The larger project laid the scientific basis for the successful implementation of biological control through surveys in 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 pest is mostly controlled with pesticides. The indigenous natural enemy fauna in these countries was scarce (7 species), compared to South Africa (33 species) or Romania (27 species) and the prevalence was generally low with exception of some areas of Ethiopia. The project also established that only one of the indigenous parasitoids was specific to DBM. As a consequence, the decision was taken to import exotic parasitoids of known value from earlier biocontrol efforts in Asia. Two larval-pupal parasitoid species were imported, *Diadegma semiclausum* (Hellen) (Hymenoptera: Ichneumonidae), that is adapted to temperate highland growing conditions and *Cotesia plutellae* (Kurdjumov) (Hymenoptera: Braconidae), that is adapted to lowland, semi-arid conditions.

For project monitoring and evaluation purposes and as an addition to the biological assessment, the present project represents a short- to medium-term ex post impact assessment. Economic impact assessment generally strives to answer the questions, 'How has the project influenced the present situation? What would have happened without the intervention?' The project thereby complements an ex ante impact assessment (projected impact before the intervention takes place), which estimated that every Euro invested in biological control yielded 24 Euros in return based on the assumption that crop loss can be reduced by 30% and pesticide use by 70%.

Progress Report and Outlook

A. The Economic Impact of *Diadegma semiclausum* in Cabbage Production

The assessment is based on a cabbage production survey in 2005 of a cross section of 1250 randomly selected households from Kenya and Tanzania. The analytical approach used a two-stage damage control production function framework, which treats pesticides and the presence of the biological control (BC) agent as damage abatement agents. Results demonstrate that farmers producing cabbage in areas where the parasitoid is present use significantly less pesticide compared to farmers from areas without presence of the BC agent. The damage control function shows on one hand that pesticides (or the presence of the parasitoid) increase cabbage output. On the other hand, the estimation results indicate that farmers using pesticides in the presence of the BC agent obtained significantly lower cabbage output. This is due to the negative interaction term, reflecting a negative impact of pesticides on the BC agent. The analysis further shows that in areas with the biocontrol agent, farmers show 20% fewer pesticide-related health symptoms than in areas without the BC agent, holding all other factors constant. It normally takes about 4–5 years before the full establishment of such an introduced natural enemy. Since the parasitoid was released in 2001, our results do not reflect a long-term steady impact but rather a short- to medium term ex post impact assessment. For this purpose, households that had participated in the 2006 surveys were located and production was monitored from September 2007. The panel data set retains 270 households from Tanzania and 221 from Kenya.

B. The Economic Impact of *Cotesia plutellae* in Kale Production

The production survey of a random sample of 250 commercial kale farmers in Eastern Province (Machakos and Makueni districts) and western Kenya (Busia, Suba and Bondo districts) was completed in January 2007. The survey design follows a modified with

and without approach, i.e. it includes households without the BC agent, with the BC agent but who are not aware of it (this was necessary due to migration of the parasitoid from Uganda to parts of western Kenya) and households with the BC agent who are aware of its presence. The latter areas are at the same time pilot sites of the DBM biocontrol project.

Descriptive results show a huge variation in the sample with respect to kale output. Both, the cabbage (see above) as well as the kale surveys for this project, show a lower pesticide application frequency than was initially estimated by the DBM project. The data were further analysed from December 2007 following the same approach as for estimating the impact of *D. semiclausum*.

In the next review period, one main strategy will be pursued. This is:

- Impact assessment of new *icipe* projects, e.g. for leafminer flies.

Participating Scientists: D. Mithöfer (PI) (*icipe*, Kenya)

Key Collaborators: University of Hanover (Germany)

Main Donors: GTZ/BMZ (Germany)

VEGETABLE INTEGRATED PEST MANAGEMENT IN THE EASTERN ARC MOUNTAINS PROGRAMME

Promotion of Integrated Pest Management in Horticultural Crop Production in the Eastern Arc Mountains and East African Coastal Forest Mosaic Biodiversity Hotspot

General Background

Commercial vegetable cultivation for urban centres is an important contributor to rural livelihoods and has been identified as a key threat to biodiversity conservation efforts in the Eastern Arc Mountains and East African Coastal Forest Mosaic (EACF) hotspot. This is because cultivation leads to forest clearance, and pollution of the soil and water due to excessive use of inorganic agrochemical inputs. To minimise the negative effects of increased vegetable production in the hotspot, promotion of more sustainable and productive farming methods is required to mitigate the threat. This can be done through effective agricultural extension, and more particularly, integrated crop and pest management in vegetable production. The *icipe*-led diamondback moth IPM-based biocontrol programme for Eastern Africa has already started to promote the technology for brassica crops and the results, in terms of reduced insecticide spraying in the Taita Hills, are quite impressive. In this area, spraying cabbage and kale to control the DBM, one of the key pests, has been reduced from 12 sprays to zero per season. This was achieved through the introduction of a successful biocontrol agent, and awareness creation and training of farmers and extension agents about effective IPM approaches for brassica crops. The fact is that a wide range of vegetables is grown in the target area, but the DBM project has developed solutions mainly for brassica crops; thus there is need to promote IPM for other popular vegetables grown in association with brassicas to facilitate wide-scale use of environmentally acceptable production practices. It is in this context that the red spider mite project has developed some IPM options that could be used to improve tomato production with reduced pesticide application. This three-year

project started in 2006 and links the Plant and Environmental Health divisions. Lessons and experiences from the *icipe*-led DBM biocontrol and red spider mite projects are used as the basis. The project broadens and integrates outputs of the projects—from crop-specific to multiple vegetable production—in the context of vegetable farming systems, livelihoods and biodiversity conservation and utilisation. The pilot phase was carried out in Taita Hills, Taita District, Coast Province of Kenya



Farming soybeans, a new valuable crop in East Africa

and Western Usambara, Lushoto District, Tanga Region of Tanzania, and implemented in collaboration with the ministries of agriculture, extension departments of Tanzania and Kenya, Horticultural Research and Training Institute Tengeru, Arusha, Tanzania and the Cross-Border Biodiversity Conservation Project (Taita-Taveta).

Progress Report and Outlook

A. Baseline Study (April/May 2006)

A baseline study on the types of vegetables grown, production constraints, market access, and use of synthetic pesticides was conducted in the Taita Hills (Kenya) and Western Usambara (Tanzania), which are two areas within the Eastern Arc Mountains Conservation Hotspot, in April /May 2006.

The objective of the study was to collect baseline information that could be used as a basis for the formulation, development and implementation of locale-specific integrated pest management (IPM) training programme for small-scale vegetable growers in the areas.

The study provided this evidence:

- A wide range of vegetables is grown for sale in urban centres (Mombasa and Voi in Kenya; and Dar es Salaam, Tanga, Zanzibar and Arusha in Tanzania).
- Vegetable production in both project sites is a source of income and therefore, contributes to livelihood for the communities living in the environs of conservation forests.
- A wide range of synthetic pesticides is used in vegetable production and therefore, this is a threat to human health and biodiversity conservation efforts.
- Pesticide use is the first pest control option for the majority of vegetable producers.
- Indiscriminate use of agrochemical inputs (pesticides and inorganic fertilisers) is rampant; hence the need for the introduction of IPM and good agricultural practices to reduce over reliance on such inputs.

Whereas in Western Usambara some farmer groups have established organised market outlets, the Taita Hills farmers sell individually to brokers. Based on this information, two organised farmer groups in Taita Hills and three in Western Usambara were selected for IPM training using modified farmer field schools (FFS) during the pilot phase starting from July 2006.

B. Farmer Field Schools (2006/07)

Season-long hands-on farmer field schools were started in July 2006 in Taita Hills (one group) and Western Usambara (two groups). At both sites, brassicas and tomatoes were used as entry crops to initiate the FFS. Additional pesticide-dependent crops (sweet pepper and cucumber) were included. Good agricultural practices (GAP) concept was emphasised as the backbone to sustainable vegetable production.

DBM biocontrol was used as the entry point in cabbage and kale production. In tomatoes, varieties with resistance and/or tolerance to key pests were tried out. For the first time in Taita Hills and in Western Usambara, farmer groups evaluated two new lines [Shengena (44-2) and Meru (19-2)] from HORTI-Tengeru, Arusha, Tanzania with tolerance to late blight, a major cause for heavy fungicide application. 44-2 is also resistant to tomato mosaic virus (ToMV), root knot nematodes and powdery mildew whereas 19-2 is tolerant to root knot nematodes and ToMV. These two new lines, which were officially released in Tanzania in 2007, were compared with Tengeru-97 and Tanya (two conventional varieties popular with farmers and consumers in the two countries), and the farmers' own selections. (Farmers process seeds from previous crops and keep for planting in which case the varieties are not pure. In western Usambara such selections are known as 'dumudumu' and in Taita Hills as 'chawia'.)

The two new tomato lines survived unexpected heavy rains in September–December 2006 and the produce was of good quality. By combining good agronomic practices (proper spacing, mulching, plant feeding, staking, and routine inspection for insect pest damage and diseases) with tolerance to blight, the key disease, spraying was reduced from 16 to 7 and 20 to 6 per crop season in Taita Hills and Western Usambara, respectively. Farmers in both areas were impressed by the new introductions and requested for more seeds for planting in 2007.

C. On-farm Quality Tomato Seed Production

During the baseline study in 2005, on-farm tomato seed extraction was identified as a common practice in the project areas as a strategy to reduce production cost. Commercially available seeds are costly and therefore farmers produce own seeds each season, a practice that has high potential of eroding the inherent qualities of varieties grown, e.g. in-built tolerance/resistance to pest attack and yield potential, because farmers are not versed with quality seed production methods. Through participatory review of the FFS sessions conducted in 2006, the farmer groups requested to be trained in on-farm tomato seed production. All groups identified C line 44-2 as a potential variety of their choice for further development. The Tanzania national seed policy provides an enabling platform for the national agricultural research institutions to facilitate quality seed production of various crops at farm level and the seeds so produced sold among farming communities in their localities. Similarly in Kenya, KEPHIS has been facilitating farmers to produce quality seeds that they can sell among themselves. Based on this, and taking advantage of national seed policy framework of Tanzania and Kenya, foundation seeds were obtained from AVRDC Regional Centre for Africa in Arusha, Tanzania for the FFS sessions which were conducted in 2007.

D. GAP in Cucumber Production

Cucumber, Ashley variety, one of the most popular varieties in East Africa for many years, is one of the vegetables widely grown by farmers in the target project areas in rotation with other vegetables. The vegetable is highly susceptible to powdery mildew, the melon

fly, and vector-borne viral diseases, and therefore, production is pesticide-based. Pesticide spraying in cucumber production is highly undesirable because the fruits are consumed raw, and therefore this is a threat to human health. Furthermore, continued pesticide use in cucumber production in the target project areas is likely to jeopardise sustainability of the already established DBM biocontrol programme and other biodiversity conservation initiatives. During the tomato/cabbage IPM FFS sessions, the issue was put forward with the farmers to increase their awareness about the potential threat of the current practice and possible solutions. Two groups (one in Taita Hills and another in Western Usambara) agreed to be trained in GAP in cucumber production.

As a follow-up, the project approached the East-West Seed Company in Arusha, Tanzania for alternative cucumber varieties. The seed company has successfully introduced Kande variety, a hybrid of Ashley, to small-scale farmers in Arumeru District of Northeastern Tanzania. This new variety is gradually replacing Ashley in the district. Its good attributes include early maturity (flowering starts 10–14 days earlier than Ashley), quality fruits, high yield, long harvesting period, and tolerance to mildew (particularly powdery mildew) and virus complexes. Farmers and consumers alike in Northeastern Tanzania are adapting to Kande because it is cheaper to produce and healthier to eat (due to less pesticide spraying in production).

Kande and Ashley seed samples were given to the groups for planting. The two varieties were planted at the same time for comparison purposes on the FFS field plot in July 2007.

Overall, the farmers appreciated cucumber production because of these facts:

- When well managed, Ashley can give a good quality crop;
- Staking is essential for quality fruit production and makes other operations, e.g. spraying, picking and weeding much easier;
- Feeding the plants through timely top dressing will prolong the production cycle irrespective of variety;
- Field sanitation is a useful IPM practice that can reduce damage caused by melon fruit fly;
- There is no need for pesticide spraying once picking has started;
- Insect-damaged fruits can be picked and removed from the field for safe destruction;
- Group members who also do fish farming can use the insect-damaged fruits as additional fish food instead of having to bury them to reduce build up of adult fly populations.

E. Intermediate Impact Assessment

An intermediate impact assessment was organised to get an impression of how the vegetable IPM introduced to a small group of farmers was diffusing to the other members of the farming community and to evaluate the course content and the training approach used. The study started in July 2007 and will be completed in 2008.

In the next review period, one main strategy will be pursued. This is:

- More technical support to the communities and their local extension service providers before they can fully internalise GAP/IPM as a practice in vegetable production. This will require resources to cover publicity, facilitation of additional GAP/FFS sessions, marketing of GAP/IPM-produced vegetables (product development and marketing), and linking vegetable production practices and biodiversity conservation for a further three years.

Participating Scientist: B. Nyambo (PI) (*icipe*, Kenya)

Key Collaborators: HORTI-Tengeru and Lushoto District Horticulture Division (Tanzania), UNDP/GEF East Africa Cross-border Biodiversity Project (Kenya)

Main Donor: Biovision Foundation (Switzerland)

PRODUCTION OF A GENERIC QUALITY MANAGEMENT SYSTEMS MANUAL PROGRAMME

Production of a Generic Quality Management Systems Manual for Use by Smallholder Export Horticultural Farmer Groups in Kenya to Achieve Certification Under Option 2 of EurepGAP Regulations

General Background

The pilot project for the production of a generic quality management systems (QMS) manual for use by smallholder export horticultural farmer groups in Kenya to achieve certification under Option 2 of the EurepGAP Regulations was funded by the DFID-BSMDDP and GTZ/PSDA-Kenya. It ran from September 2005 to October 2006. Its key objectives were to: (1) field-test a draft GTZ QMS generic manual under Kenya production systems as part of an international study conducted in Brazil, Ghana, Macedonia and Vietnam to facilitate development of a generic QMS manual for EurepGAP Option 2; (2) adapt the manual to Kenya smallholder out-growers' farmer group horticultural production systems; and (3) facilitate EurepGAP certification under Option 2 of project participating out-grower farmer groups.

Progress Report and Outlook

A. Field Testing of the Draft GTZ QMS Generic Manual under Kenya Production Systems

Nine smallholder farmer groups in three clusters (Kirinyaga, Meru and Thika) were selected to participate in the pilot project. The farmer groups were selected on the basis of legal entity, existing contractual linkage to exporter(s) or product marketing organisation(s), having basic common facilities (grading shed/stores/health amenities) and access to water source(s) for irrigation.

icipe provided managerial services and technical backstopping throughout the process, and conducted training in HACCP. Agribusiness & Allied (Kenya) Ltd (Agribus), a private service provider, conducted hands-on training of the farmer groups on basic concepts of integrated pest management, good agricultural practices and EurepGAP regulations, and facilitated the establishment of a quality management system (QMS) for all nine participating farmer groups, including use and management to achieving EurepGAP certification under Option 2, and the internalisation of the QMS generic manual developed by the project. GTZ-PSDA/MoA ran a five-day residential course for all the participating farmer groups on 'Farming as a Business'. Standards & Solutions (Consulting) Ltd, also a private company, conducted the monitoring and evaluation of project implementation activities.

B. Adapting the Manual to Kenya Smallholder Out-Growers' Farmer Group Horticultural Production Systems

Development of the draft Kenya QMS generic manual took place in two phases. Phase I involved deskwork (formulation of the first draft using the generic GTZ QMS manual). Then, GTZ HQ in Germany and AfriCert Ltd in Kenya rigorously reviewed it, after which was the launch of the second draft at the end of February 2006. Phase II of its development involved field-testing and end-user feedback (farmer groups/service providers/export companies/product marketing organisations). This was done over a period of five months (March–July 2006). The views of end users on the second draft were used to fine-tune the final version to suit the smallholder horticultural production systems in Kenya.

C. EurepGAP Certification under Option 2 of Project Participating Out-grower Farmer Groups

Pre- and certification audits were conducted by AfriCert between end of May and September 2006. Six farmer groups out of the nine participating in the project were EurepGAP certified under Option 2.

Lack of group cohesion, and poor farmer group–buyer (exporter) commercial relationships and farmer group–landlord relationships were major challenges to the implementation of the project.

In the next review period, two strategies will be pursued. These are:

- Frequent updating of the QMS manual in line with new requirements, as GlobalGap has replaced EurepGAP with effect from 2007.
- Widespread testing and fine-tuning of the QMS manual to local production/market requirements.

Participating Scientists: B. Nyambo (PI) and A. A. Seif (icipe, Kenya)

Key Collaborators: GTZ Sectoral Project Agriculture and Trade (Germany)

Main Donors: DFID-BSMDP and GTZ/PSDA (Kenya)

IMPACT ASSESSMENT IN HORTICULTURE PROGRAMME

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

General Background

The horticultural sector is rapidly growing in importance in Africa. Vegetables are an important source of income for small-scale farmers and are vital for the supply of vitamins and other micronutrients to consumers.

Exotic vegetables such as French beans have become important export commodities with a high potential to contribute to poverty alleviation.

This generally positive development is put in jeopardy by at least three developments: (1) increased use of agrochemicals, (2) public legislation on maximum pesticide residue limits and traceability systems and (3) private, non-legal industry production standards like EurepGAP (now GlobalGAP). Both the public and private standards may endanger smallholder participation in export production, since it is questionable whether small-scale farmers have the resources and especially the skills to implement them. Key concerns in both standards are related to pest control.

Previous research at *icipe* has demonstrated that alternative safer methods of pest management exist. However, policies that could facilitate a diffusion of these methods have not been put in place possibly due to lack of information on the economic and social benefits of such changes. Therefore, this project is a comprehensive study on the expected impact of environmentally benign and less hazardous crop and pest management technologies and a status quo analysis of the impact of production standards on the horticulture sector in Kenya.

Progress Report and Outlook

A. Impact of Standards on Horticultural Production

Studies show that smallholders benefit from EurepGAP certification, but access to information, capital and services are major factors influencing their ability to adopt the standards. Smallholders take longer to recover their investment and to break-even than large-scale farmers. However, they operate on a lower input-output level so that overall, measured by the turnover-cost ratio, smallholder farms operate as efficiently as large-scale exporter-owned farms and better than large-scale contracted farms. Taking the different prices into account, from an exporter perspective, it is however, cheaper to source from smallholder farms than from medium- to large-scale farms despite higher transaction costs in terms of monitoring of production.

On large farms, employees receive significantly higher income and health care benefits. EurepGAP certification contributes to a higher level of training on small as well as on large farms, and tendency to use protective clothing during pesticide application.

B. Impact of Sustainable Technologies and Farmer Training

International standards, for example EurepGAP, have raised interest in sustainable production methods and food safety issues. However, sustainable pest control is a key difficulty. Parallel to this, Kenyan agriculture is undergoing reforms, which also target the extension system, calling for private sector involvement and focusing on potential economies of scale by using group training approaches. In light of this the study 'Impact of training on smallholder (horticultural) production in Kenya: The role of social capital and information' focuses on IPM training in horticulture in Kenya and two group approaches, the farmer field school (FFS) and the common interest group (CIG). The common interest group approach is a more recent development than FFS in Kenya. A preparatory survey was conducted in 2007 to assess the scale of IPM training in horticulture using these two approaches. Results show that more farmers are enrolled in common interest groups than in farmer field schools. In both approaches, IPM is not taught as a topic on its own but rather is integrated into general production issues. Further analysis will be carried out throughout 2008.

Research on the influence of group culture on participation in the export market shows that farmer groups with clear rules, good structure and organisation are more successful

in participating in the export chain. Group activities such as meetings, elections and working on commercial plots increase group cohesion and social capital but are not essential for success. A continued link with one buyer does not seem to be a necessary indicator for the success of a group but rather the group's continual selling to the export market even if this implies trading with different buyers.

C. Policy Regimes and Sustainable Horticultural Production

Preparations commenced on a study on the external costs of pesticides in the vegetable sector in Kenya. Initial deskwork reviewed studies conducted globally on this issue and fed into development of a full research proposal. The study makes use of pesticide use and pest management data collected in previous surveys, e.g. the ones under the 'Impact of standards on horticultural production' mentioned above as well as surveys conducted for the 'Economic impact assessment of biological control of the diamondback moth in crucifers in East Africa' project, to assess potential external effects. The mean environmental impact quotient (EIQ) value was calculated at 22, 6 and 82 for farm workers, consumers and the environment, respectively with an overall average at 37. These results indicate that the sub-sector has potentially negative external effects, especially in the environmental dimension. This is being assessed further.

In the next review period, one main strategy will be pursued. This is:

- Development of a new project.

Participating Scientist: D. Mithöfer (PI) (icipe, Kenya)

Key Collaborators: University of Hanover (Germany)

Main Donors: GTZ/BMZ (Germany)

AGROMYZID LEAFMINER FLIES RESEARCH PROGRAMME

Tackling *Liriomyza* Leafmining Flies: Invasive Pests of Global Proportions

General Background

Agromyzid leafminer flies (LMF) are pests of economic importance on several horticultural crops. In Kenya, severe crop damage has been reported in vegetables including snow peas, sugar snap peas, French beans, runner beans, okra, aubergine (eggplant) and tomatoes. Yield losses range from 10–100%. Serious damage has also been reported on cut flowers and passion fruit. To-date there is no practicable method for inspectors to distinguish between LMF species since they are mostly in the larval stage when detected. As a result, whole consignments are rejected in case any LMF is detected. Thus, the aim of this project is to improve natural control of LMF in major food and horticultural crops, and more specifically, to reduce pesticide use through introduction of efficient exotic parasitoids and other environmentally friendly control methods.

Progress Report and Outlook

A. Evolutionary History of Agromyzidae in Africa and Its Implications for Parasitoid Efficiency

A review of the evolutionary history of Agromyzidae in Africa and its implications for parasitoid efficiency has been completed. Agromyzid diversity in the Afrotropical region is much reduced compared to the Palaearctic, Neotropic and Nearctic regions, where active co-evolution of insects and plant hosts might have occurred. Afrotropical region species diversity was estimated at 9.2% of the total existing worldwide species. This suggests that most species might have evolved in those regions and only a few in the Afrotropical region. The same might have happened with the parasitoid species.

B. Surveys for Leafminer Flies and Their Parasitoids in Kenya

A countrywide survey in Kenya revealed that LMF are present in all areas sampled. The different LMF species collected and their parasitoids are being identified. The most abundant species (95%) so far are *L. sativae*, *L. huidobrensis* and *L. trifolii*, which are the three most economically important. Parasitoids are found both on horticultural crops and weeds, and the rate of parasitism estimated so far is 5.2% (SE = 3.1).

C. Identification Method of Leafminer Flies

Molecular method for identification of leafminer flies has been established at *icipe*.

D. Exploration for Leafminer Flies Parasitoids in Peru for Classical Biocontrol

In Peru, weed flora and maize plants infested with *L. sabazia* and *L. graminivora* were identified as potential sources of parasitoids for controlling *L. huidobrensis*. Twelve parasitoid species belonging to three different families, Fitigidae (1), Eulophidae (10) and Mymaridae (1), were recovered on young maize plants where percent parasitism reached an average of >77%. Surveys identified five potential biological agents of *L. huidobrensis*: *Halticoptera arduine* (Pteromalidae) and *Chrysocharis flacilla*, *C. caribea* and *Diglyphus websteri* (all Eulophidae) for lowland and *Phaedrotoma scabriventris* (Braconidae) for highland areas. Arrangements are underway to import some of these parasitoids to Kenya for classical biocontrol.

In the next review period, four strategies will be pursued. These are:

- Efforts to elucidate the pest status and impact of the indigenous natural enemies through countrywide surveys and focus group discussions with vegetable growers.
- Investigation of the role of vegetable plant species, e.g. snow pea, French bean, faba bean and tomato in maintaining populations of the LMF and their natural enemies.
- Molecular identification of the three *Liriomyza* species for laboratory experiments and rearing purposes.
- Investigations, in Peru, of the development and reproductive potential of three LMF parasitoids (*H. arduine*, *C. flacilla* and *P. scabriventris*) selected in the potato production systems, and the parasitoids mass reared prior to importation to Kenya.

Participating Scientists: B. Löhr (PI), A. Chabi-Olaye and N. K. Maniania (*icipe*, Kenya)

Key Collaborators: University of Hohenheim (Germany) and International Potato Center (Peru)

Main Donors: BMZ/GTZ (Germany)

AFRICAN FRUIT FLY PROGRAMME

Fruit Fly, Mango Seed Weevil and Mango Mealybug Research

General Background

Among the different agricultural sectors, horticultural production represents a particularly important opportunity for food security, income generation and economic growth. Across Africa, a large proportion of the population is embracing horticultural production because of the high economic returns and their nutritive value. For example, mango (*Mangifera indica* L.), which is one of the four major commodities of concern to the FAO-Intergovernmental Sub-Group on Tropical Fruits, and the second-most internationally traded tropical fruit after pineapple, is grown both for home use and cash income, in the domestic and export markets. Several factors, however, constrain mango production, among which are insect pests, regarded as among the most important. Tephritid fruit flies (e.g. *Bactrocera invadens* and *Ceratitis cosyra*), mango seed weevil (*Sternochetus mangiferae*), and mealybugs (*Rastrococcus iceryoides* and *R. invadens*) cause direct damage to fruits leading to 40–80% losses depending on locality, variety and season. Quarantine restrictions on fruit fly and weevil-infested mango fruits limit export to lucrative markets in Europe, the Middle East, Japan and USA, where these insects are quarantine pests. The African Fruit Fly Programme, using mango as a model crop, is addressing these pest problems through extensive studies on their biology and ecology, and development of IPM technologies, while simultaneously exploring for natural enemies in the aboriginal homes of the invasive pests, *B. invadens* and *R. iceryoides*, for which classical biological control will play a major role in their management, for introduction and release in Africa. Capacity building through training of PhD and MSc students, as well extension and quarantine personnel, is also a primary focus of the project.

Progress Report and Outlook

A. Bioecological Studies

Distribution and abundance of *Sternochetus mangiferae*. Survey for the incidence and distribution of the mango seed weevil (MSW) in Kenya in 5 provinces commenced during the July/August 2007 mid mango season. All export varieties sampled (Kent, Apple, Tommy Atkins, Keitt, Sensation, Van Dyke and Haden) and local varieties (Boribo Muyuni, Dodo, Ngowe, Peach and Kagege) were infested. The local varieties, however, had higher levels of infestation ranging from 45 to 73% compared with the improved export varieties with infestations varying from 2 to 65%. Across provinces, weevil infestation was highest in Eastern and lowest in Central. In Eastern Province, there was no consistent level of infestation in samples from sites in the same locality and similar environmental characteristics. For example, samples from Mwingi and Mbeere in the same province recorded 0 and 37% infestation, respectively.

Distribution and abundance of *Rastrococcus iceyroides*. In Kenya, survey for distribution and abundance was carried out at the low elevation regions along the periphery of the coastal plane from June–December 2007 in Taveta, Voi, Mombasa, Lunga-Lunga, Muhaka, Kinango, Kilifi, Malindi and Lamu. During the survey, the mealybug was only recorded at Kinango and Malindi. Mealybug population was at 18.4 and 26.8/leaf at Kinango and Malindi, respectively.

Seasonal dynamics of mango infesting fruit flies. Abundance and seasonal dynamics of fruit flies on mango using NuLure and weekly collection of mango fruits at Nguruman



Mango grower in Embu, Kenya

revealed the presence of three main fruit fly species—*Bactrocera invadens*, *Ceratitis cosyra* and *C. capitata*. The relative abundance index (RAI) was found to be $B. invadens > C. cosyra > C. capitata$. The RAI values for *B. invadens* ranged from 0.70–1.00 and 0.73–1.00 in three different surveyed orchards. Indices of adult population density using NuLure attractant showed extreme dominance of *B. invadens* compared to other fruit fly pests of mango. *Bactrocera invadens* catches ranged from 93–116 flies/trap/week compared to 2–15 flies/trap/week for *C. cosyra*. Annual

population trend showed a distinct peak abundance of these fruit fly pests in October to December, which correlated with peak fruiting of mango.

B. Evaluation of Commercial and Locally Developed Food Baits

During the October to December 2006 mango season the efficacy of three commercial, and one locally produced, attractants was evaluated for capture of the invasive fruit fly *B. invadens* at Nguruman Division, Kajiado District in Kenya. Three trap types were tested including the Multilure, Easy and Lynfield traps, all baited with NuLure, Torula yeast, corn steepwater and a local yeast attractant. *Bactrocera invadens* male catches varied significantly among the different trap/attractant combinations ($F=15.34$, $df=11, 24$, $P<0.0001$). Catches were highest with the Multilure trap/Torula yeast (13.63 flies/trap/day [FTD]) followed by Multilure trap/NuLure (9.86 FTD). The least number of males was captured with the Easy trap/yeast product (0.76 FTD) and Lynfield trap/corn steepwater (0.85 FTD). Female catches during this season were highest with Multilure trap/Torula yeast (16.67 FTD). The Lynfield trap/corn steepwater (0.73 FTD) and Easy trap/yeast product (0.68 FTD) caught the lowest number of flies. The NuLure and Torula yeast attractants, irrespective of trap type, attracted significantly higher percentage of *B. invadens* female flies (56–57% and 55–59%, respectively) compared to the other attractants.

C. Isolation and Characterisation of Microsatellite Markers

Genomic DNA was extracted from *B. invadens* in an effort to isolate and characterise microsatellite markers for the invasive pest. A total of 200 plasmid inserts were analysed on an ABI PRISM® 310 Genetic Analyzer (Applied Biosystems, Foster City, CA, USA).

Twenty-six clones contained microsatellite sequences. Primers were designed for 11 loci with suitable flanking sequence using Primer3. Preliminary PCR screening performed on 18 females and 27 males from the *icipes* strain of the insect yielded single locus amplifications and the loci were polymorphic in both sexes. The 11 primers were tested to assess their polymorphism in two wild populations: Sri Lanka (Ranbukpitiya 07°02'54"N, 80°30'52"E) and Democratic Republic of Congo (Kisantu Botanical Garden 05°07'S, 15°05'E). Because only males are captured with methyl eugenol attractant, all the analyses were performed on male individuals, 27 from each population. All loci were polymorphic across the two samples. The number of alleles per locus ranged from three to 15, and eight loci had a polymorphic information content (PIC) > 0.5. Genetic variability within populations was analysed using Genepop, version 3.4. A comparable high level of polymorphism was detected for the majority of loci in the two populations analysed, which also displayed the presence of private alleles. None of the loci displayed linkage disequilibrium (Fisher's exact test, Genepop). One case of deviation from Hardy-Weinberg equilibrium was observed at locus Bi6 after Bonferroni correction with heterozygote deficiency in the Sri Lankan population. The use of MICRO-CHECKER, version 2.2.3 indicates that this may be due to the presence of null alleles. This study provides the first set of microsatellite markers available for *B. invadens*. The range in repeat sequence length and diversity of these markers will allow the investigation of population structure and invasion history of this species.

D. Characterisation of Fruit Flies Complex in Sri Lanka and Exploration for Natural Enemies of *Bactrocera invadens*

A second exploratory trip was embarked on during the period 20 February–30 June 2007 to conduct a survey of fruit flies and their natural enemies in various agroecological zones with the aim of finding additional effective natural enemies and screening them as biological control candidates.

Adult fruit fly population assessment. Adult population density was assessed using Lynfield trap and methyl eugenol (ME) lure. ME traps were deployed at 64 sites in 30 localities across all agroecological zones in 7 of the 9 provinces of the Island. Flies were present in all sampling sites. Fly predominance was as follows: *B. kandiensis* > *B. correcta* > *B. invadens* > *B. zonata* > others. Species and numbers varied with the agroecological zone. In the low and mid areas of the wet zone, *B. kandiensis* was the predominant species, followed by *B. zonata*, *B. invadens* and *B. correcta* (36, 28, 25 and 7% and 43, 29, 16 and 8%, respectively), while the high areas were predominated almost exclusively by *B. paraverbasifoliae* (96%). For the combined results of all three areas, the composition was like in the low and mid areas—*B. kandiensis* (40%), *B. zonata* (27%), *B. invadens* (19%) and *B. correcta* (7%). In the intermediate zone, the trends were slightly different. *Bactrocera invadens* dominated the low areas (51%) followed by *B. kandiensis* (24%), *B. correcta* (19%) and *B. zonata* (6%). In mid areas, the trend was reversed for the first three species—*B. correcta* (61%), *B. kandiensis* (27%) and *B. invadens* (6%) while *B. zonata* (5%) maintained its fourth position. In the high areas *B. paraverbasifoliae* (38%), *B. invadens* (23%), *B. kandiensis* (15%) and *B. zonata* (11%) were the predominant species. When combined, *B. invadens* (34%), *B. correcta* (31%), *B. kandiensis* (24%) and *B. zonata* (6%) were the dominant species. In the dry zones (all low), *B. correcta* (47%), *B. invadens* (33%) and *B. kandiensis* (12%) were the predominant species.

Collection and processing of host fruit for fruit flies and parasitoids. Fruit collection was also undertaken and involved collection from a range of cultivated and wild host plants of *B. invadens* with emphasis on the major wild host plants. Puparia were collected by sieving the sand which was used as pupation medium and then they were counted

and held till flies and/or parasitoids emerged. Total flies and parasitoids emerging were counted, sexed and identified. In total, 144.79 kg of fruits were processed from 39 species in 16 plant families. Ten (10) species did not yield any flies or parasitoids. Attack depended on fruit type, availability and locality. Fly predominance in fruits was as follows: *B. kandiensis* > *B. invadens* > *B. cucurbitae* > *B. zonata* = *B. paraverbasifoliae* > others. Interestingly, *B. correcta* was not recorded from any fruit—they were only recorded from traps. These were mainly from the bulk fruit assessment. Infestation levels ranged from 0–0.75 pupae/g of sampled fruits.

A number of natural enemies were recovered from both cultivated and wild fruits and consisted of 7 parasitoid species, 2 coleopteran predators and 1 species of mite. The 7 parasitoids came from 5 fruits [mango (*Mangifera indica*), tropical almond (*Terminalia catappa*), guava (*Psidium guajava*), woolly nightshade (*Solanum mauritianum*) and banana (*Musa* sp.)] and in the genera *Diachasmimorpha* (1 species, a larval parasitoid), *Fopius* (1 species, an egg parasitoid), *Psytalia* (2 species, larval parasitoids), *Tetrastichus* (1 species, a larval parasitoid), *Spalangia* (1 species, a pupal parasitoid) and *Trichopria* (1 species, a larval/pupal parasitoid). The solanaceous fruit, *S. mauritianum* (1.0–1.2 cm), was a very rich source of parasitoids including the long-tailed parasitoid (*Diachasmimorpha longicaudata*). Percent parasitism was between 0 and 24.9%.

E. Introduction of Parasitoids of Closely Related Species from Already Established Laboratory Parasitoid Colony

The egg prepupal parasitoid *Fopius arisanus* (Sonan) (Hymenoptera: Braconidae) and larval-prepupal parasitoid *D. longicaudata* (Ashmead) (Hymenoptera: Braconidae) were introduced into Kenya from Hawaii where they are used for management of *B. dorsalis* (a close relative of *B. invadens*). Since their importation into Kenya in September 2006, they have been kept at the *icipe* quarantine facility for evaluation. The two parasitoid species were tested for their preference and performance on *B. invadens* and five other *Ceratitidis* species (*C. capitata*, *C. cosyra*, *C. rosa*, *C. fasciventris* and *C. anonae*) using host eggs and third instar larvae for *F. arisanus* and *D. longicaudata*, respectively. *Bactrocera invadens* was the most accepted host for oviposition and most suitable for immature development of *F. arisanus*. This, coupled with effective searching behaviour and high foraging efficiency, is a clear indication that this parasitoid can be regarded as an efficient biocontrol agent for this pest and when used together with other control tactics will help to suppress

the exploding population of *B. invadens* in Africa. On the other hand *D. longicaudata* was unable to successfully counteract the immune system of *B. invadens*. However, it performed relatively well on the native most notorious fruit fly pests, *C. cosyra* and *C. capitata*. Therefore, it is anticipated that this parasitoid can contribute to parasitism of these host species, as parasitism by native parasitoids is generally low.

In the next review period, 14 strategies will be pursued. These are:



Bactrocera invadens, a new invasive fruit fly species in Africa

- Focus on bioecological studies to quantify the abundance, distribution, seasonal occurrence and host plants of the mango mealybug (*R. iceryoides*).
- Generation of additional data on the same for the MSW in Tanzania and Kenya.
- Making an inventory on the indigenous parasitoid species of the target pests.
- Laboratory studies of the native parasitoids to test for competitive interaction between native and introduced parasitoids.
- Field exploration for natural enemies of *R. iceryoides* in India because it is native to the country, as well as exploration in Sri Lanka.
- Investigation of the performance of the two main braconid parasitoids (*F. arisanus* and *D. longicaudata*), if detected in Sri Lanka. In this regard, biological studies concerning the life history traits, host preferences and non-target effects will be conducted.
- Importation of *Fopius vandenboschi* from Hawaii for laboratory testing as an import permit for the early instar larval parasitoid has been granted by the Kenya Plant Health Inspectorate Service (KEPHIS).
- Mass rearing of the egg parasitoid *F. arisanus*, which has shown tremendous efficacy against *B. invadens* in the laboratory.
- Field releases of *F. arisanus*, which are expected to commence in 2008 in Kenya and Tanzania, with the granting of field release permits by KEPHIS and the National Plant Protection Advisory Service of Tanzania, respectively.
- Additional evaluation of commercially available lures.
- Development of attractants from cheap locally available alternatives such as waste brewer's yeast for attraction and suppression of all mango-infesting fruit fly species, with emphasis on the invasive *B. invadens*.
- Field suppression trials to validate, through large-scale field experiment, locally developed and commercial baits in combination with pesticides for suppressing the various fruit fly complexes on mango.
- Testing of various 'soft' pesticides for their efficacy against fruit flies (especially the invasive *B. invadens*).
- Trunk application of these (soft) pesticides and entomopathogenic fungus for mango seed weevil control.

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Key Collaborators: International Institute of Tropical Agriculture (Benin), Horticultural Crops Research and Development Institute (Sri Lanka), Kenya Plant Health Inspectorate Service, Ministry of Agriculture, and Nthagaiya mango growers (Kenya)

Main Donors: German Ministry of Economic Cooperation and Development (Germany) and International Atomic Energy Agency (Austria)

LOCUSTS AND MIGRANT PESTS GROUP

LOCUSTS AND MIGRANT PESTS PROGRAMME

Development of Semiochemical-based Management Strategies for Locusts

General Background

The desert locust (*Schistocerca gregaria*) and the Madagascar locust (*Locusta migratoria capito*) show density-dependent phase polymorphism, transforming reversibly in a graded manner between two extreme phases—solitaria and gregaria. The two phases differ from each other in morphology, behaviour and physiology. The chemical communication system of the gregarious phase of the desert locust has been studied extensively in the last 17 years at *icipe*, but research work on the Madagascar locust only began at the end of 2006. An interesting finding from the studies on the desert locust has been the identification of phenylacetone nitrile (PAN), a mature adult male-produced pheromone, as a disruptive agent of grouping in conspecific nymphal stages. Since this discovery, we have been exploring the development and use of PAN, through extensive field trials, as a preventive integrated management tool for the desert locust in collaboration with national plant protection agencies in locust-affected countries and donor partners. An aspect of this study has been to investigate the ecotoxicological effect of PAN on selected arthropod predators of hoppers. The science underlying the effect of PAN on hoppers has not been fully explored and is the subject of intensive investigation in our laboratories. Similarly, ongoing studies on the Madagascar migratory locust are aimed at identifying their aggregating pheromone and determining whether there are any components in it that have similar effects as PAN on conspecific nymphs.

Progress Report and Outlook

A. Contact Effect of Phenylacetone nitrile (PAN) on the Desert Locust Schistocerca gregaria

In field tests in Port Sudan, an oil formulation of PAN sprayed on nymphs disrupted grouping in hopper bands of the desert locust. A mechanism proposed for the disruptive effect of PAN on nymphs is that of olfactory inhibition, that is, nymphs are unable to detect their own pheromone blend in the presence of PAN. Laboratory experiments indicate that olfactory inhibition is temporary. To maintain a permanent inhibitory state requires that nymphs remain in continuous contact with PAN suggesting that other factors may contribute to the disruptive effect of PAN on nymphs. We used a glass-vial bioassay to test the contact effect of PAN on nymphs after 2 hr and quantified the amount of the pheromone absorbed and released by the nymphs after 2 and 12 hr. We also tested the contact effect of PAN on sexually mature adult males and females and monitored the knockdown effect and mortality in treated adults after 4 and 12 hr.

In general, the knockdown effect in PAN-treated locusts was dose-dependent and stage-specific. In nymphs, the knockdown effect was higher in 3rd than in 4th instars and this difference was maintained in the analysis of the survival rate of the different instars after 12 hr. Immature adults were more tolerant to the pheromone than mature adults. In tests with sexually mature adults, females were more tolerant to the pheromone than males. After 10 hr post-treatment, PAN-treated nymphs absorbed 13.0–33.0 µg/locust/hr and

released the pheromone at a rate ranging between 20 and 130 ng/nymph/hr over the dose range tested. This study contributes to the knowledge of the use of PAN as a potential preventive management tool for the desert locust.

B. Ecotoxicological Studies on PAN

Since PAN has a disorienting effect on hoppers of the desert locust, experiments were carried out to study the effects of PAN alone and PAN + fractional doses

of GM and Marshal (conventional locust control insecticides) and diesel (control and carrier for these agents) on selected arthropod predators of hoppers of the desert locust. PAN and GM are registered in the Sudan for locust control. Two tenebrionid desert beetle species *Adesmia antiqua* and *Trachyderma hispida* and the ant lion *Bankisus* sp. were selected for testing. In topical applications, only high doses of PAN and diesel caused significant mortality in the test arthropods. In another experiment, soil treated with PAN, GM+PAN and Marshal had no significant effect on the test arthropods (ant lions and tenebrionids). In feeding assays, only Marshal caused high mortality in the ant lions.



A desert locust nymph in Sudan

C. Aggregation Pheromones of the Malagasy Migratory Locust (*Locusta migratoria capito*)

The aggregating Malagasy migratory locust (*L. migratoria capito*) is the major threat to food production in Madagascar during outbreaks and plagues as occurred in 1999–2000. A preventive management approach for this and other locusts requires targeting the insects in the early stages of gregarisation in the breeding habitats to suppress the development of outbreaks. This requires an in-depth understanding of the processes that promote and maintain gregarisation in this locust species.

This study is a component of the project 'Sustainable, environment-friendly management system for the Malagasy migratory locust'. The objective is to identify pheromones that maintain grouping in the hopper and adult stages of the gregarious phase of *L. migratoria capito* and to evaluate whether any of these components exert a disruptive effect on grouping behaviour of hoppers. The use of a pheromone combined with a biopesticide and/or low doses of insecticide has been demonstrated in the desert locust. We anticipate developing a similar method for use against the Malagasy locust. This would lead to significant savings in revenue for control against this locust species and a drastic reduction in the use of insecticides that pollute the environment in control operations.

An important component of this project is the training of two PhD students from Madagascar in semiochemical research. The students' projects are summarised below.

The aggregation pheromone of adult *L. migratoria capito*. Aggregation responses of adult *L. migratoria capito* of various ages (sexually immature and mature) and the different sexes to their own volatiles from live conspecifics in the same group and to

those of the others were investigated in a one-chamber olfactometer. The immature locusts responded to their own body and faecal volatiles. They responded weakly to those of mature adults. Sexually mature adult locusts responded to their own volatiles irrespective of sex, but the responses of males were higher than those of females. This suggests that the aggregating signal in mature adults is associated with both sexes with the females possibly forming the nuclei around which groups form.

The aggregation pheromone of nymphal *L. migratoria capito*. The same bioassay set up as described in (a) above was used to evaluate the responses of nymphal *L. migratoria capito*. It appeared from the results obtained that the rearing conditions influenced nymphal responses. Depending on the rearing conditions (either in the presence or absence of adults in the rearing room), the nymphs exhibited varying responses ranging between positive aggregation indices and at times, negative values. Chemical analysis showed no significant difference in the volatile profiles of the nymphal stages over the experimental period. Identification of nymphal pheromone is in progress.

D. Oviposition-aggregating Pheromone of *L. migratoria capito*

In the field, female locusts of *L. migratoria capito* and those of other species (*Schistocerca gregaria* and *L. migratoria migratoroides*) oviposit egg pods at sites where other conspecific females have oviposited. In addition to visual cues, chemical cues emanating from volatiles deposited into the oviposition medium play a role in aggregating the locusts. Oviposition responses of gravid females of *L. migratoria capito* were investigated in the laboratory in a two-choice assay. Locusts were offered clean moist sand (control) and sand into which conspecific locusts had previously laid an increasing number (5, 10 and 15) of egg pods. These had been removed prior to setting up the experiment with the sand only. Females of *L. migratoria capito* preferred to oviposit in response to volatiles emanating from the oviposition substrate into which conspecifics had previously oviposited. The preference for oviposition into treated sand over the control increased significantly ($df = 18$; $P < 0.05$ and $P < 0.001$ at 10 and 15 egg pods respectively) with the number of egg pods deposited into the substrate. This indicates that ovipositing *L. migratoria capito* females deposit compounds into the sand that aggregate other females to lay in the proximity. Identification of the active components is ongoing.

In the next review period, four strategies will be pursued. These are:

- Investigation of the physiological-induced responses of PAN on the desert locust.
- Further ecotoxicological studies on PAN against desert arthropods.
- Contact effect studies of PAN on the Malagasy locust.
- Identification of the aggregation pheromones in the different locust stages and elucidation of the cross-stage effects of pheromones, with a view to identifying aggregation disruptive components for nymphs which can be tested and validated in the field.

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Key Collaborators: Plant Protection Directorate (Sudan), CNLA (Mauritania), AGRHYMET (Niger), and Projet de Lutte Preventive Antiacridienne, Ministère de l'Agriculture and Malagasy Research Centre (Madagascar)

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OUTPUT

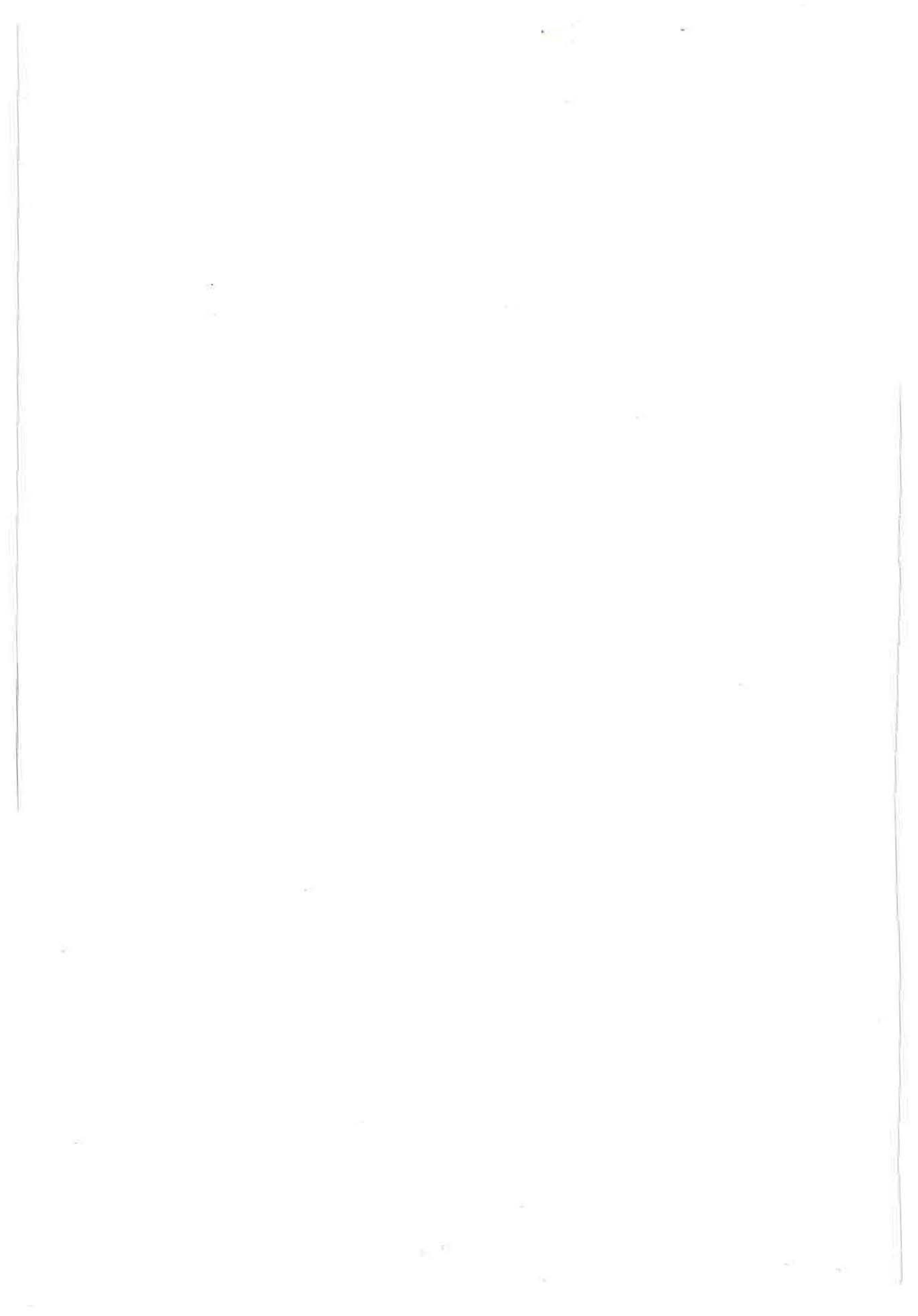
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ENVIRONMENTAL HEALTH RESEARCH

Overview

The Environmental Health Division (EHD) has five main programmes in its research and development (R&D) agenda: (1) Agrobiodiversity, (2) Biodiversity Conservation, (3) Commercial Insects, (4) Applied Bioprospecting, and (5) Biosystematics.

The five programmes are to some extent overlapping and to a high degree synergistic. Together they seek to further our understanding of the links between natural and human habitats, to demonstrate the positive impacts of arthropod biodiversity on human welfare, and to support the conservation and sustainable use of insects and other arthropods.

The Agrobiodiversity Programme (AP) focuses on the interplay between agroecosystems and wild or semi natural habitats. It has three components: (1) interactions between cereal stemborers and their wild relatives, associated natural enemies and host plants (run by IRD scientists in collaboration with the Stemborer Project in the Plant Health Division); (2) potential consequences of gene flow from genetically modified cowpea to its wild relatives (in collaboration with the Molecular Biology and Biotechnology Department); and (3) pollination as an ecosystem service provided to crops by natural habitats (again in collaboration with Plant Health and linking Biodiversity Conservation and Commercial Insects).

The Biodiversity Conservation Programme (BCP) has focused on forests because tropical forests are home to two-thirds of all insects. A habitat as opposed to a species approach is cost-effective and realistic, given the lack of iconic flagship arthropods and the staggering diversity of insects. For maximal impact, the BCP has aligned itself with the Global Biodiversity Hotspots strategy of Conservation International (CI), and is concentrating its efforts on key biodiversity areas within the East African Coastal Forest and Eastern Afromontane Hotspots. It exploits synergies with the Applied Bioprospecting and Commercial Insects Programmes by using their technologies to demonstrate

biodiversity values and to alleviate the poverty in forest-adjacent communities that drives forest degradation. More recently, focus has shifted to Ecosystem Services and Climate Change, but again in a Hotspot context.

The Commercial Insects Programme (CIP) researches and develops technologies for honey and silk production. It goes beyond domesticated species to examine the potential for wild silks and stingless bee honey. In addition to its role in alleviating rural poverty, CIP is able to provide tangible evidence for the value of biodiversity and to persuade local communities that the conservation of wild and semi-wild habitats is in their economic interest. It is thus highly synergistic with BCP and is being increasingly linked to forest conservation through its engagement with forest-adjacent communities in the hotspots.

The Applied Bioprospecting Programme (ABP) has a two-pronged approach: high and low technology. The high tech end engages with multinational companies in a search for useful products (ranging from antifeedants and pesticides to industrial enzymes) while the low tech component develops marketable natural products that can be produced by local communities. Again a focus on forest adjacent communities provides synergies with the BCP and again there is an emphasis on demonstrating the economic values of biodiversity.

The Biosystematics Unit provides essential backup to all *icipe's* research activities by ensuring that the taxonomy is sound. It also provides the focal point within EHD for dealing with the Convention on Biological Diversity, including Access and Benefit Sharing issues that impact on the import and export of biological control agents.

BIODIVERSITY CONSERVATION PROGRAMME

Tropical Forests and Global Biodiversity Hotspot Activities

General Background

icipe's major strategy for biodiversity conservation is 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, and (2) presence of at least 1500 plant species endemic to the hotspot. 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, and includes the emerging issue of carbon trading.

Progress Report and Outlook

A. Compilation of an Ecosystem Profile for the Eastern Arc Mountains and Coastal Forests of Tanzania and Kenya Global Biodiversity Hotspot

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. 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. 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. On the basis of the recommendations 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. Together with WWF, BirdLife International and the Tanzanian Forest Conservation Group, *icipe* has been assisting CEPF to administer these funds.

By the end of 2007, over 80 projects had been funded, with a total of just over US\$ 6.5 million, including three projects supporting the research of *icipe* students and interns (on carbon studies, bees and mites), and two others to *icipe* scientists (on community livelihoods and hotspot butterflies).

B. Carbon Baseline Surveys for Four Important Kenyan forests

The carbon studies by an *icipe* intern (Glenday, 2006; in press, published online 2007) have provided carbon baseline surveys for four important Kenyan forests (Kakamega, Tana River, Arabuko-Sokoke and Madunguni). Significantly, they have provided hard data for Kenya's application to the World Bank for support under the Reduced Emissions from Deforestation and Degradation (REDD) funding, established after the Bali Climate Conference. Kenya has since been chosen as one of 6 African countries that may benefit from this facility.

C. Influence of Forest Proximity on Honey Quality and Yields, and on Pollination of Forest Adjacent Crops

The bee research (an ARPPIS PhD) is on the influence of forest proximity on honey quality and yields and, through its influence on bees, on pollination of forest adjacent crops. Early results from Arabuko-Sokoke Forest suggest a doubling of yields close to the forest. Although it is conventional wisdom that forests are important for beekeeping, this is the first time it has been scientifically demonstrated.

D. Mites Biosystematics

The mite work (also an ARPPIS PhD) has led to the discovery of two new mite species.

E. Beekeeping, Butterfly Farming and Bioprospecting in Tana River and Taita Hills in Kenya, and in the East Usambara Mountain Ranges in Tanzania

The livelihood project has introduced beekeeping, butterfly farming and bioprospecting activities to communities at three key hotspot sites: Tana River, Taitas and the East Usambaras in Tanzania. Over 500 farmers have been trained in the appropriate techniques. Butterfly monitoring has confirmed the continued presence of two red-listed butterfly species in the Taita Hills, and has led to the discovery of their food plants.

The hotspot butterfly project addressed one of the issues raised by the External Review: marketing. Although butterfly farming has been highly successful as a conservation enterprise in the hotspot it remains constrained by a low market ceiling. This project

aimed at promoting a niche market in the butterfly exhibit industry through exhibits dedicated to hotspot butterflies. It led to an agreement with Fairchild Tropical Botanic Garden that they would feature the East African hotspot butterflies in their new exhibit which will open in 2009.

F. *The Evolutionary Biology of Male-killer Endosymbionts in the African Queen Butterfly*

Additional research activities under Biodiversity Conservation include ongoing long-term research on the evolutionary biology of male-killer endosymbionts in the African queen butterfly (Herren et al., 2007).

The long-term research on male killers has led to an invitation to present a joint paper at the Royal Entomological Society's Darwin-Wallace meeting at Rothamsted in April 2009. This meeting will celebrate the 200th anniversary of Charles Darwin's birth and 150th anniversary of the publication of *The Origin of Species*.

G. *Investigation of the Molecular Genetics of Mimicry in Papilio dardanus*

The molecular genetics research in collaboration with Exeter University aims to sequence the genes responsible for mimicry in this famous butterfly. *Papilio dardanus* shows spectacular diversity in its female colour patterns, arising from recombination within a multi-allelic supergene. It has long been a model organism for the study of the evolution of mimicry, but the molecular genetics of the polymorphism is poorly understood.

H. *Cocoa Pollinators in Ghana*

The cocoa pollination project (a PhD) is investigating the roles of midge pollinators and the influence of forest fragments on cocoa yields. Surveys have revealed that less than 12% of cocoa farmers were aware of the importance of pollination and none knew that midges were involved. In collaboration with the FAO Global Pollinator Initiative and the University of Guelph, DNA barcoding is being used to identify the midge species and their breeding substrates.

I. *Pachycondyla Semiochemicals*

The PhD work on semiochemicals in the Matabele ant (*Pachycondyla analis*), is exploring the co-evolutionary arms race that has existed between this species and its termite prey for millions of years. Work in 2006–2007 concentrated on understanding the field ecology of termite raids. This demonstrated for the first time the occurrence of nocturnal raiding. Subsequent work will analyse the semiochemicals involved in ant–termite encounters, in the hope of discovering chemicals that could be useful in controlling termites.

In the next review period, three strategies will be pursued.

- The Hotspot Programme with CEPF comes to an end in 2008, and its achievements will be reviewed in a workshop in Tanzania in February in 2009. Although CEPF has consolidation funds to keep activities going, the East African hotspot just misses out because of a pre-planned funding cycle. Our ongoing partnerships with WWF, BirdLife and TFCC in the CEPF Coordination Unit will therefore depend on further funding being obtained. Alan Rodgers (ex UNDP-GEF) and

Neil Burgess (WWF-US and Cambridge University) have been engaged by CEPF and WWF for one year to raise funds for the CU.

- Our major activity within the hotspot has been with community livelihoods, and we anticipate that this will continue to be an important element in the Biodiversity Conservation Programme in collaboration with CIP and the ABP. Nature-based enterprises can simultaneously address poverty and conservation issues while demonstrating the economic values of wild biodiversity; they are therefore, integral to the efforts of the BCP at *icipe*.
- As suggested by the External Review, there will be significant new efforts in the fields of climate change and ecosystem services. A 5.2 million Euro proposal has been submitted to the Ministry of Foreign affairs in Helsinki to examine the impacts of climate change on ecosystem services in the Eastern Afrotropical Biodiversity Hotspot. This project will involve close collaboration with Plant Health in *icipe* (looking at pollination and natural pest control in coffee and maize) and with external partners (BirdLife International, WWF, CI and the universities of Helsinki, Cambridge, Cranfield, York and Santa Barbara) looking at water provision, valuation of ecosystem services, and habitats and refugia.

Participating Scientists: I. Gordon (PI), S. Raina, E. Muli and W. Lwande (*icipe*, Kenya)

Key Collaborators: TFCC (Tanzania), WWF-EARPO, BirdLife International, ICRAF and East African Wildlife Society (Kenya), Pretoria University (South Africa), Fairchild Tropical Botanic Garden (USA), University of Oxford, University of Exeter and University of Edinburgh (UK), University of Cape Coast (Ghana) and FAO (Italy)

Main Donors: Critical Ecosystem Partnership Fund of Conservation International (USA)

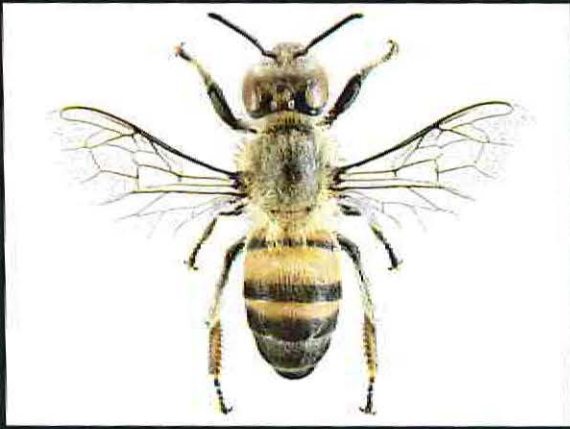
COMMERCIAL INSECTS PROGRAMME

Developing Incentives for Community Participation in Forest Conservation Through the Use of Commercial Insects in Kenya

General Background

The overall goal of the Project is that the national protected area system of forest reserves is strengthened through incentives for collaborative forest management with communities.

The Project is targeting rural farming forest community groups in three Kenyan forests: Kakamega, Arabuko-Sokoke and Mwingi. Kenya is internationally considered as a low forest country since it has less than 10% of its total land area classified as forest. This project is focused on reversing the loss of forests and their resources through provision of poverty alleviation incentives, alternative income sources and institutional capacity building to forest adjacent communities. The project is intended to show that there is greater economic value in biodiversity conservation than in the direct unsustainable exploitation of the resource.



The African honeybee, *Apis mellifera scutellata*

Based on the understanding that management of the national system of forest reserves will be strengthened through improved incentives for collaborative management of forests with communities, this Project, through on-farm and in-forest livelihood support systems involving the use of commercial insects (honey bees, stingless bees, wild silkmths and mulberry silkworms) for the production of honey and silk, has supported participatory forest management aimed at protecting the target forest areas from further degradation.

The Project has monitored the biodiversity and population dynamics of wild silkmths focusing on three species: *Anaphe panda* in Kakamega, *Gonometa postica* in Mwingi and *Argema mimosae* in Arabuko-Sokoke. Their spatial distribution, parasitoid interactions and host plant diversity have been researched and the results published.

Progress Report and Outlook

A. Spatial Distribution of the Silkmth *Anaphe panda* Cocoon Nests, Egg Clusters and the Host Plant *Bridelia micrantha* in the Kakamega Forest of Western Kenya

High quality wild silk has drawn the attention of silk users, providing excellent opportunities for African producer countries to diversify and optimise any source of production. However, insight on the spatial distribution of wild silkmths in indigenous forests is one of several challenges faced by wild silk production in many African producer countries, which would help in developing management plans for their conservation and sustainable utilisation for income generation.

The study aimed at providing new insight on the spatial distribution of *Anaphe panda* (Lepidoptera: Thaumetopoeidae) silkmth egg-clusters and cocoon nests, and the host plant *Bridelia micrantha* (Hochst) (Euphorbiaceae) using GIS data for visualisation purposes. It was conducted in two different habitats of the Kakamega Forest, i.e. indigenous forest habitat (Ikuywa) and a mixed indigenous forest habitat (Isecheno). Sampling was carried out from February to April 2006. This period is characterised by an abundance of *A. panda* egg clusters in the field, each egg cluster containing between 250–560 eggs.

Results showed that the mean densities of cocoon nests, egg clusters and *B. micrantha* were significantly different in the two blocks, and were not semi-randomly distributed. The host plants were underdispersed in the indigenous forest, whereas they were overdispersed in the mixed indigenous forest. The cocoon nests were overdispersed and the silkmth egg clusters were underdispersed in the two blocks of forest. The study revealed 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 and confirms the insufficient presence of this silkmth in the mixed indigenous forest compared with the

indigenous forest. Consequently, indigenous forest should be managed in a sustainable way and more indigenous species should be used in reforestation campaigns.

B. *Monitoring the Wild Silkmoth Gonometa postica Abundance, Host Plant Diversity and Distribution in Imba and Mumoni Woodlands in Mwingi, Kenya*

Survey of the abundance of larvae and pupae of *Gonometa postica* Walker (Lepidoptera: Lasiocampidae) and host plants was undertaken in the long rainy season in 2006 at six sites in the Imba and Mumoni forests of Mwingi, eastern Kenya. One hundred trees of the primary host species of *G. postica* were sampled at each site, in addition to minor host species with *G. postica* pupae. The density of each tree species was calculated and the height, canopy, diameter and number of branches measured. In order of decreasing abundance, the host plants in Imba forest were *Acacia tortilis*, *A. elatior* and *A. nilotica*; and in Mumoni forest, *A. tortilis*, *A. nilotica*, *A. mellifera* and *A. brevispica*. *Acacia elatior* had significantly more larvae than other host plants in Imba. In Mumoni, *A. tortilis* and *A. mellifera* had significantly more larvae, followed by *A. nilotica* and *A. brevispica*. The minor host plants harbour significantly more pupae than the major host plants in the two forests. In general, Imba had a significantly higher abundance of larvae and pupae than Mumoni. Host plant species richness did not differ between the two forests but their evenness was significantly higher in Imba than Mumoni.

C. *Parasitoids of the African Wild Silkmoth, Gonometa postica in the Mwingi Forests in Eastern Kenya*

Gonometa postica produces high quality silk but is affected by parasitoids attack. A study on the parasitism of *G. postica* larvae and pupae on host and non-host plants was undertaken for the first two of its generations, corresponding to the long (March–May) and short (October–December) rainy seasons in 2006 at six field sites, three each in the Imba and Mumoni forests. All freshly spun *G. postica* cocoons were sampled at each site from a total of 100 host plant trees and other non-host plant trees where they had migrated before pupation. Two dipteran and four hymenopteran larval-pupal parasitoids were identified from the two forests. The most common parasitoids were *Palexorista* sp. (Diptera: Tachinidae) and *Goryphus* sp. (Hymenoptera: Ichneumonidae) with parasitism ranging from 1.8–32.7% and 2.2–7.5%, respectively. Parasitism varied significantly according to host or non-host plant, season and site. This study indicates that, of the six parasitoid species recovered, only two had a significant impact in reducing the quality of the cocoons.

D. *Relative Abundance of the Wild Silkmoth, Argema mimosae on Different Host Plants in the Arabuko-Sokoke Forest in Coastal Kenya*

A study on food plant distribution and relative abundance of *Argema mimosae* was done. Food plants and cocoons were sampled in 1 km² transects in Dida zone. A global positioning system (GPS) was used to establish the geographical position and distribution pattern of its food plants. *Argema mimosae* larvae were reared in semi captive net sleeves to determine their developmental period and host plant preference. The study provides important information to evaluate the wild silk production potential of the moth and helps to link it to community livelihood development and biodiversity conservation.

In the next review period, eight strategies will be pursued. These are:

- Efforts to scale up the livelihood support mechanism in forest adjacent villages, which are around three different globally significant forest areas, to a critical

mass that has the ability to protect the neighbouring forest, as the source of sustainable income.

- Continuation of our activities with this target group of 1500 farmers as experience has shown that even small numbers of farmers benefiting from commercial insects can have significant impacts on forest conservation. We, therefore, expect meaningful conservation benefits for the forests.
- Evaluation of the medium-term impacts from the validation trials. An appropriate approach would be to implement activity plans in the three forest areas and their corridors, where the impact of human pressures on the resource base and biodiversity is immediate.
- Compilation of the baseline biodiversity survey.
- Actions to map out forest corridors.
- The assignment of identifying and sensitising the new groups from the proposed corridors and new sites.
- Awareness building in forestry and commercial insects activities.
- Land use analysis through GIS.

Participating Scientists: S. K. Raina, E. N. Kioko, V. Adolkar, E. M. Muli, E. Nguku and I. Gordon (*icipe*, Kenya)

Key Collaborators: Nature Kenya, National Museums of Kenya, Kenya Forest Service, National Environmental Management Authority, Ministry of Foreign Affairs, District Livestock Production Officers, and community-based organisations (all in Kenya)

Main Donors: UNDP-GEF (Kenya) and IFAD (Italy)

Development of Sericulture and Apiculture Products for the Poor in Fragile Ecosystems Using the Value Chain Approach

General Background

Sustainable livelihoods can be achieved in Africa through access to a range of combined livelihood resources. The IFAD project on wild and domesticated silkworm rearing for silk production (sericulture), and honeybees rearing for beehive products (apiculture), attempts to achieve this, through the value chain approach. 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 Africa (NENA) region and other African countries. Among others, the IFAD and co-financer's research components aim to 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.

Progress Report and Outlook

A. Larvae, Cocoon and Post-Cocoon Characteristics of *Bombyx mori* L. (*Lepidoptera: Bombycidae*) fed on Mulberry Leaves Fortified with Kenyan Royal Jelly

Royal jelly is rich in nutrients and energy. It contains 12–13% protein, 12–15% carbohydrates, 5–6% beneficial lipids, B complex vitamins including high amounts

of fatty acid, and 10-hydroxy-2-decanoic acid (10-HDA), which is involved in growth regulation and immunity. Fourth-instar *Bombyx mori* silkworm larvae were fed on mulberry leaves to which royal jelly had been added. The impact on the larval, cocoon, shell and pupal weight, shell ratio percentage, filament length and weight, and the number of breaks during reeling were examined. Results indicated that a royal jelly-enhanced diet significantly increased larval, cocoon and pupal weights, but had no significant effect on shell weights and denier. Similarly filament length, weight and filament reeling breaks were significantly different between controls and royal jelly fed groups. The cocoon shell ratio percentage was significantly higher in the control compared to the royal jelly fed groups. Results established positive trends in all the values of different parameters observed in the experimental group against the control group, apart from the cocoon shell ratio percentage. Results imply that supplementing mulberry leaves with royal jelly has the potential to enhance the commercial qualities of silk and can be used in sericulture for yield improvement.



Silk cocoons ready for reeling

B. Quality Testing of *Bombyx mori* L. (Lepidoptera: Bombycidae) Raw Silk and Fabric

Textile quality control and assessment of textiles is of vital importance for both manufacturers and consumers. An increased number of knowledgeable consumers with firm demands for specific performance, behaviour and longer life textile goods, in combination with the advances in textile technology have made it essential to better understand the properties of fibres, yarn and fabrics.

The purpose of this study was to assess the quality of silk fibre and fabric produced by three selected strains of the domesticated silkworm *Bombyx mori* namely *ICIPE* I, *ICIPE* II and Chun-Lei \times ZhengZhu (C \times Z) reared in Kenya. Raw silk characteristics were evaluated and performance tested to determine its suitability for silk production. Quality tests of each post-harvest production process were carried out to establish the overall quality of the product. Results indicated that winding breaks varied among the silkworm strains. The study also established that there were significant differences in the cleanliness, neatness and tearing strength parameters among the silkworm strains.

Tenacity of the three strains was evaluated and it ranged between 3.78 and 3.71 g/denier. This was within the ISA standards. *ICIPE* I and *ICIPE* II had no significant differences in their cleanliness and neatness means, however C \times Z had a significant difference in the two parameters.

This study verified that there was no significant difference among the strains in breaking load and the average breaking load for warp yarns, of denier 20/22 ranged between 124.08 and 124.21N and the weft yarns of the same denier was between 256.21 and 256.43N.

There was no significant difference in the warp tearing strength among the strains, however, it was noted that *ICIPE II* differed in the weft tearing strength.

In this study it is significant to note that results of tests carried out were within the international standards.

C. *Melissifolia* of Arabuko-Sokoke Forest, Kenya

Tropical forests are facing 'extinction' worldwide. This is because of unsustainable harvesting of timber and non-timber products. Nearby fragments of natural vegetation act as important sources of pollinators because they provide a food source for bees. Indeed bees with their specific requirements for nutrition and nesting are good indicators of landscape structure and overall biodiversity of a forest, provided the ecological and seasonal patterns they show are taken into consideration. Most bees collect only two food resources: nectar and pollen grains. The source of nectar ultimately affects the composition and properties of honey. Amount of pollen produced is determined by the mode of pollen dispersal.

Two years studies on floral calendar were carried out in Arabuko-Sokoke Forest and more than 160 *Melissifolia* species were recorded. Some species flower throughout the year. The foraging activities of bees and other pollinators were also recorded in different seasons of the year.

D. Stingless Bees Research for Species Diversity, Pollination Services and Rural Income

Stingless beekeeping (meliponiculture) is an activity that can be integrated into forestry or horticulture and contribute to the increase of the agricultural production and regeneration of natural forest vegetation through pollination services. Stingless bees are important pollinators, especially of native plants including crops.

In Africa, stingless bee honey is mostly obtained by harvesting from wild colonies, an activity that kills or destroys them. *icipe* has replaced this destructive harvesting of stingless bees in Kakamega rainforest with well-designed bee nest management practices to save the colonies and provide honey for food, medicine and income to the community.

Research on stingless bees focused on:

- Determining the species diversity and distribution.
- Promoting meliponiculture as a means of income generation while conserving stingless bees species.
- Developing a colony management system for the stingless bees in artificial hives.
- Evaluating their pollination potential and pollinator efficiency on various fruits and vegetables of commercial value.

Results of the behavioural biology of stingless bees in Kakamega Forest showed that there are 6 species of stingless bees in the forest that are suitable for meliponiculture: *Meliponula bocandei*, *M. lendiana*, *M. ferruginea*, *M. ogouensis*, *Hypotrigona gribodoi* and *Pleibeina hildebrandti*. *icipe*-hives were distributed to domesticate the bee species. Their preference in nesting with regard to the tree species was identified. Several households adopted stingless bees farming in Kakamega Forest and increased the number of colonies and their income successfully. Queen rearing methods has been established by *icipe* to multiply the colonies.

Results were obtained on the antibacterial activity of honey from Kenyan stingless bees and honeybees [*Meliponula bocandei*, *M. ferruginea* (black), *M. ferruginea* (white), *Hypotrigona gribodoi*, *Pleibeina hildebrandti* and *Apis mellifera scutellata*). Five forest sites situated in different ecological zones and 21 honey samples (15 from stingless bees and 6 from *A. m. scutellata*) were tested against 5 strains of bacteria [*Pseudomonas aeruginosa* (ATCC 27853), *Salmonella typhi* (ATCC 2202), *Escherichia coli* (STD 25922), *Staphylococcus aureus* (ATCC 20591) and *Bacillus subtilis* (ATCC 6633)], using the agar diffusion method with filter paper discs. Streptomycin was used as a control to test the antimicrobial activity. Significant differences were observed in the antibacterial activity of honey from stingless bees and honey from *A. m. scutellata* depending on the test bacteria. *Escherichia coli* and *P. aeruginosa* were susceptible to all test honey. Honey from *P. hildebrandti* and *M. ferruginea* was effective on all test bacteria. In conclusion, the study suggests that traditional use of stingless bees in Kenya, as a universal remedy against different illnesses, is rational if the infection to be treated is caused by bacteria.

E. Molecular Characterisation of Honeybees, *Apis mellifera* in East Africa

The study was undertaken to select molecular markers for characterisation of African honeybee *A. mellifera* races collected from various altitudes to achieve specific objectives that include:

- Characterisation of the behavioural traits in selected colonies.
- Selection of markers based on mapped expression quantitative trait loci (eQTL) for different production traits in breeds of honeybees.
- Analysis of the extent of hybridisation in the East African honeybee populations using microsatellite and mitochondrial DNA markers.

Progress has been achieved as follows:

- DNA extraction was done successfully with Qiagen® DNeasy® Blood & tissue DNA extraction kits. A total of 150 samples have been extracted.
- Eight samples were used in optimisation reactions using 10 fluorescent-labelled microsatellite markers. The markers were tested on different amplification conditions and optimised, through trial and error in different annealing temperature regimes and PCR component conditions. They are being used in this study for multiple genotyping reactions in population genetics.
- Five mitochondrial markers have been tested and three of these have been optimised for polymerase chain reaction conditions. LCO 1490F and HCO 2198R have been used in DNA barcoding of samples. The other marker will be used to analyse variations in the races. PCR conditions for two markers have yet to be realised. Sequence analysis for 91 bee samples collected from 5 different regions in Kenya and Tanzania (Mwingi, Taita Hills, Tana River, Tanga and Arabuko) has revealed a sequence consisting of approximately 657bp. The sequence represents the barcode for the African honeybee *Apis mellifera scutellata* that is due to be deposited in the barcode of life data (BOLD) system. A number of sequences with interspecific variation are being analysed. BLAST search using the sequence reveals that it is an *A. mellifera* mitochondrial COI gene section. The sequenced genomic DNA for *A. mellifera* is unannotated and still in contigs form.
- Over 80 microsatellite markers spanning various QTL regions for foraging and stinging behaviours are listed in the database. Of these, between 20 and 30 polymorphic markers across the QTL regions will be selected for use in the population genetic studies as well as QTL linkage studies (linkage with phenotypic characteristics).
- Two colonies showing distinction in phenotypic characters (stinging behaviour) have been identified through preliminary experiments in Nairobi. These are being characterised.

F. Morphometrics and DNA Barcoding of Stingless Bees (Apidae: Meliponinae) in Three Selected Forests in Kenya

This study has been undertaken to develop molecular and morphometrical tools to identify stingless bees in three Kenyan forests, namely Kakamega, Arabuko-Sokoke and Mwingi.

The objectives are to:

- Develop and apply DNA barcodes for identifying stingless bees in selected forests.
- Measure morphological features of the stingless bee species (*Trigona* species) to identify the variation among the species.

Random samples were collected from three Kenyan forests. DNA was extracted using Qiagen kits. A 1.5% agarose gel was prepared to confirm the presence of the DNA in the sample solution. Polymerase chain reaction (PCR) was carried out using specific markers: The forward primer LCO 1490-- 5'GGT CAA CAA ATC TAA AGA TAT TGG 3' and the reverse primer HCO2198 5'TAA ACT TCA GGG TGA CCA AAA AAT CA 3'.

The presence of PCR products (92) was confirmed. The products were purified using PCR purification kit (Quick PCR kit by Quiagen). They were then sequenced using a 3700 ABI machine in both directions. The resulting sequences were edited using Chromas Programme and aligned using Cluster W. Software. The sequences are showing barcodes for different species in the three forests. The results will be presented in the next report.

G. Proximity to a Forest Ensures Better Honey Yields: Another Reason to Conserve Forests

Although tropical forest conservation is a top priority for human and environmental health, deforestation persists mainly because of food and economic needs. No community will totally give up economic activities for the sake of ecological integrity, unless it is given alternative economic activities from which to draw its livelihood. Beekeeping in the forest buffer zone instead of traditional destructive honey harvesting from forest trees is one such option at Arabuko-Sokoke Forest (ASF) in Kenya. ASF is a dry coastal forest that is home to endangered and threatened fauna and is a hotspot considered a priority for conservation. To find out whether honey quantity and quality differed at various distances from the forest, we obtained samples from hives placed at varying distances from ASF in two successive years. All the honey samples met the internationally required standards and honey yield increased with proximity to the forest. Indeed the yield almost doubled in hives <1 km from the forest compared to those >3 km. This study convincingly demonstrates to the ASF community that they should conserve the forest.

H. Marketing Information System of Honey- and Silk-Based Products

The market potential for apiculture and sericulture products was identified based on a market survey conducted by the stakeholders, in particular private traders supporting the project activities and included:

Market study. A market study has identified the market potential for apiculture and sericulture products, through identification of potential markets and players in the value chain. It has assessed margins at each stage and formulated a strategy to maximise returns to the producers. This has included creation of common brands such as Eco-honey, Rainforest Silk, Savanna Silk, Coastal Silk and Immune Booster Honey, as well as

Golfers' Putt Honey with royal jelly. These brands were organically certified in Mwingi and efforts are on to certify them in other Kenyan forests and in Uganda, S. Sudan, Egypt and Madagascar.

Customer requirements and market standards. The Kenyatta National Referral Hospital requires honey for wound healing and signed a contract with Viking Limited to supply organically certified honey from Mwingi District in specially designed coated plastic bottles. Golfers in Kenya prefer royal jelly included in their honey to improve performance, reason why *icipe* named the honey, Golfers' Putt. It has 2% active royal jelly lyophilised powder, which is supplied to Viking Limited by Mwingi beekeepers. Wild Living requires a blend of mulberry and wild silk in the scarves for the export market and are regularly supplied Uganda silk. The Uganda Farmers' Silk Association was linked to the Egypt Carpet Factory and negotiations are in progress to finalise supply of 200 kg of 50-denier silk yarn per month to the carpet factory. A German organic firm has contacted *icipe* to link it to the Mwingi Marketplace for the supply of organic honey. Nimai Natural Products Ltd is providing a market for the honey produced by the PPRR project in Madagascar.

Training needs of stakeholders. All the project private partners were given intensive training in product development and were familiarised with the field sites and marketplaces in all project countries.

Partnerships. The private sector companies willing to work with and train community groups on marketing and business aspects agreed to sign MoU's with private traders to work with the communities in all countries.

Primary data collection: Primary data for any decision support system is generated from a survey, observation, or experiment to solve the particular problem under investigation. This data were collected from several project countries to identify what silk and honey based products exist in each country.

In the next review period, six strategies will be pursued. These are:

- Assessment of the environment disturbances affecting agrobiodiversity in the face of climate change and development of pro-poor coping mechanism through management practices and income generation options. It is hoped that through the project there will be improved performance and impact by IFAD/UNDP-GEF, AFESD, OPEC and IDB-supported forest biodiversity conservation and rural development projects and programmes.
- Investigation of the population dynamics of key stingless bee species to exploit their potential in honey production and pollination services to the crops and forest species.
- Training in pollination services to the crops and forest tree species in eastern Africa and the NENA region.
- Further DNA fingerprinting of key silkworm and honey species for identification of key species of economic importance.
- Support to community associations through certification and fair trade of insect-based and forest products for value addition.
- Development of forest corridors linking the fragmented forests in Kenya, which will be monitored through GIS and GPS techniques.

Participating Scientists: S. K. Raina, E. N. Kioko, V. Adolkar, E. M. Muli, E. Nguku, I. Gordon and S. Wren (*icipe*, Kenya)

Key Collaborators: National Museums of Kenya, Kenya Agricultural Research Institute, Viking Limited, Wild Living and Paperazzi Limited (Kenya), Ministry of Agriculture and Animal Resources (Rwanda), Ministry of Agriculture, Animal

Wealth and Irrigation, Ministry of Agriculture and Central Coordination Unit for IFAD Projects (The Sudan), Ministry of Agriculture and Forestry (Government of Southern Sudan), Hoima District Local Government and Bushenyi Silk Association (Uganda), PPRR (Madagascar), AMSD Programme (Tanzania), Delege Provincial de l'Agriculture et du Developement Rural de l'Adamaoua (Cameroon), Ministry of Agriculture (Yemen), Ministry of Agriculture (Egypt), Terra Verde (Switzerland), and IFAD Loan Project Coordinators in Yemen, Egypt and Uganda

Main Donor: IFAD (Italy)

Development of Community-driven Income Generating, Integrated Use of Commercial Insects in the Sudan, Egypt and Yemen

General Background

The overall objective of this Pilot Project in the NENA region (The Sudan, Egypt and Yemen), is to reduce poverty through improved food security and income levels of farmers, especially for rural women by promoting more effective use of forest resources and biodiversity through introducing income generating activities using honeybees and silkmoths. The project has introduced improved management practices for better crop yield through pollination services and is in the process of providing honey and silk marketplaces and marketing linkages for the products. This will contribute to the governments' poverty reduction and environmental conservation strategies.

Three pilot areas have been selected for implementation of the project activities, namely,

- Southern Kordofan and Gash Region, Kassala State the Sudan.
- Al Dhala governorate, Yemen.
- Western Noubaria, Egypt.

The project area covers the protected forests and poverty stricken semi-arid zones with spiny woodlands of the Sudan, Yemen and reclaimed land in Egypt. In these areas, the OFID/IFAD grant is supporting the IFAD ongoing loan projects and assisting them to fulfill their objectives through training, marketplace development and capacity building.

Progress Report and Outlook

A. Addressing the Causes and Impacts of Ecosystem Degradation/ -

Minimising the Anthropogenic Threat in the Forest and Reclaimed Land

The project has employed a two-pronged approach to poverty reduction and ecosystem restoration. The first is by addressing the causes and impacts of ecosystem degradation. The second is by minimising the anthropogenic threat in the forest and reclaimed land by introducing through capacity building, alternative sources of income through the development of silkmoth and honeybees technologies using minimal forest resources and by improving agricultural produce through pollination services in the reclaimed land.

To make protection more sustainable in the long term, the local population has been actively involved in the design and implementation of conservation strategies. This participation in planning and management will not necessarily cover the short-term losses incurred. This project aims to achieve protection through utilisation of natural resources and also to achieve protection through exclusion. In the first group the restrictions on utilisation are of limited duration and are confined to a few forms of

utilisation; the ban on utilisation in the second group extends to the entire protected area and reclaimed land.

To achieve success in both types of approaches the project has provided training to the local community through NARS and *icipe*-trained technical staff. This has brought changes in behaviour on the part of resource use. Village level organisations control by-laws and rules and at the same time act as a stimulus for change within the social system. Capacity development at all levels (community, district, central forestry) is targeted within all project outputs. The project is providing local people with needed expertise in community forestry inputs, institutional support as well as product enterprise in sericulture and apiculture.

In the next review period, two strategies will be pursued. These are:

- Capacity building in all areas of commercial insects farming and pollination service management for key crops.
- Support to community associations through marketplace development, certification and fair trade of insect-based and forest products.

Participating Scientists: S. K. Raina, E. N. Kioko, E. M. Muli, I. Gordon and S. Wren (*icipe*, Kenya)

Key Collaborators: Ministry of Agriculture and Environment (Sudan), Ministry of Agriculture and Environment (Egypt), Ministry of Agriculture and Environment (Yemen), IFAD loan and grant projects, and community associations

Main Donor: OPEC Fund for International Development (Austria)

Wild Silk and Honeybee Farming for Income Generation and Biodiversity Conservation through the Value Chain Approach

General Background

The overall objective of the project is to support nature-based enterprises (wild silk and stingless bee honey farming) through technical training, marketing and management assistance to the rural poor in the dry woodland forest of Mwingi District, Kenya. As national and international consumer demand is increasing for unique nature-based organic products for health and fashion, there are significant opportunities for future expansion of such enterprises. There is still a need to scale up and out, opportunities in marketing of these environmentally endorsed products. It is also necessary to improve existing products to meet national and international statutory standards and non-statutory buyer requirements. The goal is to develop these enterprises at the commercial scale and set up markets as well as organic certification.



Rearing wild silkworms in Mwingi, Kenya

Progress Report and Outlook

A. Development of Nature-based Enterprises in Mwingi District, Kenya for Organic Certification

The farmers in Mwingi District have been trained and their representatives, mainly the group secretaries, have launched the internal control system (ICS) manual. Organic farming rules have been developed that have become part of each participating group's constitution. Experts from the Institute of Marketecology (IMO) did the first external inspection in November 2007 and the groups were found to be compliant and have since been undergoing the conversion period. *icipe* and KOAN have signed a memorandum of understanding for the use of the East African Organic Standard mark by the Mwingi community association for honey and hive products.

In the next review period, three strategies will be pursued. These are:

- Development of a framework of risk management based on mitigation and adaptation to address the challenges and support scaling-up of the products for fair trade and organic certification (FTOC), to be able to compete in the global market and to protect the environment in other parts of Kenya and countries like Madagascar and Southern Sudan.
- Technical training in the management of crops through pollination services and other income generating activities such as sericulture and apiculture to enhance the capacity of the rural poor to cope with disasters incurred by climate change and loss of pollinator species, which have reduced considerably the food security, a situation that has been worsened by droughts and other natural disasters.
- Assessment of the impact of climate change on the crop and forest agrobiodiversity in the eastern African countries.

Participating Scientists: S. K. Raina, E. N. Kioko, E. M. Muli and S. Wren (*icipe*, Kenya)

Key Collaborators: Kenya Organic Agriculture Network, Kenya Forest Service, Ministry of Livestock Development, District Livestock Production Officer–Mwingi, and Viking Limited (Kenya)

Main Donor: Toyota Environmental Activities Grant Programme FY 2006 (Japan)

Project CABESI: Augmenting Camel Usage with Apiculture and Wild Silk Farming to Diversify and Enrich the Livelihoods of Rural West Pokot Communities

General Background

West Pokot is a district in the northwest of Kenya, within the East African Great Rift Valley. The community has a high rate of illiteracy and a low living standard but still maintain their unique traditional activities. There is no large industry in the whole district. The highland Pokot are mainly small-scale farmers growing sorghum and maize, and keeping cattle for milk; the lowland Pokot try to survive with a few livestock (mainly cattle, goats and sheep), and charcoal burning, firewood sales and aloe harvesting. Poverty and water problems combined with destructive activities for survival, and also cattle rustling, are the main problems in the region.

The overall objective of Project CABESI (*Camels, Bees and Silk*) is using the available resources in this semi-arid land for reduction of the poverty levels and reduction of the destruction to the fragile ecosystem.

Progress Report and Outlook

A. Camels

Due to the actual needs in the camel community, CABESI organised a workshop on 'Camel health and management' for 6 camel owners from different parts of the district in collaboration with the Ministry of Livestock, namely the District Veterinary Officer. After an intensive theoretical and practical training the participants were awarded a certificate and a 'doctors kit' (drugs). The trainees now run their own small businesses and are able to recognise the major camel diseases and treat them.

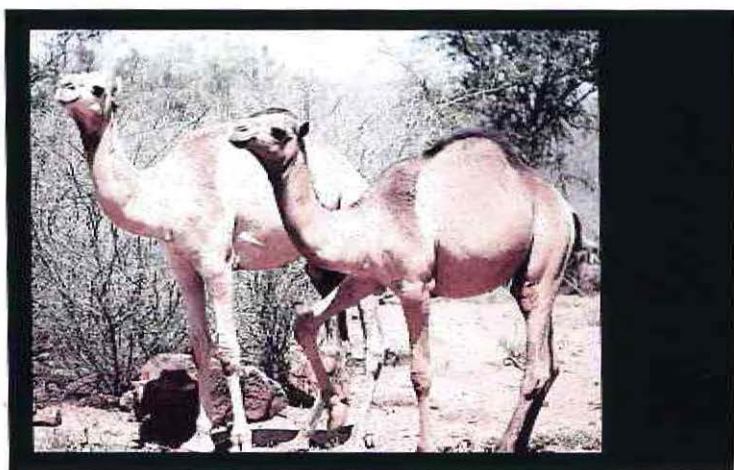
In Konyao, a special workshop for camel owners was held. They were trained in production of camel condensed milk and a way to keep it without cooling for use in tea. CABESI distributed the needed glass jars for the participants to be able to practice the technique to enhance food security in the lowlands. Camels are used in transporting honey to the collection centre. As a result of the project activities, awareness of the importance of camels in semi-arid land areas has improved, as well as camel health and productivity.

B. Bees

Three honey collection centres, in Konyao, Lomut and Psikirio, started operations with extraction of comb honey and beeswax. Production of propolis cream was also done. Langstroth hives have been introduced and farmer trainers trained on their management. In early 2007, the CABESI Marketplace was officially opened by the DG of *icip*e, Prof. Christian Borgemeister. The marketplace is fitted with a production centre for bee products, a place for holding workshops in beekeeping, a general information centre, a shop and a silk centre where wild silk is produced. The centre also holds the CABESI office. Semi processed honey from the collection centres is processed and packaged. Many different candle designs are developed and propolis cream is produced. Market for the products was established, first with individual shops, and later with honey distributors and dealers in Nairobi. New products have been developed like sun dried mango, mango jam and tamarind. The marketplace runs under the community-based organisation, CABESI Self Help Group, with a separate account.

C. Silk

Ephora sp. is being used for wild silk production. CABESI established a small centre in Chesta that is managed by the Seito Traditional Dancers, a registered community-based organisation. Trials of rearing this silk did not bring the expected results at first. One reason is the gap in the knowledge of the life cycle of this silkworm. This has been addressed through research that is currently being undertaken by a PhD scholar who is based in the region. A farmer trainer has also been trained on the post-harvest production of the



Camels in the Pokat region of Kenya (Photo: Rolf Gloor)

cocoons. Spinning wheels are now in use at the marketplace and bobbins of *Epiphora* silk are produced.

In the next review period, nine strategies will be pursued. These are:

- Monitoring camel development and ensuring that the camel drugs are available. Otherwise, the camel programme has been partly overtaken by ASAL, e.g. camel distribution as a food security issue.
- Establishment of more permanent and larger markets for bee products by putting in place transport systems from Kapenguria Marketplace to Nairobi.
- Ensure there is professionalism in all bee products procedures.
- Expand the number of beneficiary beekeepers and the general business volume.
- Establish an export market for candles.
- Enhance silk rearing based on the results of our trials.
- Expand silk rearing to Marakwet District to ensure a feasible production of cocoons and production of silk products.
- Establishment of a *Jatropha* Demonstration Plot in Loyapat in Turkana, to test the waters of *Jatropha* production.
- Produce lamp oil from *Jatropha* for the larger community.

Participating Scientists: S. Raina, E. Kioko and R. Gloor (*icipe*, Kenya)

Key Collaborators: Ministry of Livestock and Fisheries–Kapenguria, District Veterinary Officer–Kapenguria, Drought Management Officer–Kapenguria and Kenya Camel Association (Kenya), and national and international traders

Main Donors: Biovision (Switzerland), ASAL under the Office of the President and Action Aid (Kenya), DED (Germany), and private sponsors

APPLIED BIOPROSPECTING PROGRAMME

Discovery, Development and Commercialisation of Products from Arthropods, Plants and Microorganisms for Pest, Vector and Disease Management, and for Industrial and Other Uses

General Background

The Applied Bioprospecting Programme continues to undertake research and capacity building in bioprospecting for useful products from biodiversity. During the period under review, we sought to discover, develop and commercialise products from arthropods, plants and microorganisms for pest, vector and disease management, and for industrial and other uses. The Programme worked at a low- and a high-technology approach. At the high technology end, it worked with the Kenya Wildlife Service (KWS) and other partners to discover, develop and commercialise agricultural pest control products, and industrial enzymes and other products. Any income that is generated is used to support the management, protection and conservation of biodiversity, and research by *icipe* and its partners. At the low-technology end, it assisted local communities living around important forests and other biodiversity-rich areas to undertake sustainable domestication and harvesting of aromatic and medicinal plants, and to develop natural products for marketing.

Progress Report and Outlook

A. Identification of Insect- and Mammal-selective Toxins from *Parabuthus* spp. Venom

Scorpion venom has the ability to serve as pharmacological tools for the excitation of biological systems and models for target-specific insecticides. As part of the studies of the Programme on the discovery of anti-pest products from arthropods, venom was collected from two scorpion species: *Parabuthus leiosoma* and *Parabuthus pallidus* from Kenya. Subcutaneous injection and oral toxicity tests of crude and pure fractions of the scorpion venom were done in mice (*Mus musculus*), and stemborer species (*Chilo partellus* and *Busseola fusca*). The highest activity against *C. partellus* was found in *P. leiosoma* venom (LC_{50} 0.689 mg/50 mg body weight). Bioassay-guided purification by a combination of cation exchange (CE) and reverse-phase high-performance liquid chromatography (RP-HPLC) led to the isolation of three toxic peptides. A lepidopteran-selective toxin (*P. leiosoma* insect toxin, Plit) was isolated, and the partial N-terminal amino acid sequence (-KDGYPVDNANCKYE-) plus the molecular weight (6688.5 Da) determined. A peptide with significant insect toxicity coupled with mild effects on mice (*P. leiosoma* toxin, Plt) was isolated, and the partial N-terminal amino acid sequence (-CEKFKVQRLVELNCVD-) plus the molecular weight (6742.5 Da) determined. Another toxin with anti-mammalian activity (*P. leiosoma* mammal-selective toxin, Plmt), and N-terminal partial amino acid sequence of ADVPGNYPLDKNGNRY plus a molecular weight of 7145.5 Da was also isolated. Comparison of the partial N-terminal amino acid sequences with other toxins revealed that Plit showed high homology to other known insect toxins. Similarly, Plmt showed high homology with several birtoxin-like anti-mammalian toxins. Plt did not exhibit homology with any known scorpion toxin with combined birtoxin (anti-insect) and anti-mammalian activity. The isolation and characterisation of the new insect-selective toxin demonstrated that the defensive secretion of scorpions continues to be a promising source of target-specific peptides that are important for studies on evolution, structure-activity relationships, binding site location, and drug and pesticide discovery.

Participating Scientist: W. Lwande (*icipe*, Kenya)

Key Collaborators: Kenya Wildlife Service, Kenyatta University and Jomo Kenyatta University of Agriculture and Technology (Kenya), and Bio-Net International and DuPont Agricultural Products (USA)

Main Donors: DuPont Agricultural Products (USA)

B. Bacterial Diversity in the Intestinal Tract of the Fungus Cultivating Termite *Macrotermes michaelseni* (Sjöstedt)

Termites are important arthropods that are involved in the biodegradation of complex substances such as cellulose and hemicellulose found in plant materials. The ability of these Isoptera to digest complex molecules is mostly attributed to the action of enzymes produced by diverse microorganisms that inhabit their intestinal tract. These microorganisms may include novel species with potential for exploitation in biotechnology, for instance the discovery of enzymes for degradation of lignocellulose and cellulose in biofuel production.

A study was undertaken to determine the diversity of the intestinal bacterial community of the higher termite *M. michaelseni* from Kenya using both cultivation and molecular techniques. Total DNA was extracted from the gut of the termite and 16S rRNA genes

amplified using bacterial specific primers. Representatives from 41 RFLP patterns from a total of 102 clones were sequenced. Most of the clones were affiliated with three main groups of the domain Bacteria: Cytophaga-Flexibacter-Bacteriodes (73), Proteobacteria (13), and the low G+C content gram-positive bacteria (9). Two RFLPs related to Planctomycetes, but branching deeper than known members of the phylum, were detected. In addition, 1 and 2 RFLPs represented the spirochetes and TM7-OP11 groups, respectively. In studies using culture-dependent techniques, most of the isolates obtained belonged to the gram-positive bacteria with a high G+C content. However, only one of the clones represented gram-positive bacteria with high G+C content. These results showed a high bacterial diversity in the intestinal microbiota of *M. michaelseni*, which continued to escape cultivation. As is the case in other termites many of the clones represented previously uncultured bacteria. The fact that most of the clones clustered with clones from *M. gilvus* provided further support for the hypothesis that microorganisms in intestinal tracts of termites have co-evolved with their hosts.

Participating Scientists: W. Lwande and E. O. Osir (*icipe*, Kenya)

Key Collaborators: Jomo Kenyatta University of Agriculture and Technology and Kenya Wildlife Service (Kenya), and Diversa/Verenium Corporation (USA)

Main Donors: Diversa Corporation (now Verenium Corporation) (USA)

C. Capacity Building for Medicinal and Aromatic Plant-based Enterprises for Communities Living Adjacent to Kakamega, Taita Hills, Lower Tana River and East Usambara Mountain Forests in Kenya and Tanzania

The Programme undertook capacity building to enhance the sustainability of medicinal and aromatic plant-based enterprises for communities living adjacent to the biodiversity-rich Kakamega, Taita Hills, Lower Tana River and East Usambara Mountain forests in Kenya and Tanzania. The enterprises were aimed at improving the livelihoods of the communities and conserving the forests by relieving some of the pressure for economic resources. This was undertaken through training, improvement of facilities, products and operations, procurement and installation of equipment, sales and marketing of products and community mobilisation. Over 367 community members were trained as trainers in cultivation and processing of medicinal and aromatic plants. Over 120 community members were trained in the management and operation of their community-based enterprises. Facilities were acquired, renovated and improved for processing *Mondia whytei* root bark at Kakamega Town and for processing *Ocimum kilimandscharicum* plant material adjacent to the East Usambara Mountain forests. Also, facilities were acquired, renovated and improved for drying and storage of neem seeds at selected collection centres adjacent to the Shimba Hills forest. Premises were also identified for neem oil extraction and soap production, and processing of *Aloe* plant material adjacent to the forest. The community enterprises were provided with an essential oil distiller, an oven, a grinding mill, a honey extractor and an oil expeller. In addition, they were also provided with water tanks, computers and accessories, mopeds, fire extinguishers and a range of hygiene and protective clothing, as well as safety gear. The quality of Naturub® and Mondia Tonic® products was officially approved through their registration with the Kenya Pharmacy and Poisons Board, and the Kenya Bureau of Standards. It is noteworthy that Naturub® is the first natural product to be registered by the Kenya Pharmacy and Poisons Board as a medicine. Two revolving funds were established to offer credit for growth and expansion of operations of the community-based enterprises. Revenue from sales of Naturub® and Mondia Tonic® rose to US\$ 13,212. The community members earned over US\$ 13,600 from the sale of plant material to the enterprises. The total fixed asset base for the community enterprises was US\$ 165,000.

Community members used the additional income for activities such as construction of houses, education for children, and setting up of other businesses. Fifteen youth were employed by the community enterprises in production and processing. This Programme contributed to improved household income, women empowerment and conservation of the biodiversity-rich forests. Community members also had exposure from the over 1000 visitors to their enterprises and from visits made outside their regions. It was also established that the products from the enterprises helped to improve health and nutrition. As a result of the Project, 85% of respondents stated that they participated in various forest conservation activities. Over 50% of respondents reported that they had reduced their reliance on forest products as a result of the project.

In the next review period, three strategies will be pursued. These are:

- Step up studies on discovery and development of pest control products from plants because plants have shown more potential.
- Activities will be enhanced on discovery of products from insects, including insect-derived microorganisms and related enzymes for bio-fuel production.
- For the community-based enterprises, capacity building of community members will be undertaken to enable them to manage all enterprise operations including manufacturing and marketing of products.

Participating Scientist: W. Lwande (*icipe*, Kenya)

Key Collaborators: Kenya Forestry Research Institute, University of Nairobi, Kenya Wildlife Service, The World Agroforestry Centre, World Wide Fund for Nature-Eastern Africa Region Program Office, Kenya Gatsby Trust and National Museums of Kenya (Kenya), and Tanzania Forest Conservation Group and East African Wildlife Society (Tanzania)

Main Donors: Ford Foundation and Critical Ecosystem Partnership Fund (USA), and Biovision Foundation (Switzerland)

BEHAVIOURAL AND CHEMICAL ECOLOGY DEPARTMENT

Development of Semiochemical-based Monitoring and Control Programmes for Pests of the Apiculture Industry

General Background

Beekeeping is an important income-generating activity among smallholder farmers in many parts of sub-Saharan Africa. As part of *icipe's* apiculture research programme, a number of improved apiculture technologies have been introduced to beekeepers in the region to boost up bee production and farmers' income. Components of this programme include training in colony management using movable frame hives and production of non-traditional hive products such as royal jelly, propolis and pollen. In Kenya, more than 1300 beekeepers have benefited from this training programme and are currently using Langstroth hives to manage African honeybees.

African honeybees are attacked by a number of insect pests of which the key ones are wax moths and hive beetles. The small hive beetle, *Aethina tumida*, has become a notorious invasive pest in the USA and Australia where Langstroth hives are commonly used to manage European honeybees. *icipe* scientists, in collaboration with partners in the USA, have investigated the chemoecological basis of European honeybee-small hive

beetle interaction. This has led to the development of a lure and a trap for trapping the beetle. This project aims to test the performance of this odour bait and trap in trapping small hive beetles from Langstroth hives that beekeepers in Kenya are currently using to maintain African honeybees. Second, the project aims to investigate and document the presence of other species of hive beetles in these colonies, with the goal of studying their biology and chemical ecology.

Progress Report and Outlook

A. Performance of the Pollen-derived Lure Combined with an In-hive Trap in Reducing Populations of the Small Hive Beetle (SHB) from African Honeybee Colonies in Kenya

Previous collaborative studies between scientists at *icipe* and the USDA/ARS-Centre for Medical, Agricultural and Veterinary Entomology (CMAVE) in Gainesville demonstrated the effectiveness of a pollen-derived lure combined with an in-hive trap in reducing populations of the small hive beetle (SHB), a pest of honeybees from European honeybee colonies. In the present study, the performance of the trapping system was tested for trapping the SHB from African honeybee colonies in Kenya. Traps were placed under four honeybee colonies maintained in standard size Langstroth hives located at the *icipe* headquarters in Nairobi. Traps were monitored weekly for 10 weeks. In general, baited traps were more effective in capturing SHBs than unbaited traps, but the mean number of beetles captured per week in baited traps was low, ranging between 2 and 5 depending upon the colony. Work is in progress at a second site located about 70 km from Nairobi.

B. Survey for Other Hive Beetle Pests in African Honeybee Colonies and a Study of Their Biology and Chemical Ecology

A second objective was to conduct a survey for other hive beetle pests in African honeybee colonies and to study their biology and chemical ecology. The survey was conducted in honeybee colonies in five specific beekeeping areas in Kenya: Nairobi, Machakos, Kitui, Taita-Taveta and Malindi. The beetles collected from honeybee colonies at these sites were all identified at the National Museums of Kenya, Nairobi. Three of the beetles were identified as belonging to the family Scarabaeidae, subfamily Cetoniinae, with the fourth one identified as the small hive beetle belonging to the family Nitidulidae. An unidentified scarab was collected from honeybee colonies in Kitui.



Harvesting honey

A laboratory colony of each scarab species was started from the field-collected insects following a modified procedure described previously for rearing the larger hive beetle. Briefly, the adult beetles were fed on sliced banana pieces instead of pollen and honey. Sterilised soil mixed with previously frozen cattle dung served as an oviposition site for the adults as well as the diet for larvae that hatched from the eggs. On average, eggs took 7 days to hatch. Larvae took on the average 35 days to

become pupae, with adults emerging from the pupae after 25 days. The survival rate of pupae under the rearing conditions (26 ± 3 °C, 33% relative humidity) was very low, approximately 1%. Work is in progress to improve upon the rearing conditions.

In the next review period, three strategies will be pursued. These are:

- In-depth studies on the biology and ecology of the larger hive beetle.
- Effect of rainfall and temperature on trap capture of the SHB from honeybee colonies.
- Chemical ecology of the interaction between honeybee colonies and the larger hive beetle.

Participating Scientists: B. Torto and E. Muli (icipe, Kenya)

Key Collaborators: USDA/ARS Centre for Medical, Agricultural and Veterinary Entomology (USA)

Main Donors: USDA (USA)

MOLECULAR BIOLOGY AND BIOTECHNOLOGY DEPARTMENT

Genetically Modified Cowpea Biosafety Project

General Background

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. their toxicity to non-target organisms, development of insect populations resistant to toxins expressed in the GM plants, and more importantly, 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 is 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.

Progress Report and Outlook

A. Pollen Flow between Domesticated (Potentially GM) Cowpea and Its Wild Relative

The first phase of the project was focusing on pollen flow between domesticated (potentially GM) cowpea and its wild relative. Conclusions are that pollen flow can

only occur through a few large sized pollinators (several *Xylocopa* and megachilids). These pollinators are very active and under good weather conditions, visit each cowpea flower at least once. The domesticated, mainly selfing, breeding system is due to bud self-pollination. However, pollen flow can be important in some instances, especially with wild plants that are not bud self-fertilised. Competitiveness of the various pollens, flower colour, or segregation distortion in the progeny of a hybrid cannot be used to prevent gene escape.

During the first phase of the project, the fitness of the wild-domesticated hybrids and their progenies was checked. These hybrids are more fit 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 an insect's protection to boost their seed production.

Therefore, there is no way of preventing gene escape, and wild plants introgressed with a Bt gene will likely produce more seeds.

B. Seed Predation and Wild Plant Population Regulation

Next, 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?

Wild cowpea seed predation: In two wild cowpea populations from coastal Kenya, we observed that pre-dispersal predation (seeds destroyed before shattering of the pod and release of the seeds) is mainly due to a coleopteran beetle and a dipteran bean fly. Since the current GM cowpea is with a Bt gene that affects only Lepidoptera, these predators, which are destroying 5–20% of seeds, should not be affected. The three lepidopteran species (including the domesticated cowpea pest targeted by the Bt gene, *Maruca vitrata*) are destroying less than 5% of the seeds. If these results are confirmed during the coming years, this would mean the potential elimination of the three lepidopteran predators, but the Bt gene would result in a limited increase of seed production by wild plants.

On the other hand, post-dispersal (once the seeds are lying on or within the upper layer of the soil) predation is important and is mainly due to rodents. In coastal Kenya conditions, these rodents are destroying almost all the seeds produced by the cowpea plants and are leaving (and also dispersing) just the few seeds that they forget, which are producing the next generation of plants. Ongoing trials show that they can destroy a huge amount of seeds when these are offered to them; and that, adding a large amount of seeds to the soil of natural wild cowpea does not markedly increase the number of plants because rodents keep digging most of them out.

If confirmed in the coming years, these results should pave the way for the deployment of Bt cowpea in Kenya. Bt gene should move to wild plants but the fitness advantage given by the gene should be negligible for a wild cowpea plant; and so there should be no risk of increased weediness for the wild cowpea plants.

However, these results should not be applicable directly to West Africa where Bt-cowpea deployment is planned. This is due to seasonal and plant habit differences. There is almost no seasonality in coastal East Africa and all predators are active more or less all year long, while there is a strong seasonality with a marked dry season of up to nine months in West Africa. Therefore, the activity of post-dispersal predators during the dry season (and on large areas of bare soil) is not proven.

In addition, in coastal East Africa wild cowpea plants are more or less perennial and with a mixed breeding system, are easily cleared from the fields by farmers. They produce seeds almost all year long, though not profusely. On the other hand, wild plants in West Africa are annual with an inbred breeding system. More importantly, the weeds are regularly uprooted by farmers and are not so frequently found in the wild. This could be because the most suitable areas are turned into farmland. Despite intensive weeding during the first part of the growing season, weeds remain a problem due to prolific seed production within a month after the rains.

Therefore, as 'wild' plants are closely associated with cowpea fields, the impact of *Maruca* and other lepidopteran pests on wild cowpea plants may be the same as on cultivated plants. Since *Maruca* outbreaks seem to be more frequent in West Africa, elimination of lepidopteran predators could result in a significant increase in wild plant seed production. Pre-dispersal and post-dispersal predation of wild cowpea seeds is definitely needed in West Africa.

In the next review period, two strategies will be pursued. These are:

- Experiments to determine the biosecurity of Bt-cowpea.
- Doubling cowpea production with hybrid cowpea.

Participating Staff: R. Pasquet (*icipe*, Kenya)

Key Collaborators: University of California at Davis and University of Virginia (USA), Lund University (Sweden), and INERA (Burkina Faso)

Main Donors: Rockefeller Foundation and USAID (BBI Program) (USA)

BIOSYSTEMATICS SUPPORT UNIT

Taxonomic Services

General Background

The BSU has the duty to provide taxonomic competence for project development and implementation, as well as for training MSc/PhD students as well as staff. Training comprises of the basics of insect biology and biodiversity; however, also the different and most efficient sampling techniques, including analytical tools for answering a scientific problem are taught.

Progress Report and Outlook

A. Information Management

A significant part of the duties is information management to find the most suitable source of information or expert, and to guide people through the enormous amount of information available on the Internet.

B. Electronic Inventory of the Insect Collection

An electronic inventory of the collection has been compiled. This will enable workers to find species and specimens for reference and scientific documentation easily.

In the next review period, three strategies will be pursued. These are:

- A stronger and added integration of the collection into databases and on the Internet, through for example projects carried out together with GBIF.
- Expansion of the African Insect Taxonomy Toolkit (AITT).
- Data entry systems using ICT tools and GIS.

Participating Scientist: F. Haas (*icipe*, Kenya)

Key Collaborators: Global Biodiversity Information Facility (Denmark)

Main Donor(s): *icipe* (Kenya) and GBIF (Denmark)

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MSc:

J. B. Ochola, L. M. Mackenzie, G. N. Mokuu, J. Nonoh, P. M. Mutungi, D. Mutyambai, J. Macharia, P. W. Wainaina, P. M. Musyoka and N. Ndung'u

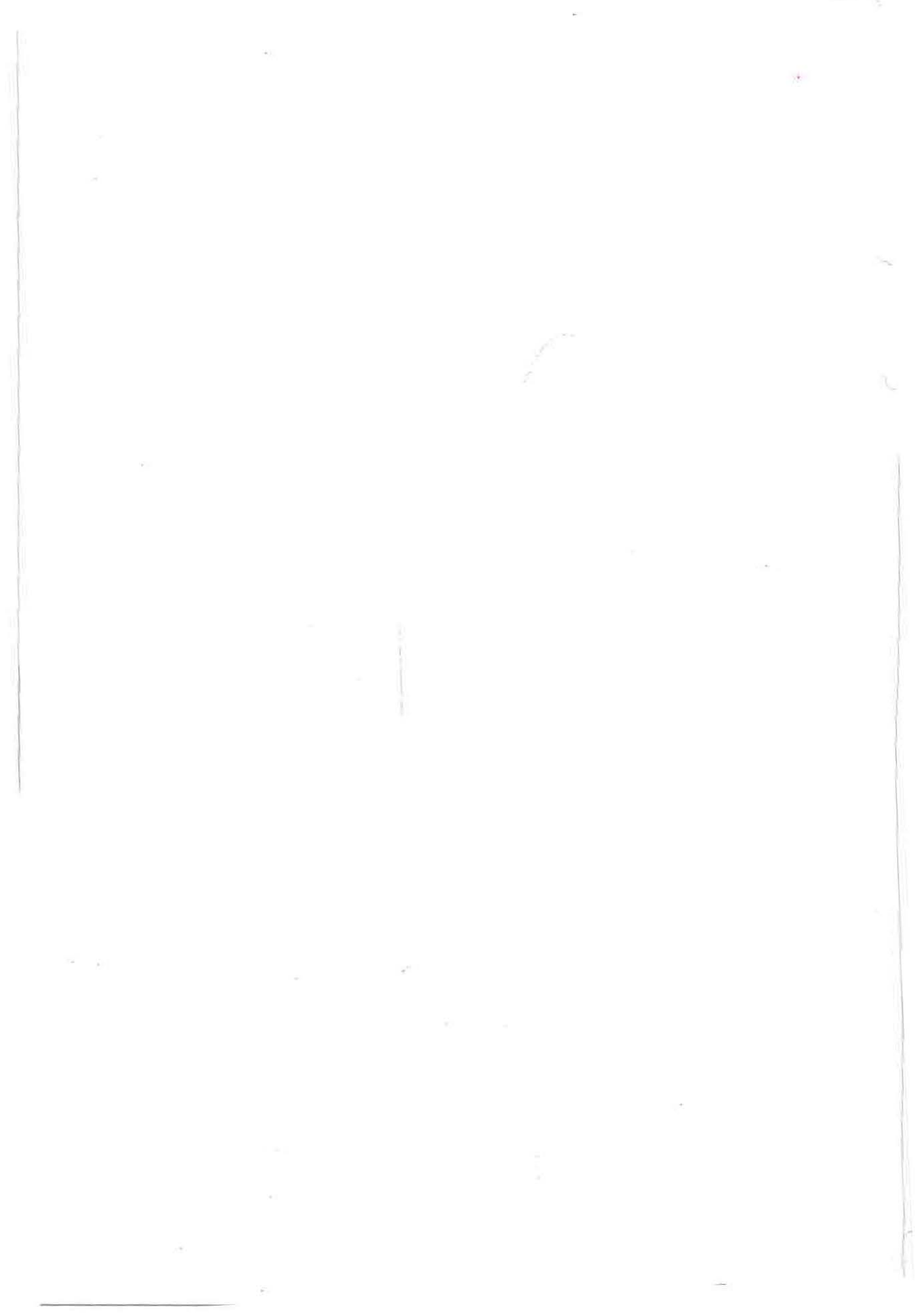
PARTICIPATING INTERNS

J. Glenday and J. Herren

OUTPUT

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ANIMAL HEALTH RESEARCH

OVERVIEW

icipe's animal health research aims to improve livestock health and productivity through development of integrated strategies and tools for the control of livestock vectors, thus leading to greater availability of meat, milk, hides and draught power. Research activities focus on developing simple technologies based on detailed understanding of vector behaviour, population ecology, and vector–host and vector–parasite interactions. The research focus has been on two important vectors affecting livestock productivity in sub-Saharan Africa—tsetse flies, vectors of animal and human trypanosomosis and ticks which, among others, transmit East Coast fever.

Our tsetse and ticks research has generated technologies that enable farmers to undertake better ecological management of these major livestock disease vectors and that help in intensifying and diversifying smallholder farming systems to generate more cash income and enhance food security. The emphasis has been on developing environmentally safe methods that can be applied together in tailor-made, site-specific packages. Components of such a package include *icipe's* well-known NGU tsetse traps whose efficacy is enhanced by odour baits, biological control, and use of repellents. *icipe* is also one of the few organisations, despite its limited funding, that continues to conduct research into the control of ticks and tick-borne diseases, to develop integrated parasite vector management (IPVM) approaches which rely on biological control, use of botanicals and anti-tick pasture plants, repellents and behavioural modification of the cues ticks use to find hosts and preferred feeding and mating sites. Indigenous knowledge of communities in management of ticks is also being incorporated in developing appropriate strategies for tick control.

In the case of tsetse, the Division has also considerable experience in community mobilisation, empowerment and organisation for undertaking tsetse and trypanosomosis control in different agroecosystems and animal husbandry practices. Capacity building at all levels of society is an integral part of all Division activities.

Current and future R&D thrusts include:

- Further optimisation and validation of the tsetse repellent technology to enhance its transfer, delivery and adoption.
- Development of baits for riverine tsetse, vectors of human sleeping sickness.
- Community-based tsetse control using the adaptive management approach employing GIS technology to identify 'hot-spots' of high tsetse fly densities for strategic deployment of traps in Ethiopia.
- Reduction of human/wildlife conflicts through effective tsetse control.
- Characterisation of odour-binding proteins and receptors of tsetse.
- Use of entomopathogens like *Metarhizium anisopliae* to enhance tsetse suppression rates and thereafter, mop up residual populations.
- Exploitation of recent advances in genomics and bioinformatics, together with detailed knowledge of the behaviour of the flies for optimising existing baits and for development of new innovative technologies.
- Undertaking of any backstopping research required for implementing area-wide control/eradication programmes including detailed baseline entomological and parasitological surveys for intervention programmes.
- Developments of baits for biting flies (as an example tabanids, stable flies) that mechanically transmit trypanosomosis.
- Development of simple sustainable technologies for on-farm management of ticks and the diseases they cause based on the use of biopesticides, botanicals and behavioural manipulation.
- Development and testing of holistic, innovative, site-specific packages for sustainable animal health management/production at farmer level in different production systems and agroecological zones for adoption and wider dissemination.
- Plans to extend research to other arthropods of medical and zoonotic importance to develop technologies for their integrated management and the diseases they cause. Similarly, effects of climate change on disease vectors will be investigated.

TSETSE GROUP

TSETSE RESEARCH PROGRAMME

Livestock Keepers' Attitudes, Preferences and Perceptions on the Impacts of Repellents and Baits in Relation to Tsetse Challenge and Trypanosomosis Risk

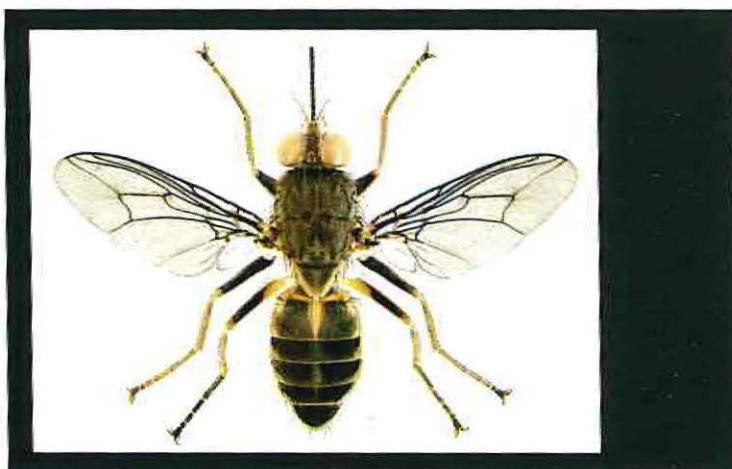
General Background

Analysis of data collected from a longitudinal study conducted to evaluate the efficacy of 'push-pull' tactic in enhancing tsetse suppression rates and trypanosomosis disease levels using on-host repellents to 'push' and baited traps to 'pull' the flies clearly demonstrated that the protection of cattle with either synthetic repellents or baited traps (or both), results in significant reductions in tsetse populations, trypanosomosis disease incidence and trypanocidal drug use. The recorded reductions were also positively associated with improved cattle body weight, body condition, mean PCV levels and household herd size.

Progress Report and Outlook

A. Study Using Open-ended Structured Questionnaires to Assess Livestock Keepers' Perceptions on the Impacts of Repellents and Baited Traps in Relation to Perceived Reduction in Tsetse Challenge and Trypanosomosis Risk

Following the successful demonstration of the potential positive impacts of repellents and baits on tsetse challenge, drug use, herd health and productivity, a study using open-ended structured questionnaires was conducted to assess livestock keepers' perceptions on the impacts of repellents and baited traps in relation to perceived reduction in tsetse challenge and trypanosomosis risk. Ninety-four livestock keepers were interviewed. Most livestock keepers considered the significant reduction in trypanocidal drug use, disease incidence and tsetse population to be the most



Glossina pallidipes, main vector of trypanosomosis in livestock in Africa

important benefits of repellents and traps. Additional benefits included quieter grazing, protection of goats, improved body condition, increased draught power and opening up of previously avoided fields for grazing and crop production. When presented with a choice between repellents and traps, all livestock keepers preferred repellents to traps. If given a choice, majority of livestock keepers (79%) preferred repellents, traps or both to other current methods (pour-on solutions, drugs and the rest) for tsetse and trypanosomosis control. The most attractive attribute of the repellents was its simplicity and mobility (the cattle move with the repellent collars wherever they go). The predominant constraints with the repellent and trap technology were, respectively the loss of dispenser stoppers and weak netting material. These perceptions clearly confirm the results from the longitudinal study that repellents and baits can significantly reduce drug use, disease incidence and tsetse populations, and improve herd health and productivity.

In the next review period, four strategies will be pursued. These are:

- To further optimise the repellent technology to enhance its transfer, delivery and adoption.
- Refine the repellent prototype dispenser to make it more robust.
- Mass-produce the repellent prototype dispenser together with the repellent compounds in collaboration with the private sector.
- Undertake large-scale validation trials of the repellent technology with the active participation of pastoralists, livestock keepers and other stakeholders involved, to facilitate its wider dissemination.

Participating Scientists: R. Saini and A. Hassanali (icipe, Kenya)

Key Collaborators: Kenyatta University and Kenya Veterinary Department-Veterinary Investigation Laboratories (Kenya)

Main Donors: IFAD (Italy) and DAAD (Germany)

BEHAVIOURAL AND CHEMICAL ECOLOGY DEPARTMENT

Responses of *Glossina fuscipes fuscipes* to Host Odours

Background

Glossina fuscipes fuscipes and other riverine tsetse are important vectors of human and animal African trypanosomosis (HAT/AAT). Over 100 million people and large herds of cattle are at potential risk of this disease in Africa. Tsetse flies are sensitive to insecticides and as such small doses are required for a lethal effect on them. Although insecticide-treated targets can kill the existing flies, successful mass trapping/control of riverine tsetse is still an illusion because few flies land on the targets. The main challenge is how to lure the flies to the targets and make a large proportion of the natural population land on them to collect a lethal dose of the insecticide. There is no doubt then, that any effort towards developing attractant odours to be used with the targets will be a landmark step towards achieving mass control of the flies. In developing attractant odours to be used with the targets, methods that have been successfully used to identify attractants for tsetse flies of veterinary importance have been adopted.

An initial screening of natural attractant odours from host animals (ox, human, pig and monitor lizard) has been done in completely randomised Latin square experimental design in the fields at Mbita Point in western Kenya.

The Tsetse Programme at Mbita has an insectary for rearing tsetse flies, which are used to run the EAG experiments.

Progress Report and Outlook

A. Responses of *Glossina fuscipes fuscipes* to Mammalian Host Odours

The numbers of *G. f. fuscipes* caught by an electric net (1 × 1 m) baited with whole natural odour from: (i) a single cow, (ii) 2 men, (iii) 3 pigs or (iv) no odour, have been compared. The hosts were placed in a plastic tent and a co-axial fan (12 v, 0.38 amp; maximum airflow ~2000 L/min) exhausted the odour-laden air from the tent down a PVC tube to various catching devices 10 m away. A target, consisting of a panel of black cloth (0.75 × 0.75 m), was placed 0.5 m upwind of the electric net to provide a visual target for tsetse. The experiment was conducted between 0900 and 1300 hours for 12 days.

Statistical analysis of the detransformed mean catches, showed that there was no significant effect of host odour on the catch ($F_{3,30} = 1.2$; $P = 0.3$). There was no significant difference in the responses of males and females.

B. Responses of *Glossina fuscipes fuscipes* to Reptilian Host Odours

Field experiments to study the responses of *Gff* tsetse to natural odours from: (i) monitor lizards, (ii) ox, (iii) human or (iv) no odour, have been done. Each host was placed in a smaller (~2 × 2 × 1.5 m) metal-and-glass cage and a co-axial fan (12 v, 0.38 amp; maximum airflow ~2000 L/min) exhausted the odour-laden air from the tent down a PVC tube to various catching devices 10 m away. A target, consisting of a panel of black cloth, 0.75 × 0.75 m, was placed 0.5 m upwind of the electric net to provide a visual target for tsetse. The experiment was conducted between 0900 and 1300 hours for 12 days.

Below is a summary of the results:

- Lizard odour increased the catch for female flies (1.9x; $P < 0.05$) and gave an indication of activity with the males as well (1.5x; $P < 0.05$ by LSD).
- Human and cattle odours had no significant effect (catch indices of 1.1–1.3x).
- Percentage of males caught on the target was 66% compared to 22% with no odour, and an intermediate 35% for ox and human odours.
- Females showed a strong response to lizard odour as well (35%).



Testing the attractiveness of monitor lizards for tsetse flies

In the next review period, four strategies will be pursued. These are:

- Analysis, in the laboratory, of the natural odours from the monitor lizard by gas chromatography, electroantennogram and mass spectrometry techniques to identify individual molecules in odours, which produce antennogram responses, and thus produce a list of candidate attractant molecules for the *Gff* species of tsetse flies.
- Identification of commercial sources of the EAG-active individual chemicals and their bioassays in the field against *Gff* tsetse.
- After determining the impact of individual molecules on fly behaviour, determine the best mixtures required to optimise attraction and so redesign traps and targets to ensure their most efficient use with the identified attractants.
- To determine suitable, low technology release systems for use in *Gff* tsetse control campaigns.

Participating Scientists: M. Omolo, B. Torto and A. Hassanali (*icipe*, Kenya)

Key Collaborators: Rothamsted Research and Liverpool School of Tropical Medicine (UK)

Main Donors: Bill and Melinda Gates Foundation (USA) and EU-INCO

MOLECULAR BIOLOGY AND BIOTECHNOLOGY DEPARTMENT

Antennome of *Glossina* Species and Molecular Dissection of the Olfactory Process

General Background

The main goal of this project is to carry out a comprehensive molecular analysis of olfactory proteins of tsetse flies. We have embarked on a study of these important components of sensory perception using libraries of complementary DNA (cDNA)

representing the genes expressed in the antenna of *Glossina pallidipes*, and the heads (with intact antennae) of *G. palpalis* and *G. tachinoides*. These libraries from expressed genes (expressed sequence tags, ESTs) have been sequenced in collaboration with the Pathogen Sequencing Unit at the Wellcome Trust Sanger Institute, UK. The dataset is available at: <ftp://ftp.sanger.ac.uk/pub/pathogens/Glossina/morsitans/ESTs/>.

Progress Report and Outlook

A. Olfactory Proteins of Tsetse

The research focuses on identifying the four main olfactory proteins, namely odorant binding proteins, pheromone binding proteins, odorant degrading enzymes and odorant receptors. Functional annotation of the transcripts with the coding sequences has identified five putative odorant binding proteins (OBPs) by computational methods along with several molecules thought to be vital in tsetse olfaction.

We are testing the tissue specificity of the OBPs identified and quantifying their expression levels in adult tsetse. This will help identify sites of activity and elucidate their function.

We anticipate that this work will help identify olfactory genes that are important for the survival of both male and female flies, and sex-specific genes whose role can be vital in responses that lead to mating. Such information may be useful to improve trapping technologies and to develop biologically sound and novel disease control strategies based on olfactory mediated behaviours.

In the next review period, two strategies will be pursued. These are:

- Testing OBP localisation by RT-PCR in selected *Glossina* tissues.
- Expression and characterisation of selected OBPs.

Participating Scientists: D. Masiga and A. Hassanali (*icipe*, Kenya)

Key Collaborators: Jomo Kenyatta University of Agriculture and Technology (Kenya), The Wellcome Trust Sanger Institute (UK) and South African National Bioinformatics Institute (South Africa)

Major Donors: UNICEF/UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases (TDR) and International Institutes Cooperation Programme (The Netherlands)

TECHNOLOGY TRANSFER UNIT

Mwea National Reserve Community-based Tsetse Control

General Background

The objectives of this effort were to promote community-based environmentally friendly tsetse control technologies and conservation-based income generating enterprises that contribute towards sustainable use of natural resources.

Progress Report and Outlook

A. Training

Three community members were trained on how to make NGU tsetse traps. These tailors made 550 traps. A total of 54 community members were trained in trap deployment and servicing, who then proceeded to deploy a total of 330 traps within the reserve and 160 barrier traps around it. Thereafter, monitoring of the tsetse population within and outside the reserve and frequent servicing of the traps was undertaken.

Overall, by March 2006, tsetse population had declined from an average of 60 flies/trap/day in August 2003 to about 10 flies/trap/day. Unfortunately, the fly population did not decline as much as anticipated at project commencement because of a major factor: fading of the trap cloth colour after a year of use due to the effects of the sun. For this reason, it was recommended that sun-fast cloth material would be used to make the NGU traps for future tsetse trapping.

B. Area-Wide Livestock Disease Control and Scaling-up of Tsetse Control by the Project

This tsetse control project was initiated in 2005 and continued into 2006. The project ended in December 2006 but Biovision Foundation of Switzerland agreed to provide bridging funds for a further 12 months. A discussion was held with PATTEC-Kenya to facilitate area-wide livestock disease control and scaling-up of tsetse control activities. During the bridging phase, we gradually handed over the project activities to PATTEC-Kenya in fulfillment of its mandate under the Mwea/Meru regional programme. Following the recommendation from the Project, PATTEC-Kenya adopted use of the sun-fast blue cloth for making the traps. It will be responsible for scaling-up the lessons learned from the Biovision-funded *icipe*/KWS initiative.

Participating Scientist: B. Nyambo (*icipe*, Kenya)

Key Collaborators: Kenya Wildlife Service, Mbeere County Council and farming communities in the environs of the Mwea National Reserve (all in Kenya)

Main Donor: Biovision Foundation (Switzerland)

ETHIOPIA COUNTRY STATION

Adaptive Tsetse/Trypanosomosis Control in Ethiopia

General Background

Trypanosomosis is the major animal disease affecting livestock and agricultural production in Ethiopia. The western, southern and southwestern lowlands and the major river basins are infested by different tsetse species. *icipe* has been undertaking an adaptive tsetse/trypanosomosis roll-back initiative since 2004 in Gurage Zone. As a result of the successful community-based tsetse/trypanosomosis intervention in Gurage, requests were received from several regional states and communities (Ghibe valley, Keto and Assosa in southern and western regions of Ethiopia) with the trypanosomosis problem to implement similar control operations and scale them up.

Progress Report and Outlook

A. Adaptive Tsetse Population Management in Gurage Area

Tsetse populations are being adaptively managed in Ghibe valley at Gurage sites, which include Luke, Doba, Shumro and Wodesha villages, and Tola site (Biftu Beri village in Oromiya region). Activities at Gurage sites are a continuation of previous activities, while activities in Tolay site were started in 2007.

In Luke and Enemor 315 NGU and monoconical traps were deployed between 2006 and 2007 for monitoring and control purposes. As the two species are found together in the area, both traps were used. Our monitoring data showed that the dominant tsetse species was *Glossina morsitans submorsitans*. Fly populations were reduced from 0.004 flies/trap/day (FTD) in 2004 to 0.0006 FTD in 2006.

B. Adaptive Tsetse Population Management in Tolay area

In Tolay area, 760 NGU and monoconical traps were deployed for monitoring and control purposes. The programme started in August 2006 and the fly catch collection continued up to December 2007. The predominant tsetse species caught were *G. morsitans submorsitans* and *G. fuscipes fuscipes*. There were also other biting flies caught along with tsetse. So far, fly populations have been reduced from 0.013 FTD in November 2006 to 0.003 FTD in November 2007.

C. Adaptive Tsetse Population Management in Keto Project Site

Keto is located in the northwestern part of Ethiopia at Baro/Akobo river basin at an altitude of 1200–1400 masl. The tsetse monitoring operation started in 2005. Twenty monitoring traps (NGU traps) were deployed on strategic tsetse habitats. In 2006 and 2007 the Oromiya Agriculture and Rural Development Bureau used insecticide-treated targets for tsetse control. According to the study results, two major tsetse species trapped were mainly *G. morsitans submorsitans* and *G. pallidipes*. The relative density of the flies has significantly reduced from 1.8 FTD to 0.119 FTD. In this area, *icipe's* role is to provide technical and scientific backstopping.

D. Adaptive Tsetse Population Management in Benshangul Gumuz Project Site

More than 98% of the total landmass of the region is infested with tsetse flies and a high trypanosomiasis incidence is experienced. On the request of the regional government, *icipe* initiated the adaptive tsetse control approach in 2003 initially in two villages, and later expanded control to six kebeles covering about 200 km² and benefiting 20,000 beneficiaries, which include Amba 7, 8 and 9, Agusha, Kushmengel and a village called Tsetse Adurnunu.

The monitoring operation resumed between July 2006 and March 2007 with 240 monoconical and NGU monitoring traps deployed in tsetse breeding sites of the six target kebeles. Traps were deployed in grids at 250-m intervals and were georeferenced with GPS. The 150 trained farmers collected the flies bi-weekly and after characterisation, data were processed to identify the hotspots. Based on the analysed monitoring data contour maps were constructed for control purposes. The dominant tsetse species were *G. morsitans submorsitans* and *G. fuscipes fuscipes* along with other biting flies. The

monitoring data showed that tsetse fly populations had drastically reduced from 0.004 FTD to 0.0011 FTD.

Disease Management in Ghibe Valley Project Sites in Ethiopia

General Background

In 2006 and 2007, 38 and 52 animals, respectively were examined for trypanosomosis. The prevalence rate was determined as 10.5% for 2006 and 7.7% for 2007.

Progress Report and Outlook

A. Auto-replication of the Tsetse Roll Back Initiative and Adaptive Management in Enemor Project Site

Enemor is a neighbouring woreda to the Luke project site. The tsetse intervention information in Luke and the subsequent reduction of trypanosomosis challenge was widely heard by this neighbouring community. As a result, in 2005, the project team was invited by the local woreda administration as well as the community to scale up the community-based roll back initiative and adaptive management of tsetse. Enemor is a model for community-based auto-replication of the project.

B. Animal Health at the Tolay Project Site

Tsetse control operations started in July 2006 in collaboration with the Western Shewa, Woliso Zone Veterinary Service.

Animals (520) were examined, out of which 156 animals were found to be positive. The infection rate was 30%. As a continuation of the survey, a second phase of parasite detection was set for September 2006 and 243 animals were examined. According to the blood examination 29 were found to be positive, with an infection rate of 12%. In a third phase, blood examination was also undertaken from 120 animals and 11 were found positive. The prevalence rate was 9%. As a consequence of strategic trapping, disease incidence in the project site was reduced from 30 to 10%.

C. Animal Health at Keto

Trypanosomosis prevalence survey conducted in June 2007 showed an infection rate of 24.5% as compared to the 60% infection rate in 2005 when the settlement programme started. The Kake Woreda animal health clinic report showed that the number of cattle treated for trypanosomosis was decreasing.



NGU tsetse trap, one of the landmark developments of icipe



Bleeding a cow for detecting trypanosome infections in livestock

The number of cattle treated for trypanosomosis was 1221 in 2005 and 733 in 2007. Farmers have indicated that reduction in the number of cattle treated is due to vector control and the drug administration activities conducted from 2005 to 2006.

D. Benshangul Gumuz Animal Disease Determination

Blood samples were taken from the randomly and proportionally selected sentinel animals and examined to determine the

trypanosome load and distribution of the disease in both target and surrounding villages. Animals to be monitored were randomly selected from all categories (calf, heifer and bull), ear tagged for disease prevalence monitoring and examined every four months. The procedures used to examine animals for blood parasites were thick blood smear, buffy coat examination method and packed cell volume (PCV). Animals found positive for trypanosomes and with low PCV were treated with trypanocidal drugs.

Between 2006 and 2007 a total of 342 and 309 animals were examined for trypanosome infection and 40 and 26 animals were found positive for trypanosome infections respectively. According to these results, the prevalence rate was 12.95 and 8% for 2006 and 2007 respectively. All infected animals and animals with low PCV were treated with trypanocidal drugs. As has been observed in two different periods the infection rate has been substantially decreased.

These results show that significant achievements were recorded and significant socio-economic changes were brought through tsetse/trypanosomosis control. Also, the region's animal health programme has learned a lot and they are replicating the operation in other sites.

In the next review period, two strategies will be pursued. These are:

- *icipe*, in partnership with Agri-Service Ethiopia, will conduct a two-year tsetse/trypanosomosis monitoring/control programme in Gelana Valley of Southern and Oromiya Regional States from January 2008 to 31 December 2009. The major activities of this joint programme are research on adaptive tsetse/trypanosomosis management and capacity building for strengthening of the government departments to sustain the intervention. Training of extension agents and target community members is one of the most important areas of this programme. More than 5890 animals are scheduled to be examined for trypanosomosis in the lifetime of the operation. In addition, control animals will also be selected for regular tryps monitoring every four months.
- About 50 mid-level professionals and 550 target farmers have been trained in adaptive tsetse/trypanosomosis management operations and are currently implementing the monitoring/control operation. As a continuation of this joint operation, both organisations are designing project proposals for the next five years in integrated tsetse and biofarming system. Similar projects are being planned for Benshangul Gumuz and Dewro Zone.

Participating Scientists: G. Tikubet, M. Girma and S. Ballo (*icipe*, Ethiopia)

Major Collaborators: *Universita degli Studi del Molise* and *Università Mediterranea di Reggio Calabria, Gallina (Italy)*

Main Donors: *Swiss Development Cooperation* and *Biovision Foundation (Switzerland)*

TICKS GROUP

TICKS RESEARCH PROGRAMME

Integrated Management of Ticks

General Background

Ticks and tick-borne diseases are responsible for severe economic losses in livestock throughout the world including in Central and eastern Africa. Acaricides have been effective in suppressing ticks' population and incidence of tick-borne diseases. However, the high costs relative to values of cattle and cattle products, development of tick resistance to acaricides, and environmental and food contamination by acaricides and their residues have prompted research for other alternatives. There is the need for an effective core technology around which several control techniques can be incorporated. Entomopathogenic fungi are being proposed as the core component of integrated vector pest management (IVPM) strategy to tackle the menace of ticks.

Progress Report and Outlook

A. Entomopathogenic Fungi: A Component of Integrated Tick Management

Bioprospecting for discovery of tick pathogens. Surveys were carried out in two localities (Kericho and Nguruman) in Kenya. Ticks were collected on grass and animals, and maintained in the laboratory until death. The cause of mortality was determined and the causal agent isolated and cultured. Soil samples were also collected. The samples were mixed with sterile distilled water and homogenised by vortexing. Aliquots were spread-plated on selective media in Petri dishes. The cultures were incubated for 3–7 days at 25 ± 2 °C. Colonies of the fungus that developed on selective media were transferred to Sabouraud dextrose agar media supplemented with 1% yeast extract (SDA + YE) to obtain pure cultures. A dozen fungal isolates have been isolated and identified as *Metarhizium anisopliae* var. *anisopliae* and *Beauveria bassiana* (Ascomycota: Hypocreales) and stored in *icipe's* Arthropod Germplasm Centre.

Strain selection. Fungal isolates obtained during surveys and the ones from the *icipe's* Arthropod Germplasm Centre were screened for virulence against adult *Rhipicephalus appendiculatus* in two steps. The first tier step consisted of dipping 10–20 ticks in 0.05% Triton X-100 conidial suspension titrated at 1.0×10^9 conidia/ml in one replicate. Ticks were transferred to glass tubes and maintained in an incubator at 26 ± 2 °C and 70–90% relative humidity. Mortality was recorded for 14 days. Fungal isolates that were highly pathogenic (causing mortality of over 60%) were subjected to the second step, whereby ticks were treated at three concentrations using a Burgerjon's spray tower (1956), which produces fine droplets. Ticks were then transferred to glass tubes and maintained in

an incubator as described above. However, mortality was checked daily for 14 days. Twenty ticks were used for treatment and the experiment was replicated four times.

In the next review period, two strategies will be pursued. These are:

- Screen isolated strains for their virulence.
- Screen isolated strains against *R. appendiculatus* and *A. variegatum*.

Participating Scientist: N. K. Maniania (*icipi*, Kenya)

Key Collaborator: CABI-Africa (Kenya)

Main Donor: BecaNet (hosted at ILRI, Kenya)

B. Improvement in Bioassay Methodology

Diverse modes of inoculation are used to perform bioassays with mitosporic entomopathogenic hyphomycetes fungi, including spraying conidia on the host organisms, exposing arthropods to treated leaves, dipping them into titrated conidial suspensions and treating the substrate. The usual mode of inoculation of ticks has so far been by dipping them into titrated conidial suspensions. This may not reflect the reality and can be misleading since ticks walk on their tarsi or pulvilli. In addition, dipping in conidial suspension can cause blockage of the spiracles of the host, resulting in high mortalities. We compared three different contamination methods using an isolate of *M. anisopliae* against nymph and adult *Rhipicephalus pulchellus*: (a) direct spray and maintaining them on the treated substrate, (b) direct spray and transferring them to untreated substrate, and (c) exposing them to fungus-treated substrate (contamination through treated substrate). Fungal suspension was sprayed using Burgerjon's spray tower in all the experiments. On the 14th day after treatment, there was no significant difference in mortality between the different methods of application used when nymphs were treated at a concentration of 10^7 conidia/ml. But the difference became obvious at higher concentrations. Nymphs that were sprayed and maintained on the treated substrate had the lowest LC_{50} value of 1.8×10^7 conidia. When adults were exposed to different modes of inoculation, hardly any mortality was observed at all the concentrations tested in the case where ticks were sprayed and later transferred to untreated substrate. Adults that were sprayed and maintained on the treated substrate had also the lowest LC_{50} value (3.3×10^9 conidia) compared to contamination through treated substrate (3.3×10^9 conidia). It can, therefore, be concluded that direct spraying and maintaining ticks on the treated substrate is the best method of contamination and is likely to reflect practical field situation where direct contact of ticks with inoculum and uptake of spores from vegetation is likely to contribute significantly to field suppression.

Participating Scientist: N. K. Maniania (*icipi*, Kenya)

C. Use of Semiochemical Bait to Enhance Exposure of *Amblyomma variegatum* to the Fungus *Metarhizium anisopliae*

Experiments were conducted to explore the use of a semiochemical baited-trap to enhance exposure of *A. variegatum* to different formulations of the entomopathogenic fungus *Metarhizium anisopliae*. Simultaneous release of 1-octen-3-ol and attraction-aggregation-attachment pheromone (AAAP) together with CO_2 from a trap in semi-field plots attracted up to 94% of adult ticks from a distance of 6 m, and up to 24% from 8 m. Formulations of *M. anisopliae* (dry powder, oil and emulsifiable concentrate) applied within the trap baited with AAAP, 1-octen-3-ol and CO_2 resulted in high levels of contamination of the ticks attracted to the traps. However, 48 hr after autoinoculation,

more conidia were lost in dry powder and least in oil emulsifiable concentrate. Samples of ticks attracted to the baited traps were transferred to plastic basins containing grass and maintained for 5 weeks. Emulsifiable formulation gave the highest relative tick reduction in rainy and dry seasons (54.7 and 46.5% in rainy and dry seasons, respectively), followed by oil formulation.

In the next review period, four strategies will be pursued. These are:

- Testing of the selected emulsifiable formulation in large field experiment at KARI-Muguga field station for two seasons.
- Studies to assess the attraction of *R. appendiculatus* and *R. pulchellus* to some plant extracts.
- Investigations on the attraction of *A. variegatum* nymphs, and adult *R. appendiculatus* and *R. pulchellus* to AAA pheromone.
- Search for alternative source of CO₂ as use of dry ice is not practical in field conditions. Fermenting fruits could be an option.

Participating Scientists: N. K. Maniania and A. Hassanali (*icipe*, Kenya)

Key Collaborators: University of Pretoria (South Africa)

Main Donors: DAAD (Germany), International Institutes Cooperation Programme (The Netherlands) and *icipe* (Kenya)

BEHAVIOURAL AND CHEMICAL ECOLOGY DEPARTMENT

Small-scale On-host Field Trials with Tick Repellent Essential Oils in Bungoma District, Western Kenya

General Background

The study evaluated the effects of *Tagetes minuta* and *Tithonia diversifolia* essential oils on *Rhipicephalus appendiculatus* infesting livestock in Bungoma District, western Kenya. *Rhipicephalus appendiculatus* transmits theileriosis and causes East Coast fever in tropical Africa. The two plants are among a group the local inhabitants have used to control livestock ticks for generations.

Progress Report and Outlook

A. Studies on the Potential of Essential Oil Formulation in Reducing Tick Burden and Associated Tick-borne Diseases

Forty-five animals naturally infested with ticks were randomly selected from 15 volunteer livestock farmers (3 animals from each farmer). Each animal was treated with about 1 g of Vaseline® formulation either of 10% *T. minuta* or *T. diversifolia* essential oil, or pure Vaseline on the inner side of the ear pinna, the preferred feeding site of the tick. The tick burden on each cattle was monitored for 18 days. Within 3 days, the tick burden on *T. minuta* essential oil-treated animal hosts significantly reduced by more than one half of the original burden, and by day 7, it had dropped by less than one-fifth. However, by day 10, tick re-infestation had started. Both male and female *R. appendiculatus* ticks were affected. There was a drop of tick burden up to day 8 in *T. diversifolia* essential oil-treated animal hosts but this drop was less significant compared with that caused by *T.*

minuta oil. Interestingly, both *T. minuta* and *T. diversifolia* essential oils affected several other but less dominant economically important tick species such as *Amblyomma variegatum* and *R. evertsi evertsi*, even though these tick species have different preferred feeding sites. The results suggest the potential for appropriate essential oil formulation in reducing tick burden and associated tick-borne diseases among the resource-limited livestock farming community in tropical Africa.

In the next review period, two strategies will be pursued. These are:

- Identification of the tick repellent blends from *Tagetes minuta* and *Tithonia diversifolia*.
- Development of a simple sustainable technology for on-farm management of ticks and the diseases they cause.

Participating Scientist: A. Hassanali (icipe, Kenya)

Key Collaborators: University of Nairobi (Kenya) and Wageningen University and Research Centre (The Netherlands)

Main Donors: International Foundation for Science (Sweden) and DGIS (The Netherlands)

PARTICIPATING STUDENTS

PhD:

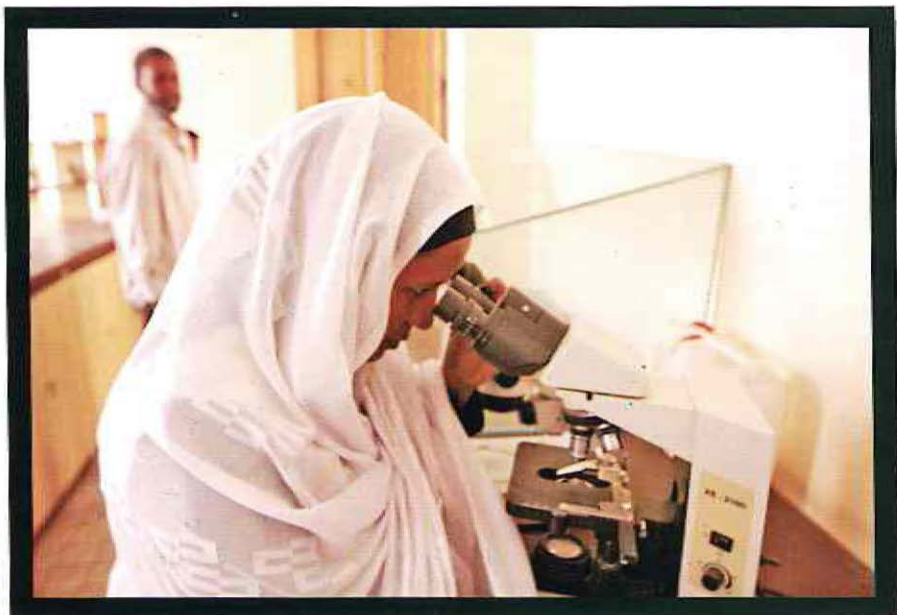
S. Ohaga, F. Nchu, W. Wanzala, P. Nana and S. Nyanjom

MSc:

E. O. Ouna, R. Rotich and B. Obonyo

OUTPUT

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CAPACITY BUILDING AND INSTITUTIONAL DEVELOPMENT PROGRAMME

Overview

Capacity strengthening activities are essential in equipping the African communities that *icipe* works with, with the necessary know-how to uplift themselves out of poverty and unlock the continent's potential for development. It is for this reason that *icipe* takes a two-pronged approach in its Capacity Building and Institutional Development (CB&ID) Programme, strategically targeted to capacity strengthening through research training and institutional building, and knowledge sharing with the Information Resources Centre (IRC).

The major objective of *icipe's* capacity building and institutional development programme is to build human resource capacity in insect science and related areas of the biosciences that is well trained, highly motivated and able to respond to the arthropod-related development needs of its African constituency. Over the years, *icipe* has developed training programmes that target every need, be it at the farmer-level, technical and extension worker level, to the postgraduate degree level and beyond. The training programmes are designed on a multidisciplinary framework for integrated development that is expected to in turn generate the much-needed additional capacity for Africa's development. In all levels, training focuses on knowledge application, skills strengthening, and attitudes and mindsets changing. To achieve wider and rapid dissemination of the technologies developed at the Centre, training of extension staff in the national systems is carried out in collaboration with the national institutions closely working with the beneficiary communities.

Working collaboratively with other institutions, the programme is structured along these major thrusts:

- Training at the postgraduate level to build capacity, i.e. leadership in scientific research and policy formulation, mainly through the African Regional Postgraduate Programme in Insect Science (ARPPIS) as well as the Dissertation Research Internship Programme (DRIP).
- Technology dissemination to NRES through International Group Training Courses mainly targeted at building capacity of practitioners in the national agricultural and health research and extension systems.
- Professional development schemes, where postdoctoral fellows, research associates and visiting scientists come to *icipe* to conduct research and share expertise.
- Interactive on-site training in participation with the beneficiary communities.
- Fostering Africa-wide cooperation and networking to build up on the continental presence of *icipe*'s R&D work through various networks such as the African Association of Insect Scientists (AAIS), ARPPIS Scholars Association (ASA) and the universities within the ARPPIS network.
- Institutional strengthening by nurturing and strengthening select strategic African organisations and institutions.

The strategic directions shown herein were discussed and endorsed by the external review team evaluating *icipe*'s programmatic work in 2007.

CAPACITY STRENGTHENING THROUGH RESEARCH TRAINING

Research Training through the African Regional Postgraduate Programme in Insect Science

General Background

Since its establishment in 1983, ARPPIS has continued to grow as a collaborative programme between *icipe* and partner universities in Africa, to train arthropod scientists and pest management specialists. As at end of 2007, the network had grown to 34 universities. ARPPIS continues to offer training programmes of two types: a three-year doctoral fellowship scheme offered at *icipe* and a sub-regional master's programme based at universities within three sub-regions of Africa (Western Africa: Ghana; Eastern Africa: Addis Ababa and Southern Africa: Zimbabwe).



Student studying insect behaviour in a Y-tube olfactometer

Progress Report and Outlook

A. Postgraduate Programmes

During the reporting period, 12 PhD fellowships were awarded through ARPPIS to successful students selected through an Africa-wide competitive process and 13 MSc fellowships were awarded to successful applicants from the sub-regions to undertake a two-year master's programme

at the ARPPIS MSc sub-regional centres. ARPPIS also successfully graduated a total of 10 PhD and 5 MSc scholars, respectively.

B. The 33rd Meeting of the African Regional Postgraduate Programme in Insect Science Academic Board (AAB)

The 33rd Meeting of the ARPPIS Academic Board (AAB) was held in early October 2007, at the Centre for African Wetlands (CAW), University of Ghana, Legon. The overarching theme of the meeting was "Building Institutional Partnerships for Enhanced Research and Training in Africa". The meeting comprised of 22 representatives of the ARPPIS participating universities and was hosted by Professor C. N. B. Tagoe, the Vice-Chancellor of the University of Ghana at Legon.

In preparation for the meeting, a sub-committee commissioned by the Board held a planning and consultative meeting in February 2007 to discuss various issues regarding the future of ARPPIS. This meeting was held at *icipe's* Duduville headquarters in Nairobi. The meeting proposed a number of strategic actions for the sustainability of the network. These recommendations were presented and adopted. As a follow-up, the AAB university representatives were mandated to discuss the recommendations with their respective Vice Chancellors. The meeting proposed the creation of the Council of Vice Chancellors (CVC), which would review the recommendations and take responsibility for identifying key concerns as far as the universities were concerned. The CVC would also take the responsibility for developing policy guidelines on how ARPPIS Sub-regional Centres would operate within their respective host universities; either as programmes or centres. Discussions with the Association of African Universities (AAU) would be held to facilitate the meeting of the CVC.

During the Accra meeting, three new university members were admitted into ARPPIS bringing the number of participating universities to 34. The new university members enrolled were:

- University of Dar es Salaam (Tanzania)
- University of Mauritius (Mauritius)
- University of Lome (Togo).

C. Introductory Courses for Postgraduate Scholars

A series of short introductory courses aimed at informing the new ARPPIS scholars on advances and new frontiers of knowledge were organised in 2006. Due to delays in having all the new research fellows in *icipe* by end of 2007, courses scheduled for that year were postponed until 2008. The courses, delivered through lectures, practical lessons and seminars are designed to stimulate interest and group discussion.

In the next review period, one main strategy will be pursued. This is:

- Collaborative training through ARPPIS with the Centre providing research facilities and supervision expertise for the student research project for the MSc and the PhD degrees. The ARPPIS Network will be the major partnership framework for undertaking this training. From an organisational development standpoint, and within the limitations of resource availability, the partners in the ARPPIS Network (*icipe* and the universities) will work jointly to implement a number of measures towards cost-effectiveness and sustainability.

Research Training through the Dissertation Research Internship Programme

General Background

The Dissertation Research Internship Programme (DRIP) provides support to MSc and PhD scholars undertaking studies in insect science through providing opportunities for research internship at the institution. The DRIP programme facilitates and enhances *icipe's* collaboration with universities and other centres of excellence in both developed and developing countries. The broad objectives of DRIP are to:

- Contribute towards human resource development for research in tropical insect science, by enabling university scholars to conduct thesis research at *icipe* as part of the requirements for the PhD or MSc degrees of their registering universities in Africa and overseas;
- Facilitate and enhance *icipe's* collaboration with universities and other centres of excellence in developed and developing countries, for interactive technology development and exchange; and
- Enhance the capacity and productivity of African universities by availing to them advanced research facilities and resources for collaborative research and training.

Progress Report and Outlook

A. Postgraduate Programmes

Through support of donors who are funding various research projects at *icipe*, 17 PhD and 23 MSc scholars undertook research training at *icipe* while registered in different universities.

In the next review period, one main strategy will be pursued. This is:

- Expanding training opportunities through DRIP where bona fide university registered scholars undertaking training at MSc or PhD level from universities throughout the world shall access *icipe's* research facilities and benefit from world class supervision and expertise. While maintaining flexibility, there is a need to streamline and align more closely the expertise resident in *icipe's* programmes and projects to the needs of the partnering universities. There is also need to implement a realistic bench fee arrangement that will enable scholars to contribute to the costs of training (e.g. laboratory upkeep and costs of supervision).

INTERNATIONAL GROUP TRAINING COURSES

General Background

icipe sponsors and hosts various group training courses and workshops intended for technologists and practitioners from national programmes. Group Training Courses aim to disseminate integrated pest and vector management (IPVM) technologies to communities on the ground by educating extension personnel and end users of the available technologies. 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.

Progress Report and Outlook

A. Group Training Course on Commercial Insects

An International Group Training Course on Conservation and Utilization of Commercial Insects in Africa was hosted in December 2006 and attracted 34 participants from 20 countries. The CB&ID programme provided support for the training, which was co-sponsored by the International Fund for Agricultural Development (IFAD) and UNDP's Global Environment Facility (UNDP-GEF). The International Group Training Course was arranged in such a way as to provide a valuable opportunity for representatives of IFAD projects, governments, non-governmental organisations (NGOs) and the private sector, to interact and share experiences to gain skills on the management of commercial insects.

B. Community Training Courses

During the reporting period, 14 other training courses were held for rural and urban poor communities in Africa, to strengthen their capability in undertaking food and health security related issues. Various divisions within the Centre held these training courses.

In the next review period, one main strategy will be pursued. This is:

- Redesigning and expanding the group training courses as they tend to focus more on the adoption of a technology or scientific approach. While this is

important, there is an increasing need to redefine the course curriculum in a more holistic way, especially in the context of development (improved livelihoods for the rural poor, poverty alleviation, food security and so forth). In this category of training it is not sufficient to invest only on managing technical change. There is need to empower communities to continuously innovate within the dynamic environment they live in. There is further need to develop training courses targeting topical issues and concerns, such as climate change, biodiversity conservation, ecosystem services, and management of invasive species. It is considered that *icipe* will capture an important niche if it can provide training in these areas.



Participatory training of women vegetable growers in Tanzania

PROFESSIONAL DEVELOPMENT: THE POSTDOCTORAL RESEARCH FELLOWSHIP SCHEME

General Background

The postdoctoral research fellowship scheme is for doctoral graduates who have worked for at least three years after graduation in their national institutions. It is aimed

at refreshing young scientists' skills and offering them an opportunity to develop collaborative research programmes in areas of mutual interest between *icipe* and the national institutions.

Progress Report and Outlook

A. Postdoctoral Research Fellows

During the reporting period, a total of 5 Postdoctoral Research Fellows were enrolled into *icipe*:

- Dr Hortance Manda (Cameroon) Human Health Division
- Dr Subramanian Sevgan (India) Plant Health Division
- Dr David M. Amudavi (Kenya) Plant Health Division
- Dr Adenirin Chabi-Olaye (Benin) Plant Health Division
- Dr Maurice V. O. Omolo (Kenya) Behavioural and Chemical Ecology Department.

In the next review period, one main strategy will be pursued. This is:

- Investing in institutional strengthening, through training of staff from partner and collaborating institutions, so that developing countries can build capacity to undertake ground breaking and relevant research themselves and sustain the development process required to uplift communities out of poverty and unlock the potential for development.

CO-OPERATION AND NETWORKING

General Background

Fostering continental cooperation and networking is important as it enhances interaction among the various stakeholders that the programme is involved with, and provides forums for intellectual engagement, feedback and for priority setting. The major mechanisms that have been utilised for fostering this engagement include consultations with African universities at the ARPPIS Academic Board (AAB) level, interaction with the ARPPIS alumni, and attending continental meetings of the African Association of Insect Scientists (AAIS).

Progress Report and Outlook

A. Staff Development for Universities Participating in ARPPIS

In September 2006, a member of staff of the University of Cape Coast, Ghana benefited from this arrangement. Mr Eric Anim Frimpong started his PhD thesis research on the topic 'Landscape Management of Wild Pollination Services in Cocoa Production Systems in Ghana', under the supervision of Dr Ian Gordon, Head of the Environmental Health Division at *icipe* and Dr Peter Kwapong, Senior Lecturer, Department of Biological Sciences, University of Cape Coast, Ghana.

In the next review period, one main strategy will be pursued. This is:

- Expanding the scientific exchange visits programme especially with universities from other regions of the world. This will be done through development of formal

linkages with selected universities and negotiating on the logistics of mounting such as a programme.

INSTITUTIONAL STRENGTHENING

General Background

Strengthening the capacity of the university partners is an important activity aimed at enabling them to undertake the mission of ARPPIS more efficiently. The AAB recommended for the revitalisation of the ARPPIS training programme. Efforts need to be made to utilise research facilities available at the partner universities, especially through undertaking collaborative research projects and further building on, and enhancing the collaborations already in place.

Progress Report and Outlook

A. Information Access for the ARPPIS Universities

During the period under review, *icipe* prepared and submitted a proposal on behalf of network partners to UNESCO, to fund ARPPIS universities to access copies of scientific journals. Funding was granted for 7 ARPPIS universities to access online and print copies of the *International Journal of Tropical Insect Science*. These ARPPIS member universities are Makerere University (Uganda), National University of Rwanda (Rwanda), Sokoine University of Agriculture and Technology (Tanzania), University of Ibadan (Nigeria), University of Malawi (Malawi), University of Nairobi (Kenya) and University of Namibia (Namibia).

In the next review period, one main strategy will be pursued.

- In developing a forward perspective for *icipe's* capacity strengthening activities, there is need to focus on enhancing the complementarities between formal and informal training. As a future strategy, more emphasis will now be made on need- and opportunity-based training, putting acquired skills and experience before formal training. In this regard, there is need to design and develop programmes that will strengthen weak linkages from both a value chain perspective as well as from an innovation systems approach. In general, it is strategically important to see more of *icipe's* programmes and projects emphasising assistance to other training institutions through training of trainers (ToT) and working with qualified institutions and NGOs in undertaking the training function, especially at the beneficiary level.

ENHANCING SCIENTIFIC EXCHANGE AND KNOWLEDGE SHARING THROUGH *icipe's* INFORMATION RESOURCE CENTRE

The Information Resource Centre

General Background

The Information Resource Centre (IRC) is a research and training library hosting specialised reference materials in the areas of insect ecology/physiology/biology and areas related

to problems of crops, livestock and man, particularly in the tropics. Though, principally serving the information needs of postgraduate scholars and research scientists, the IRC also acts as an info-hub for *icipe's* partners and collaborators, especially for the 34 African universities collaborating in ARPPIS.

Progress Report and Outlook

A. Acquisitions

During the period under review, books and journals supporting the Centre's research programmes increased, with the acquisition of 700 new titles, comprising 25 entomology journals accessed in electronic databases and 15 titles received in print format. As an Associate Member of the International Association for the Plant Protection Sciences (IAPPS), the IRC received print and electronic editions of *Crop Protection*, the Official Journal of the IAPPS. Several partners access this journal, including the three ARPPIS MSc Sub-regional centres, the Faculty of Agronomy at Eduardo Mondlane University in Mozambique, the Biological Control Programme in Kibaha Tanzania, and the Kenya Agricultural Research Institute (KARI) Biotechnology Centre. The IRC also gained access to new electronic databases, including those by Beech Tree Publications, The Cochrane Library, Journal Storage (JSTOR), Organisation for Economic Co-operation and Development (OECD), the Royal Society of Chemistry, University of California, University of Chicago Press (Chicago Journals Online) and UNEP's initiative Online Access to Research in the Environment (OARE) that are now accessible to users.

In the next review period, one main strategy will be pursued. This is:

- Establishment of strong linkages as an active member of the Kenya Libraries and Information Services Consortium (KLISC) which works to address shared collection management, information sharing and staff development of the librarians. The

consortium members are currently sharing online databases through the Pharmaceutical Education and Research Institute (PERI) project, and there is unlimited potential for joint information access activities and partnerships, which will create synergy and efficiency for all the concerned stakeholders.

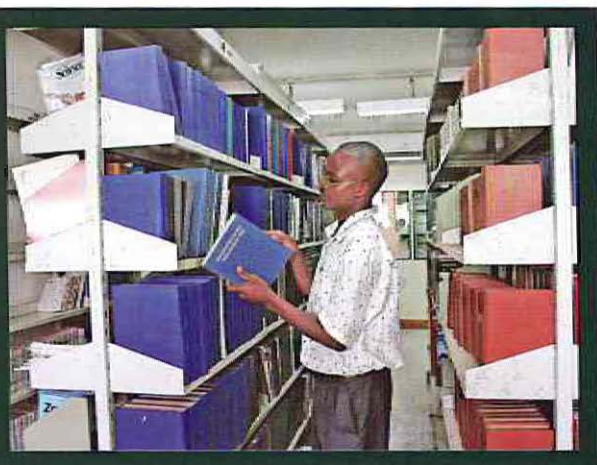
B. IRC's General Access Laboratory

To enhance services and encourage more research trainees to access internet-based information, the IRC rolled out a general access

laboratory, offering 8 computer stations intended to backstop research-related information acquisition and e-mail. This has enhanced easy access of electronic articles.

In the next review period, one main strategy will be pursued. This is:

- Post Online Public Access Catalogue (OPAC) and content on the web to help keep up with technology and stay current in the next two years.



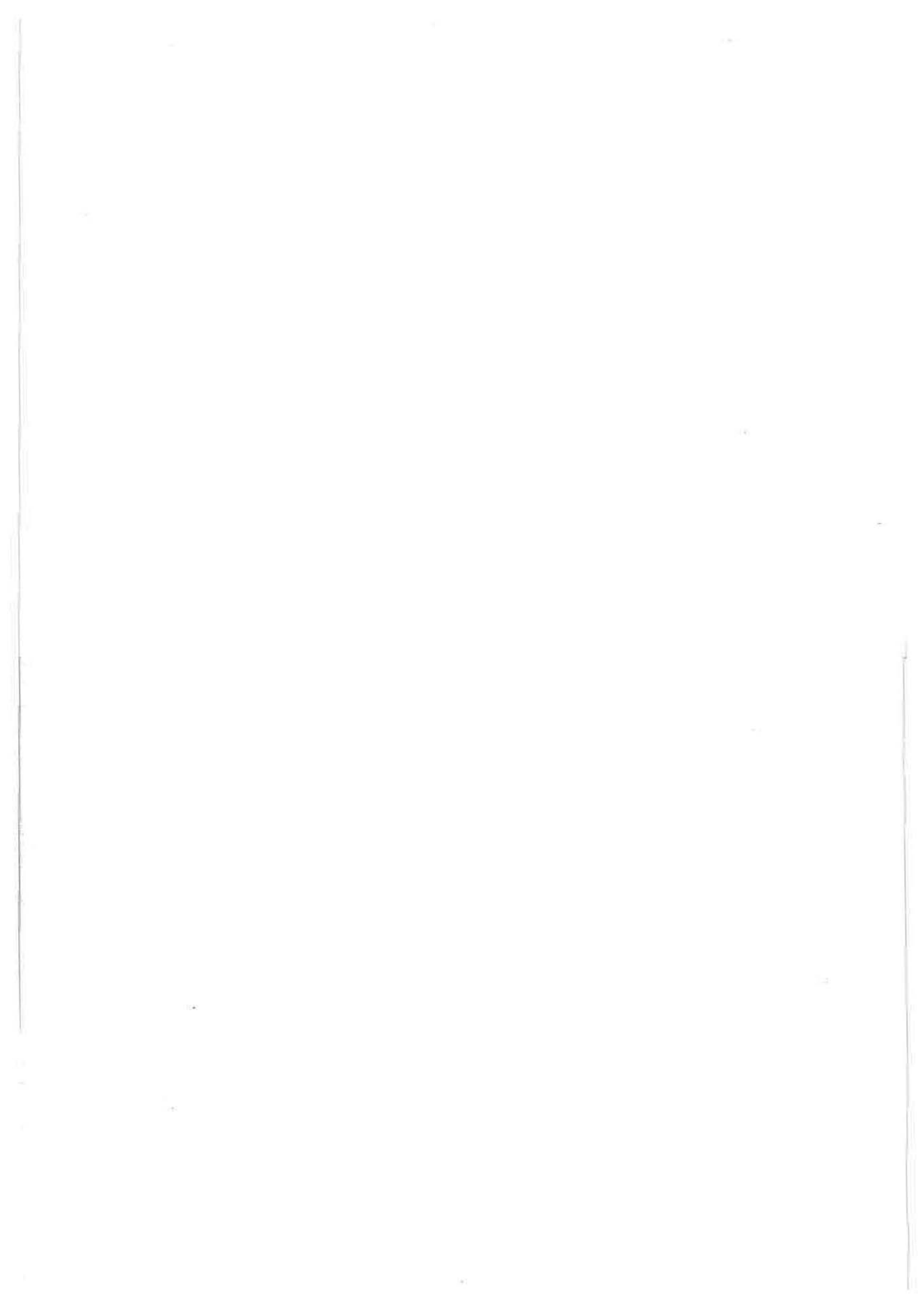
The icipe Information Resource Centre

Participating Scientist: J. P. R. Ochieng'-Odero (*icipe*, Kenya)

Key Collaborators: The 34 partner African universities in ARPPIS

Main Donors for ARPPIS: German Academic Exchange Service (Germany) and International Institutes Cooperation Programme (The Netherlands)

Main Donors for DRIP: African Development Bank (Côte d'Ivoire), Federal Ministry for Economic Cooperation and Development and Deutsche Gesellschaft für Technische Zusammenarbeit (Germany), International Fund for Agricultural Development and Third World Organization for Women in Science (Italy), Institut de recherche pour le développement (France), National Institutes of Health (USA), World Health Organization, Swiss Agency for Development and World Federation of Scientists (Switzerland), and CGIAR Systemwide Initiative on Malaria and Agriculture



ACRONYMS AND ABBREVIATIONS

- AAAP** attraction–aggregation–attachment pheromone
AAB ARPPIS Academic Board
AAIS African Association of Insect Sciences
AAT animal African trypanosomosis
AITT African Insect Taxonomy Toolkit
ADB African Development Bank
AFFI African Fruit Fly Initiative
AGRHYMET Centre Regional de Formation et d'Application en Agrométéorologie
Hydrologie Opérationnelle
AMSD Agricultural Marketing Systems Development Programme
ARPPIS African Regional Postgraduate Programme in Insect Science
ASA ARPPIS Scholars' Association
ASAL arid and semi arid lands
ASF Arabuko-Sokoke Forest
AVRDC The World Vegetable Center
BC biological control
BMZ Bundesministerium für Wirtschaftliche Zusammenarbeit [Federal
Ministry of Economic Cooperation and Development]
Bs *Bacillus sphaericus*
BSMDP Business Services Market Development Project
Bt *Bacillus thuringiensis*
Bti *Bacillus thuringiensis israelensis*
CABI Commonwealth Agricultural Bureaux International
CBO community based organisation
CEPF Critical Ecosystem Partnership Fund (of Conservation International, CI)
CABESI Camels, Bees and Silk project
CIG common interest group
CU Cambridge University
DAAD German Academic Exchange Service
DBM diamondback moth
DED Deutscher Entwicklungsdienst (The German Development Service)
DFID Department for International Development
DGIS Directorate General for International Cooperation
DRIP Dissertation Research Internship Programme
EACF East African Coastal Forest Mosaic
EAWLS East African Wildlife Society
EU-INCO international scientific cooperation section of the European Commission
Research Framework Programmes
EurepGAP European Retailers Programme on Good Agricultural Practices
FAO Food and Agriculture Organization of the United Nations
FFS Farmers' Field School
FOFIFA Le Centre National de la Recherche Appliquée au Développement Rural
(Malagasy Research Centre)
FTOC fair trade and organic certification
GAP good agricultural practices
GBIF Global Biodiversity Information Facility
GEF Global Environment Facility
GFTAM Global Fund Tuberculosis, Aids & Malaria
GIS geographic information system
GMC genetically modified crops
GPS global positioning system
GTZ Gesellschaft für Technische Zusammenarbeit
HACCP hazard analysis critical control point
HAT human African trypanosomosis
HM habitat management

- HMF** hydroxymethylfurfural
- HORDI** Horticultural Crops Research and Development Institute
- IAEA** International Atomic Energy Agency
- IAPPS** International Association for the Plant Protection Sciences
- IARC** international agricultural research centre
- ICRAF** World Agroforestry Centre
- ICS** internal control system
- ICT** information communication technology
- IDB** Islamic Development Bank
- IFAD** International Fund for Agricultural Development
- IFS** International Foundation for Science
- IGA** income generating activity
- IITA** International Institute of Tropical Agriculture
- ILRI** International Livestock Research Institute
- IMO** Institute of Marketology
- INERA** Institut de l'environnement et des recherches agricoles
- IPM** integrated pest management
- IPVM** integrated pest and vector management
- IRAD** Institut de recherche agricole pour le développement
- IRD** Institut de recherche pour le développement
- IRS** indoor residual spraying
- ISAR** Institut des Sciences Agronomiques du Rwanda
- ITN** insecticide-treated net
- IVM** integrated vector management
- IVPM** integrated vector and pest management
- JKUAT** Jomo Kenyatta University of Agriculture and Technology
- JSTOR** Journal Storage
- KARI** Kenya Agricultural Research Institute
- KCA** Kenya Camel Association
- KEFRI** Kenya Forestry Research Institute
- KEMRI** Kenya Medical Research Institute
- KEPHIS** Kenya Plant Health Inspectorate Service
- KLISC** Kenya Libraries and Information Services Consortium
- KOAN** Kenya Organic Agriculture Network
- KSTCIE** Kenya Standing Committee on Imports and Exports
- KWS** Kenya Wildlife Service
- LMF** leafminer flies
- LLN** long lasting insecticide-treated net
- MoA** Ministry of Agriculture
- MoH** Ministry of Health
- MSW** mango seed weevil
- NALEP** National Agriculture and Livestock Extension Programme
- NARO** National Agricultural Research Organisation
- NEMA** National Environmental Management Authority
- NENA** Near East and North Africa region
- NGO** non-governmental organisation
- NIH** National Institutes of Health
- NRES** national research extension and education systems
- OARE** Online Access to Research in the Environment
- OECD** Organisation for Economic Co-operation and Development
- OFID** OPEC Fund for International Development
- OPAC** Online Public Access Catalogue
- OPEC** Organisation of the Petroleum Exporting Countries
- PAN** phenylacetone nitrile
- PATTEC** Pan African Tsetse and Trypanosomosis Eradication Campaign
- PERI** Pharmaceutical Education and Research Institute
- PPRR** Le Programme de Promotion des Revenus Ruraux
- PUMMA** Malindi Mosquito and Malaria Control Association

R&D	research and development
REDD	Reduced Emissions from Deforestation and Degradation
SANBI	South African National Bioinformatics Institute
SDC	Swiss Agency for Development Cooperation
SHB	small hive beetle
SIMA	Systemwide Initiative on Malaria and Agriculture
TFCG	Tanzania Forest Conservation Group
ToT	training of trainers
TWOWS	Third World Organization for Women in Science
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children's Fund
USAID/BBI	United States Agency for International Development/ Biotechnology and Biodiversity Interface (BBI) Competitive Grant Program
USDA-ARS	United States Department of Agriculture-Agricultural Research Station
WFS	World Federation of Scientists
WHO/AFRO	World Health Organization/Regional Office for Africa
WHO/TDR	World Health Organization/Special Programme for Research and Training in Tropical Diseases Research
WWF/EARPO	World Wide Fund for Nature/ Eastern Africa Regional Programme Office



CORRIGENDUM

'Community-based Malaria Control in Urban and Rural Malindi, Kenya Coast' project report

We wish to apologise for the omission on page 9, line 37, of a main donor of the malaria project in Malindi (Biovision Foundation).

This list should read:

Main Donors: *Biovision Foundation (Switzerland) and Global Fund to Fight AIDS, Tuberculosis and Malaria, and KEMRI and icipe (Kenya)*



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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