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LA RECHERCHE AGRONOMIQUE POUR LE DÉVELOPPEMENT

WORKSHOP

« Towards a multi-scale approach for improving pest management »

Amphi Jacques Alliot

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Bienvenue à Montpellier !

Background

Pest management strategies dealing with agricultural, veterinary and medical issues use various methods to better understand the dynamics of insect populations from the habitat to the landscape and region. Remote sensing, GIS, sampling, and biogeochemical and molecular markers, together with spatially-explicit models are unique tools to decipher biological and ecological processes that govern the spatio-temporal distribution of insects. Knowledge of these multi-scale and multi-factors processes is useful to evaluate the impact of different scenarios on the dynamics of insect populations, and to propose tools for risk assessment, detection and monitoring, and sustainable management, as part of an overall strategy known as area-wide integrated pest management (AWIPM).

Objective

This workshop will bring together insect scientists, ecologists, geneticist, modelers, and remote sensing specialists from various research institutions, to discuss common issues in the spatially-explicit dynamics of insect populations. Our hope is that researchers can benefit from insights to develop new strategies based on spatial ecology.

Scientific sessions

Session 1 System management for sustainable insect pest control: from local to regional approaches

Session 2 Methods for tracking movement and dispersal of insect pest individuals and populations

Session 3 Sampling methods, Remote Sensing and GIS: applications to insect ecology and management

Session 4 Simulation models for unraveling spatial patterns of insect pest populations

Invited speakers

- Nancy Schellhorn, CSIRO Ecosystem Sciences, Brisbane, QLD, Australia
- Marc Vreysen, Entomology Unit, FAO/AIEA, Seibersdorf, Austria
- Fabrice Vinatier, INRA, UMR 211, Paris-Grignon, France
- Philippe Solano, UMR177, IRD, Bobo Dioulasso, Burkina Faso
- Yves Carrière, Department of Entomology, University of Arizona, Tucson, AZ, USA
- Annie Ouin, Université de Toulouse, UMR DYNAFOR, Castanet Tolosan, France
- Felix Bianchi, Univ Wageningen, Wageningen, The Netherlands
- Steven L. Peck, Dpt of Biology, University of Brigham Young, Provo, UT, USA

CIRAD organising team

Jérémy Bouyer UMR 15 « Contrôles des maladies animales exotiques et émergentes »
Thierry Brévault UPR 102 « Systèmes de cultures annuels »

Session 1 System management for sustainable insect pest control: from local to regional approaches (Chair: Jérémy Bouyer, CIRAD, UMR 15)

01- Landscape scale pest management: Approaches for understanding habitat function
Nancy Schellhorn (CSIRO, Brisbane, Australia)

02- Principles and recent applications of AW-IPM with a SIT component
Marc Vreysen (IAEA, Vienna, Austria)

03- Optimizing Pest Insect Monitoring in viticulture
Maarten Van Helden (ISVV/ENITA, Bordeaux)

04- Management strategies of noxious mosquito species on the French Mediterranean coast
Dominique Gindre (EID Méditerranée, Montpellier)

05- Spatial ecology of *Dermolepida albohirtum*, a major pest of sugarcane in Queensland: importance of a landscape approach
François-Régis Goebel (CIRAD UPR 102/BSES, Brisbane, Australia)

06- Combination of field margin manipulation and genetic resistance to limit *Aphis gossypii* outbreaks and virus epidemics in melon crops
Alexandra Schoeny (INRA, UR 407, Avignon)

Session 2 Methods for tracking movement and dispersal of insect pest individuals and populations (Chair: Régis Goebel, CIRAD, UPR 102)

07- Factors and mechanisms affecting spatial heterogeneity of insect populations
Fabrice Vinatier (INRA, UMR 211, Paris-Grignon)

08- Use of population genetics to choose between vector control strategies: the example of tsetse in West-Africa
Philippe Solano (IRD UMR177/ CIRDES, Bobo-Dioulasso, Burkina Faso)

09- 'Cosmodrome': an experimental design to study movements of the banana weevil, *Cosmopolites sordidus*, using RFID
Dominique Carval (CIRAD, UPR 26, Le Lamentin, Martinique)

10- Genetic inferences about the population dynamics of codling moth females at a local scale
Pierre Franck (INRA, UR PSH, Avignon)

11- Population genomics to detect local adaptation: application to Bti resistance monitoring in mosquitoes at a regional scale.
Laurence Després (Université J. Fourier, UMR CNRS 5553 LECA, Grenoble)

12- Can Deuterium stable isotopes be used to infer geographical origins of an auxiliary hoverfly and a pest moth?
Lucie Raymond (ENSAT, UMR Dynafor, Toulouse)

Session 3 Sampling methods, Remote Sensing and GIS: applications to insect ecology and management (Chair:Valérie Soti, CIRAD, UPR 102)

13- Predictive metapopulation ecology for improving insect pest management
Yves Carrière (University of Arizona, Tucson, USA)

14- Learnings, tools and pitfalls of agroecology at landscape scale. Lessons from projects in DYNAFOR Lab
Annie Ouin (ENSAT, UMR Dynafor, Toulouse)

15- Remote sensing for spatial ecology
Agnès Bégué (CIRAD, UMR Tétis, Montpellier)

16- Use of remote sensing to determine target populations of glossines in Senegal
Jérémy Bouyer (CIRAD UMR 15/ISRA, Dakar, Sénégal)

17- Landscape characterization of Rift Valley Fever risk areas using very high spatial resolution imagery – case study in the Ferlo area, Senegal
Valérie Soti (CIRAD, UPR 102, Montpellier)

18- Coupling long-term prospection data and remote-sensing vegetation index to help in the preventative control of desert Locust
Cyril Piou (CIRAD, UPR 106, Montpellier)

19- Inventory of mosquitoes in Mayotte, French Departement in the Indian Ocean
Vincent Robert (IRD, MIVEGEC, Montpellier)

Session 4 Simulation models for unraveling spatial patterns of insect pest populations (Chair: Thomas Balenghien, CIRAD, UMR 15)

20- Landscape scale pest management: what can we learn from models?
Felix Bianchi (Wageningen Agricultural University, The Netherlands)

21- Use of the metapopulation theory and individual-based models to improve pest control
Steven L. Peck (University Brigham Young, Provo, USA)

22- Development of a mathematical model for tsetse population dynamic to optimize the control in the Niayes (Senegal)
Abdoul Aziz Fall (CIRAD, UMR 15, Montpellier)

23- Mosaic-Pest: a spatially explicit model for landscape management of pests
Fabrice Vinatier (INRA, UMR 211, Paris-Grignon)

24- Agent-based models for an interdisciplinary approach of pest management (the potato tuber moth in Ecuador)
François Rebaudo (IRD, UR 072 BEI, Gif-sur-Yvette)

25- Ocelet modelling language and simulation tool: possible applications in pest management?
Danny Lo Seen (CIRAD, UMR Tétis, Montpellier)

26- Individual based model to assess spatio-temporal distribution of *Helicoverpa zea* at the field scale
Isabelle Grechi (CIRAD, UPR 103, Montpellier)

01-Landscape scale pest management: Approaches for understanding habitat function

Nancy A. Schellhorn[1] and Alejandro C. Costamagna[1,2]
[1]CSIRO Ecosystem Sciences, Brisbane, QLD, Australia; [2]Department of Entomology, University of Manitoba, Winnipeg, Canada - E-mail: Nancy.Schellhorn@csiro.au

While IPM has traditionally focused on the field scale, two observations have triggered interest in developing IPM at larger spatial scales. First, mobile pests do not recognize field or farm boundaries. Second, some landscapes appear less prone to invertebrate pest infestations than others, suggesting that there are features that may be managed to create more pest suppressive landscapes. Landscape complexity has been shown to increase the ecosystem service of pest suppression, although the mechanisms responsible remain elusive. Using a range of approaches including survey, large-scale experimentation and GIS from two production systems, cotton-grain in the Darling Downs, and vegetables in the Lockyer Valley, QLD, we'll explore the link between surrounding habitats, pest and beneficial insect dynamics and pest suppression. In the cotton/ grain systems, we show that natural enemies (as well as some pest species) use native vegetation as reproduction habitat, move between native vegetation and crops, and colonize crops. We also show that some pest species are more strongly suppressed by natural enemies in crops near native vegetation than further away, and that native plants have higher predator : pest ratios compared to crops. In the vegetable system, we tested the effect of earliness of predator impacts on the suppression of pests in 19 vegetable landscapes that differ in landscape complexity. We found that predators have a significant impact on pests, but only some landscapes contributed predators early. Most of the variation in pest suppression was explained by the amount of Lucerne (alfalfa) around the focal fields up to 2 km. Lucerne was shown to be good habitat for predators, but high predator numbers explained most of the variation in high pest numbers in focal fields. This paradox demonstrates the challenge of managing for pests and pest control services at multiple spatial scales. We'll conclude by showing how these findings can contribute to guidelines for IPM at the field, farm and landscape scale.

02-Principles and recent applications of Area-Wide-IPM with an SIT component

Marc J.B. Vreysen
Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Insect Pest Control Laboratory, Vienna, Austria - E-mail: M.Vreysen@iaea.org

E.F. Knipling, on the occasion of receiving the World Food Prize in 1992, stated that "major advances in coping with most of the major arthropod pest problems will require a change in the tactics and the strategies to manage those pests. They must change for the currently used limited scale, reactive, broad-spectrum measures to preventive approaches that are target specific and applied on an area-wide basis". Since then, practices to manage these pests have hardly changed and pesticide use is still on the rise every year to the detriment of the environment, human health and the ecosystem. The need for more target specific, sustainable, environmentally-friendly and cost-effective control tactics and pest management strategies remains to date more pertinent than ever.

Integrated pest management (IPM) aims at the careful integration of several control tactics which are the most opportune for the particular ecosystem, while safeguarding human health and the environment. It has remained the dominant paradigm of pest control over the last half century. IPM can be applied on a field-by-field basis (localised IPM), or against an entire pest population within a delimited geographic area (area-wide (AW-IPM). AW-IPM seeks to treat all habitats, also those that are of no economic interest to the farmer, so that none produces migrants to re-establish significant infestations in areas of concern. This is in contrast to the field-by-field approach that focuses narrowly on defending the valued entity (crop, livestock, people, building, etc.). In most cases, AW-IPM leads to more effective and sustainable management of the insect pest.

The sterile insect technique (SIT) is a species-specific autocidal control tactic that interferes with the reproductive potential of the target insect pest. It is a very powerful tool that is most effective when insect populations are low and when applied on an area-wide basis. The SIT within an AW-IPM context can be applied for the suppression, eradication, containment or prevention of insect pest populations. There are numerous AW-IPM programmes where the SIT has been used successfully, especially against dipteran and lepidopteran pests, and examples will be given to illustrate this. On economic, environmental and biological grounds, the case for SIT is compelling.

03-Optimizing Pest Insect Monitoring in viticulture

Maarten van Helden[1], Séverine Mary[2], Antoine Verpy[2], Frédéric Gil[2], and Virgil Fievet[3]
[1]ENITA de Bordeaux, ISVV, Vitinnov, Gradignan ; [2]GDON du Libournais, Saint Emilion ; [3]Univ. de Bordeaux 1, UMR 1202 Biogeco Bordeaux
Email: m-vanhelden@enitab.fr

Pest insect monitoring in French viticulture focuses on leafrollers (*Lobesia botrana, Eupoecilia ambiguella*) and leafhoppers (*Empoasca vitis, Scaphoideus titanus*) showing 1 to 4 generations annually. Monitoring of these insects through adult trapping, eggs and larval counts should be optimized for best performance. Large size (up to 12000 ha) monitoring networks have been developed over the last few years. Observation period, density and frequency are based on incomplete expert knowledge on dynamics and mobility.
Insect dynamics show strong spatial-temporal structure that seems relatively stable among years. Depending on the species, landscape does influence local abundance. Causal explanations of spatial differences in phenology should relate to meso-climatic factors (temperature, rainfall and drought) through their impacts on key events in the insects life cycle (mating, egg laying). Differences in phenology can also have a huge impact on population dynamics since reproductive success is strongly depending on weather conditions during such key events. Progress is being made to optimize the monitoring network in a socio-economic context as its performance and accuracy depends on its acceptance by the farmers.

04-Management strategies of noxious mosquito species on the French Mediterranean coast

Dominique Gindre[1] and Nicolas Sidos[1]
[1]Entente Interdépartementale pour la démoustication du littorale méditerranéen (EID Méditerranée), 165, avenue Paul Rimbaud, Montpellier cedex 4
E-mail: dgindre@eid-med.org

Founded in the late fifties EID Méditerranée is a public operator whose primary mission is to control the nuisance associated with the presence of mosquitoes. This mission takes place in an area spreading from the Etang de Berre near Marseille, to the Franco- Spanish border. Perfect knowledge of the ecology of target species is the key to successful control strategy. This strategy is based on larval control, which allows the most effective control with the least environmental impact: an integrated approach, targeted in space and in time, using the most selective pesticides.
The procedures implemented uniformly on an interregional scale, guarantee the efficacy of the plan of action. The crucial first step consists in mapping mosquito breeding sites and creates a truly operational tool. The strategy also includes a process for environmental monitoring and assessment (traceability of activities (GIS, GPS), study of effects on non-target fauna). The introduction in South-eastern France, in 2006, of *Aedes albopictus* a strongly noxious tropical invasive and potential arbovirus vector, has necessitated the establishment of an entomological monitoring taking into account this mosquito's ethology and expansion, in order to organize when necessary vector control operations.
Thus, the strategy is being constantly improved thanks to the permanent and indispensable relations between the operational observations and the structure's integrated research and development approach, ensuring its sustainability while taking into account the wider socio-economic and regulatory contexts.

05-Spatial ecology of *Dermolepida albohirtum*, a major pest of sugarcane in Queensland: importance of a landscape approach

François-Régis Goebel [1] and Nader Sallam[2]
[1] CIRAD, UR Systèmes Cultures Annuels, Montpellier ; [2] BSES Limited, Q Crops, Gordonvale, Australia
E-mail: goebel@cirad.fr

Ecology has become increasingly permeated by the notion that everything takes place within a spatial context and that the distribution of habitat may strongly impact on distribution, dynamics and evolution of natural populations. In the agricultural context, understanding the influence of landscape structure (i.e. arrangement, connectivity and quality of habitat patches) on the movements of insect pests and pest outbreaks has become essential for implementing good pest management strategies. The subterranean habitat of white grubs ("larvae") and ability of beetles ("adult") to fly through the landscape once emerged make these insects difficult to manage. Adult dispersal depends on spatial and environmental factors that are generally poorly understood in agricultural systems. Beetles spend much of each year as larvae, feeding actively on many roots of food crops (sugarcane, rice, sorghum, vegetables, grain legumes, pastures, etc.) as well as garden lawns and turf of golf courses.
In Australia, 19 species of scarab beetles ('canegrubs') attack sugarcane and the greyback canegrub *Dermolepida albohirtum* Waterhouse (Coleoptera: Scarabaeidae) is the most devastating pest, with estimated annual losses of AU$10 million. Information on the population dynamics is available at the field scale but studies have mainly focused on grubs and chemical management strategies for many years. However, information is scattered in many sources, particularly information on the adult behaviour at both the field and landscape scale. Major factors such as flight behaviour, feeding, resting, mating and oviposition sites in sugarcane, other crops and trees are little documented and mainly rely on old field observations. The lack of information on beetle behaviour impedes understanding of the distribution of this pest and hence application of efficient control methods. This paper provides an overview of the information already available on the ecology of this pest and present new tools that are currently used to investigate adult movement and damage distribution and the influence of the vegetation surrounding the sugarcane areas.

06-Combination of field margin manipulation and genetic resistance to limit Aphis gossypii outbreaks and virus epidemics in melon crops

Alexandra Schoeny[1], Patrick Gognalons[1], Nathalie Boissot[2], Pascale Mistral[2], Virginie Chareyron[2], Catherine Wipf-Scheibel[1], and Hervé Lecoq[1]
[1]INRA, UR 407 Pathologie Végétale, Avignon; [2]INRA, UR 1052 Génétique et Amélioration des Fruits et Légumes, Avignon
E-mail : alexandra.schoeny@avignon.inra.fr

Aphis gossypii is a major pest of Cucurbitaceae crops as much by causing primary damages (sap uptake) as by being an important vector of viruses. The Vat gene confers to the melon a resistance to the colonization by *A. gossypii* as well as a resistance to the not persistent viruses (CMV, WMV,..) transmitted by these aphids. It is however ineffective to block the transmission of the viruses carried by other aphid species. The use of Vat is thus generally coupled with aphicid treatments to limit the viral transmission by the not colonizing aphids. However, the progressive reduction of the usage of the phytosanitary products in the crop protection imposed by the evolution of the regulation (plan Ecophyto 2018) leads to look for new strategies integrating cultural practices and genetics for the management of the bioagressors.
The bibliography suggests that the management of field margins (strips sown with non host grass or flower mixtures) could be an effective option to decrease 1) the aphid pressure (and thus the risk of bypassing Vat) by favoring the development of natural enemies and 2) the virus pressure by constituting a filter reducing the viral load of aphids before they reach the crop. The hypothesis tested in this project is that an adequate manipulation of the environment of the crop can contribute to regulate the populations of aphids and\or their viral load and therefore to reduce the risk of viral epidemics. The effect of three types of field margins (naked soil, grassy strips and flower strips) is evaluated on the efficiency of the Vat-mediated resistance.

07-Factors and mechanisms affecting spatial heterogeneity of insect populations

Fabrice Vinatier[1], Philippe Tixier[1], Pierre-François Duyck[1], and Françoise Lescourret[2]
[1]CIRAD, UPR 26, Le Lamentin, Martinique, France ; [2]INRA, Unité Plantes et Systèmes de Culture Horticoles, UR 1115, Domaine St. Paul, Site Agroparc, Avignon, France
E-mail: Fabrice.Vinatier@grignon.inra.fr

1. The spatial distribution of populations is affected by the dispersal abilities of the species, interactions among individuals, or habitat selection. Linking these ecological processes to spatial patterns is of primary importance for understanding and prediction purposes.
2. We review both statistical and mechanistic methods for studying the spatial distribution of populations. Statistical methods, such as spatial indexes and nearest-neighbour analyses help characterizing the spatial pattern. They allow testing the effect of environmental variables on spatial patterns using regression analyses.
3. Mechanistic modelling can be used to analyse the effect of mechanisms underlying the spatial pattern. We review mechanistic models (e.g. metapopulation, individual-based and cellular automaton models) devoted to represent dispersal abilities, interactions among individuals and habitat selection.
4. We illustrate each method by works on insects, which cover a broad range of spatial patterns.
Strengths and limitations of methods are discussed according to the process and type of data set.
5. Scientists can use statistical or mechanistic methods in an iterative manner to infer process from spatial pattern. New approaches such as 'pattern-oriented modelling' or 'space as a surrogate framework' determine whether alternative models reproduce an observed pattern. It allows selection of the process that best explain the observed pattern.

08-Use of population genetics to choose between vector control strategies: the example of tsetse in West-Africa

Philippe Solano[1], Sophie Ravel[2], Jeremy Bouyer[3], and Thierry de Meeûs[1]
[1]IRD, UMR IRD-CIRAD INTERTRYP, CIRDES Bobo-Dioulasso, Burkina Faso; [2]IRD, UMR IRD-CIRAD INTERTRYP, Montpellier, France; [3]CIRAD UMR CMAEE, ISRA Dakar, Sénégal
E-mail: philippe.solano@ird.fr

In sub-Saharan Africa, tsetse transmitted Trypanosomiases have an enormous impact on human health and economic development. Both the World Health Organisation and African countries through the Pan African Tsetse and Trypanosomiasis Eradication Campaign
(PATTEC) have recently asserted their determination to rid the sub-continent of these diseases, and it is increasingly recognised that vector control should play an important role. This review mainly focuses on population genetics of tsetse of the *palpalis* group, the main vectors of sleeping sickness, and reports recent results on tsetse population structure and on measures of gene flow between populations. Implications of these studies for large-scale tsetse control programmes being undertaken in West Africa are important, particularly regarding control strategies (suppression or eradication).

09-'Cosmodrome': an experimental design to study movements and behavior of the banana weevil, Cosmopolites sordidus, using RFID

Dominique Carval, Philippe Tixier and Pierre-François Duyck
CIRAD, UPR 26, Le Lamentin, Martinique
Email : dominique.carval@cirad.fr

The banana weevil *Cosmopolites sordidus* (Germar) is an important pest of banana crops. Radio-tracking and capture-recapture studies at the scale of the field have revealed a limited capacity of dispersion of the banana weevil. However, for a better understanding of the epidemiological process more information on the movement at a finer scale is needed. To analyze the behavioral response of individuals, we use the Cosmodrome, an experimental design composed of two patches whose quality may vary (bare soil, banana rhizome). The patches are connected by a tunnel of one meter of length at the ends of which RFID tag readers are placed. We analyzed the behavioral response of individuals to variation in patch density. The statistical analysis of results using generalized linear model revealed that the individuals shows a non-linear response of movement to the density in patches. The banana weevil tends to move at a higher rate at intermediate density than at low and high density. The movement response to patch density differs also according to the sex, with a higher activity of females than males at low and intermediate patch density. These preliminary results on the effect of density may reflect the individual strategies of colonization of banana fields by *Cosmopolites sordidus* that maximize the individual fitness (mating, oviposition). The information on movement and behavior of the banana weevil at the plant level is of great importance for the understanding of the dynamic of the epidemiological front during the colonization process.

10-Genetic inferences about the population dynamics of codling moth females at a local scale

Pierre Franck[1], Benoit Ricci[1], Etienne. Klein[2], Jérôme Olivares[1], Sylvaine Simon[3], Jean-Marie Cornuet[4], and Claire Lavigne[1]
[1]UR1115 Plantes et Systèmes de culture Horticoles, INRA, F-84000 Avignon cedex 9, France. [2]UR546 Biostatistique et Processus Spatiaux, INRA, F-84000 Avignon cedex 9, France. [3]UE695 Recherches Intégrées, Gotheron, INRA, F-26320 Saint-Marcel-les-Valence, France. [4]UMR1062 Centre de Biologie et de Gestion des Populations, INRA, IRD, CIRAD, SupAgro Montpellier, F-34988 Montferrier-sur-Lez cedex, France
E-mail : pierre.franck@avignon.inra.fr

Estimation of demographic parameters is important for understanding the functioning of natural populations and the underlying ecological and evolutionary processes that may impact their dynamics. Here, we used sibship assignment methods to estimate the local dynamics of codling moth females in eight orchards in a 90-ha domain near Valence, France. Based on full-sib inference among 1,063 genotyped moths, we estimated i) the effective number of females that had offspring, ii) their fertility and iii) the distribution of their oviposition sites within and among orchards. The average number of females in all the orchards increased between the first (~130) and the second (~235) annual generations. The average fertilities of the females were similar at each generation according to the host plant considered (apple, pear, or walnut), but differed between commercial (~10) and non-treated (~25) apple orchards. Females mainly clustered their eggs on contiguous trees along orchard borders, but they also occasionally dispersed their eggs among different orchards independently of the cultivated host plants or the inter-orchard distances (up to 698 m) during the second annual generation. The mean distance between two oviposition sites was 30 m. Sibship estimates of both the effective number of females and the inter-orchard migration rates (~5%) were in agreement with the observed genetic differentiation among the eight orchards ($0.006<Fst<0.013$). These results confirm and extend previous field and laboratory observations in Cydia pomonella, and they demonstrate that sibship assignments based on genetic data are an interesting alternative to mark–release–recapture methods for inferring insect population dynamics.

11-Population genomics to detect local adaptation: application to Bti resistance monitoring in mosquitoes at a regional scale

Laurence Després, Guillaume Tetreau, Margot Paris, and Aurélie Bonin
Université J. Fourier, UMR CNRS 5553 LECA, Grenoble
E-mail : laurence.despres@ujf-grenoble.fr

Identification of genes involved in local adaptation is particularly challenging in species functioning as a network of inter-connected populations undergoing frequent extinction-recolonisation, because populations are submitted to contrasted evolutionary pressures. Using AFLP markers, population genetic structure of the mosquito *Aedes rusticus* was analyzed in five geographical areas of the French Rhône-Alpes region, including sites treated with the bio-insecticide *Bacillus thuringiensis* subsp. israelensis (Bti) for more than 15 years. Most of the genetic variability was found within populations, with no significant variation among geographical areas, although variation among populations within areas was significant. Pairwise FST values were significant and no isolation-by-distance was observed, suggesting a metapopulation structure in this species at the regional scale. Bti treatment had no effect on genetic structure, and within-population diversity levels were not significantly higher in non-treated compared with treated sites, suggesting that these are rapidly re-colonized by a diversified population of migrants after Bti treatment. However, signatures of positive selection associated with Bti treatment were detected for five loci, even though standard toxicological bioassays performed on field-collected larvae showed no significant difference in mortality between Bti-treated and non-treated sites. The absence of resistant phenotypes may result from the polygenic basis of resistance mechanisms to Bti, together with a high resistance cost measured in a laboratory selected mosquito strain. We also showed that selected mosquitoes are only moderately resistant to the full commercial Bti mixture, but show high levels of resistance to separate Bti toxins. This suggests that monitoring resistance in field populations should require evaluating mosquito resistance to individual Bti toxins, rather than to full commercial Bti mixture. We propose new methods for monitoring Bti resistance evolution in mosquito populations, in order to detect resistance at the very early steps of its appearance, when bioassays using Bti fail to detect resistance.

12-Can Deuterium stable isotopes be used to infer geographical origins of an auxiliary hoverfly and a pest moth?

Lucie Raymond[1, 2], Philippe Menozzi[3], Andrew J. Hamilton[4], Jean-Pierre Sarthou[1, 2], Noelline Tsafack[1, 2, 3], Aude Vialatte[1, 2], Sergine Ponsard[5,6], and Annie Ouin[1, 2]
[1]Université de Toulouse, UMR DYNAFOR, INRA/INP-ENSAT/INP-EIPurpan, BP 32607, 31326 Castanet Tolosan, France; [2]INRA, UMR DYNAFOR, BP 52627, 31326 Castanet Tolosan, France; [3]CIRAD, UPR 102, 34 398 Montpellier, France; [4]The University of Melbourne, Department of Agriculture and Food Systems, Dookie Campus, Dookie College, Victoria 3647, Australia; [5]Université de Toulouse, UMR EDB, 118, route de Narbonne - 31062 Toulouse, France ; [6]CNRS – UMR 5174, Laboratoire Evolution & Diversité Biologique, 118 route de Narbonne, 31062 Toulouse cedex 09, France
E-mail: ouin@ensat.fr

Deuterium δD isotopic analysis is increasingly being used to trace wildlife movement, and undoubtedly has much to offer in this respect but questions still remain as to the feasibility and practicality of the method in ecology. Here we report our attempt to determine the geographic origin of an auxiliary hoverfly, *Episyrphus balteatus*, in South-western France and a pest moth, *Helicoverpa armigera* in Western Africa. We used quantile regression to calculate the minimum separation distance, based on the International Atomic Energy Agency / World Meteorological Organization (IAEA / WMO) data, at which two insects could be said to originate from different latitudes with a given degree of confidence. Our results revealed greater variability of hoverfly adults δD in autumn than in spring. From this we infer an autumnal migration of the auxiliary hoverfly species. Despite the complications encountered in Europe, the minimum separation distance model proved a useful first step to get a first range of possible origins of *E. balteatus* and its application to other arthropod species in Europe warrants investigation. The lack of IAEA /WMO data in western Africa prevents the calculation of a minimum separation distance for the pest moth. The interpretation of water simulated δD in the study area in Western Africa and preliminary results on wild moth advocate for a restricted use of stable isotope to infer the geographical origin of the pest moth.

13-Predictive metapopulation ecology for improving insect pest management

Yves Carrière
University of Arizona, Tucson, USA
E-mail: ycarrier@ag.arizona.edu

Many insect pest species exploit several types of habitats in agricultural landscapes. As these habitats may export or import individuals, identifying habitats acting as sources and sinks and determining the spatial scale of their effects is critical for managing landscapes to enhance pest control. Here I describe a systematic, spatially-explicit approach that can be used to characterize and test the effects of source and sink habitats and of local factors on pest attributes. This approach was used to predict spatial variation in population dynamics in Lygus hesperus and evolution of insecticide resistance in Bemisia tabaci, suggesting that it has the potential to improve the design of landscape-level management strategies in many pests.

14-Learnings, tools and pitfalls of agroecology at landscape scale. Lessons from projects in DYNAFOR Lab

Annie Ouin[1, 2], Claude Monteil[1, 2], Philippe Menozzi [3], Jean-Pierre Sarthou[1, 2], Aude Vialatte[1, 2], and Marc Deconchat [2,1]
[1]Université de Toulouse, UMR DYNAFOR, INRA/INP-ENSAT/INP-EIPurpan, BP 32607, 31326 Castanet Tolosan, France; [2]INRA, UMR DYNAFOR, BP 52627, 31326 Castanet Tolosan, France; [3]CIRAD, UPR 102, 34 398 Montpellier, France
E-mail: ouin@ensat.fr

There is a growing concern about the use of ecosystem services components (such as soil protection, conservation of water quality, pollination, biological control of pests) provided by landscape through the presence of semi-natural elements and the spatial arrangement of crop mosaic. The DYNAFOR Lab was firstly mostly involved in issues on biodiversity in small forests and rural landscape with a landscape ecology approach. Here we present our main conclusions from various projects dedicated directly or not to pest control by beneficial insects.
First, we compared aphid and hoverfly abundance in wheat fields differing in woodlot density in their vicinity, from spring 2003 to spring 2007. In addition, the rate of survival of a hoverfly species (*Episyrphus balteatus*, De Geer, 1776) after overwintering was simulated in a multi-agent model and compared to field data in spring. Simulations with the winter survival model showed higher survival rates in wooded landscapes with floral resources, but these only matched the actual spring abundance of hoverflies in 2003. Although aphids and hoverflies were both present earlier in wheat fields in wooded than in less wooded contexts, the higher ratio of hoverflies to aphids in wheat fields in wooded contexts suggests that the latter offer better potential biological control. Emergence traps in wood border showed a high variability of the abundance of overwintering beneficial insects.
The study of carabid beetle communities in emergence traps in wood edges, field borders (inside and outside fields) pointed out the drastic number of zoophagous carabid beetles overwintering in wood edges but also in field borders themselves even when ploughed.
Our global conclusion is that even if wood edges, hedges have proved their beneficial effects to support beneficial species, the field itself and its management are worth to be studied in relation to the landscape context. The temporal window at which a landscape effect could be identified is sometimes very narrow.

15- Remote sensing for spatial ecology

Agnès Bégué, CIRAD, UMR Tétis, Montpellier

16-Use of remote sensing to determine target populations of glossines in Senegal

Jérémy Bouyer[1,2], M.T. Seck[2], B. Sall[3], E.Y. Ndiaye[3], Laure Guerrini[4], and Marc J.B. Vreysen[5]
[1]Cirad, CMAEE; [2]ISRA-LNERV, Dakar, Sénégal; [3]DSV, Dakar, Sénégal; [4]Cirad, AGIRs; [5]Entomology unit, FAO-IAEA, Vienna, Austria
E-mail: Jeremy.bouyer@cirad.fr

The riverine tsetse species *Glossina palpalis gambiensis* Vanderplank 1949 (Diptera: Glossinidae) inhabits riparian forests along river systems in West Africa. The government of Senegal has embarked on a project to eliminate this tsetse species, and African animal trypanosomoses, from the Niayes area using an area-wide integrated pest management approach.A stratified entomological sampling strategy was therefore developed using spatial analytical tools, remote sensing and mathematical modeling. A preliminary phyto-sociological census identified eight types of suitable habitat, which could be discriminated from LandSat 7ETM+ satellite images and denominated wet areas. At the end of March 2009, 683 unbaited Vavoua traps had been deployed, and the observed infested area in the Niayes was 525 km2. In the remaining area, a mathematical model was used to assess the risk that flies were present despite a sequence of zero catches. The analysis showed that this risk was above 0.05 in 19% of this area that will be considered as infested during the control operations. The remote sensing analysis that identified the wet areas allowed a restriction of the area to be surveyed to 4% of the total surface area (7,150 km2), whereas the mathematical model provided an efficient method to improve the accuracy and the robustness of the sampling protocol. The study thus allowed defining the limits of the target population for the eradication campaign. This entomological sampling procedure might be used for other vector or pest control scenarios.

17-Landscape characterization of Rift Valley Fever risk areas using very high spatial resolution imagery – case study in the Ferlo area, Senegal

Valérie Soti[1,2,3], Véronique Chevalier[1], Jonathan Maura[1], Diam Abdoul Sow[5], Agnès Bégué[3], Camille Lelong[3], Renaud Lancelot[4], and Annelise Tran[1]
[1]Cirad, UPR AGIRs ; [2]Cirad, UPR SCA ; [3]Cirad, UMR TETIS ; [4]Cirad, UMR15 ; [5]ISRA, Institut Sénégalais de Recherche Animale de Dakar, Sénégal
E-mail : valerie.soti@cirad.fr

The objective of this study was to explore the potential of very high spatial resolution imagery to contribute to a better understanding of the Rift Valley Fever (RVF) transmission at the local scale in the Ferlo Region in the northern Senegal. We propose a landscape approach to map the favourable mosquitos' biotopes and to test for associations between landscape variables and RVF incidence rates around the village of Barkedji, Ferlo region, Senegal.
A very high spatial resolution satellite image (2.4 m /pixel resolution) provided by the Quickbird sensor was used to detect and characterize the temporary ponds, which are the breeding sites for *Aedes Vexans* and *Culex Poicilipes*, the two main mosquito vectors of the RVF virus. We applied object-based image-processing techniques, which exploit both spectral and textural information, to provide a detailed pond map, a vegetation map around the ponds, and a general land use map. Then, we derived from these maps five landscape variables, based on bibliographic knowledge of the vector ecology:
- a landscape closure index,
- an index of water vegetation coverage,
- and a pond density index,
- the location of the pond,
- the surface area of the pond.

To test the relations between these landscape variables and RVF incidence, we used a beta-binomial regression model. The Akaike's information criterion allowed selecting the best fitted models. The 500-m landscape closure index was significantly correlated with higher serologic incidence ($p<0.05$) showing the influence of the vegetation density on the RVF incidence rates in small ruminants herds.

18-Coupling long-term prospection data and remote-sensing vegetation index to help in the preventative control of Desert Locust

Cyril Piou[1], Ahmed Salem Benahi[2], Vincent Bonal[3], Mohamed el Hacen Jaavar[2], Valentine Lebourgeois[1,3], Michel Lecoq[1], and Jean-Michel Vassal[1].
[1] CIRAD, UPR Bioagresseurs analyse et maîtrise du risque, F-34398 Montpellier, France ; [2] CNLA, Centre National de Lutte Antiacridienne, Nouakchott BP665, Mauritanie ; [3] CIRAD, UMR TETIS, Maison de la Télédétection, F-34093 Montpellier, France
E-mail : cyril.piou@cirad.fr

Prospection data are generally collected in oriented manner and toward the immediate needs of pest management. Despite the evident statistical bias these data present, when coupled with external indicators of environmental status, prospection data can help in characterizing interesting relationships between the focused pest and its environment. Desert Locust management is generally done through a preventative control avoiding population to reach high and uncontrollable densities. The areas of potential start of gregarization process for Desert Locust are large and preventative management teams need to prospect all these areas to be efficient. A challenge of ongoing research is to be able to guide on where prospection surveys should be done depending on meteorological and vegetation conditions. An analysis of relationship between long-term prospection data of Desert Locust observations from 2005 to 2009 and spatio-temporal statistics of a vegetation index gathered by remote-sensing was conducted using logistic regressions. The vegetation index was a composite Normalized Difference Vegetation Index (NDVI) given every 16 days and at 250m spatial resolution (MOD13Q1 from MODIS satellite). The statistics extracted from this index were: 1) spatial means at different scales around the prospection point, 2) relative differences of NDVI variation through time before the prospection and 3) large scale summary of vegetation quality. Identical statistics could potentially be computed for actual NDVI. By extrapolation of the chosen logistic regression model, maps of probability of presence of locust could be constructed. This methodology should help in focusing prospection toward sensible parts of the gregarization areas at specific times.

19-Inventory of mosquitoes in Mayotte, French Departement in the Indian Ocean

Gilbert Le Goff[1], Nil Rahola[1], Betty Zumbo[2], and Vincent Robert[1]
[1] Institut de Recherche pour le Développement , Montpellier, MIVEGEC, UMR IRD 224 - CNRS 5290 - UM1 - UM2 ; [2] Agence Régionale de Santé - Océan Indien, Mayotte
E-mail: vincent.robert@ird.fr

Mayotte is an island situated in a region of the world particularly exposed to vector borne diseases. Several potential vectors, a tropical climate, an increasing urbanization, important movements of populations in the region, are among the relevant factors which favour the endemicity, the emergence or the re-emergence of vector transmitted diseases. Many vector born diseases are transmitted by mosquitoes: malaria, dengue, chikungunya, Rift Valley fever and, in the past, the Bancroftian filariosis.
A collaborative project was recently initiated between IRD and ARS-OI to update the inventory of the mosquito species present in Mayotte. With the final goal to facilitate an integrated control against vector born diseases transmitted by mosquitoes, an entomological survey was performed in 2011 from March 21st till April 8th, at the end of the rainy season, with special attention in the best-protected natural areas. The breeding sites positive for preimaginal mosquitoes were geolocalised with a GPS and its environment was characterized. A semi-individual breeding of specimens was realized in the insectary from larval and pupal stages. Some mosquitoes were put in collections and the others were put in alcohol to allow further genetic researches by DNA sequencings, in Montpellier.
The data concern 27 visited sites, and 426 points of collections. Our provisional results count 26 species (among 36 previously listed). A noticeable result is the discovery of *Aedes* (Stegomyia) nov. sp., belonging to a new species for Mayotte and for the science, collected in the humid forest at the top of the island (forest reserve of Majimbini) near the locality "The convalescence".

20-Landscape scale pest management: what can we learn from models?

Felix Bianchi
Wageningen University, Department of Soil Quality, P.O. Box 47, 6700 AA Wageningen, The Netherlands
Email: felix.bianchi@wur.nl

Empirical evidence is mounting that the composition of landscape matters for the suppression of pests in agricultural crops. Non-crop habitats like forest, for instance, have been associated with higher levels of predation and parasitism of several agricultural pests. Yet, the identification of priority areas where implementation of conservation biological control is most effective has received only limited attention. This can be explained in part by the fact that landholders base management decisions at convenient land management scales such as the field, but there is also a lack of practical guidelines on spatial planning for ecosystem services. For this purpose, mechanistic, process-based models can be advantageous. In this presentation I will show using spatially-explicit simulation models how functional traits of predators and the spatial arrangement of their source habitats in the landscape can influence pest populations in crops. I will further highlight how biocontrol mediated by parasitoids can be disrupted by broad-spectrum pesticide use and demonstrate that there are strong thresholds in the proportion of the landscape subject to such pesticide applications for acquiring meaningful levels of biocontrol. This information can inform management strategies that recognize the importance of larger scale issues and may be better suited to capitalize on the pest control services provided by natural enemies.

21-Use of the metapopulation theory and individual-based models to improve pest control

Steven L. Peck
University Brigham Young, Provo, USA
E-mail: slp3141@gmail.com

The tsetse fly complex (*Glossina* spp.) is widely recognized as a key contributor to the African continent's continuing struggle to emerge from deep economic, social and political problems. Control efforts for the fly have resulted in both successes and failures and good decision-making tools are imperative in tsetse control programs. In this paper I use spatial network structure combined with classic metapopulation modeling in order to explore how extinction probabilities differ from simpler formulations that do not take into account spatial structure. The model shows how that as network connectivity increases, metapopulation persistence also increases, and the probability of extinction decreases. In addition, agent-based systems have become very important to understanding the complex interactions of organisms in ecological and evolutionary systems. Like the complexity found in natural systems, these models allow complexity to bubble-up from lower-level scales as digital organisms allow representation at multiple spatial and temporal scales. These types of models present several challenges to understanding how a simulation represents the real world and what role it can play in scientific discourse and adaptive management in insect control programs.

22-Development of a mathematical model for tsetse population dynamic to optimize the control in the Niayes (Senegal)

Abdoul Aziz Fall[1], Jeremy Bouyer[1], and Renault Lancelot[2]
[1]CIRAD UMR 15/ISRA, Dakar, Sénégal; [2]CIRAD UMR 15, Montpellier, France
Email: aziz.fall@cirad.fr

The Niayes area in Senegal is infested by a tsetse population, which is presently targeted by a national eradication effort. The area infested is about 1000km2 but tse-tse fly distribution changes rapidly due to environmental changes, climatic condition, humidity, temperature and vegetal cover etc.. The availability of tsetse fly presence/absence data in Senegal is limited to the database survey conducted during the feasibility study (2008/2009), that's why we decided to use a matrix model based on the tse-tse life cycle to predict the actual fly distribution in the Niayes area during the control program. The model describes biological process and the effects of the daily contribution of the temperature on the development of the pupae, the teneral and the adult flies. The model will be fitted to field demographic data to estimate parameters.
The sensivity analysis and uncertainty analysis of the model will allow to predict the ecological niche of tsetse in the area and thus their temporal distribution according to climatic variations. We'll use MODIS data and field data as an input in our model to characterize the habitats suitable for tse-tse population establishment.

23-Mosaic-Pest: a spatially explicit model for landscape management of pests

Fabrice Vinatier and Muriel Valantin-Morison
INRA, UMR 211, Paris-Grignon
E-mail : Fabrice.Vinatier@grignon.inra.fr

We developed a lattice model to simulate the spatio-temporal interactions between beetles (*Meligethes aeneus*) and parasitoids (*Tersilochus heterocerus*) in relation with landscape composition and structure. The model describes the most important processes (dispersal, mortality and fecundity) affecting population structure in space and time. Parasitism rate was described by Thompson formalism. Landscape elements (semi-natural habitats, crops and grasslands) and agricultural processes (crop rotation, soil tillage, pesticides use) were explicitly considered in the model, considering their influence on beetle and parasitoid populations. Species-specific parameters were derived from the literature available on the species or its closed taxon. Landscape mosaic was defined on the basis of GIS maps collected in north-western France, figuring contrasting situations in terms of landscape complexity. The model was confronted to real population levels of beetle collected in the zone. A sensitivity analysis of the model allowed evaluating the importance of each species trait and landscape parameters in the explanation of population level. By linking species traits and landscape complexity, the model helps us understanding the ecological processes underlying landscape patterns. We discussed the potential of this model to use ecological services provided by landscape to select landscape managements that limit populations of beetles.

24-Agent-based models for an interdisciplinary approach of pest management (the potato tuber moth in Ecuador)

François Rebaudo[1] and Olivier Dangles[1,2]
[1] IRD, UR 072, Laboratoire Évolution, Génomes et Spéciation, UPR 9034, CNRS, 91198 Gif-sur-Yvette Cedex, et UP11, 91405 Orsay Cedex, France ; [2] Pontificia Universidad Católica del Ecuador, Facultad de Ciencias Exactas y Naturales, Laboratorio de Entomología, Quito, Ecuador
Email: francois.rebaudo@ird.fr

Worldwide, the theory and practice of agricultural extension system have been dominated for almost half a century by Rogers' "diffusion of innovation theory". In particular, the success of integrated pest management (IPM) extension programs depends on the effectiveness of IPM information diffusion from trained farmers to other farmers, an important assumption which underpins funding from development organizations. Here we developed an innovative approach through an agent-based model (ABM) combining social (diffusion theory) and biological (pest population dynamics) models to study the role of cooperation among small-scale farmers to share IPM information for controlling an invasive pest. The model was implemented with field data, including learning processes and control efficiency, from large scale surveys in the Ecuadorian Andes. Our results predict that although cooperation had short-term costs for individual farmers, it paid in the long run as it decreased pest infestation at the community scale. However, the slow learning process placed restrictions on the knowledge that could be generated within farmer communities over time, giving rise to natural lags in IPM diffusion and applications. We further showed that if individuals learn from others about the benefits of early prevention of new pests, then educational effort may have a sustainable long-run impact. Consistent with models of information diffusion theory, our results demonstrate how an integrated approach combining ecological and social systems would help better predict the success of IPM programs. This approach has potential beyond pest management as it could be applied to any resource management program seeking to spread innovations across populations.

25-Ocelet modelling language and simulation tool: possible applications in pest management?

Danny Lo Seen [1], Pascal Degenne [1] , Valérie Soti [2] , and Annelise Tran [3]
[1] Cirad, UMR TETIS, Montpellier; [2] Cirad, UR SCA, Montpellier; [3] Cirad, UR AGIRS, Montpellier
Email: danny.lo_seen@cirad.fr

Modelling spatial dynamics may be used to gather understanding on how insect populations develop in a given environment. Hypotheses and independent knowledge inferred from ground observations can be confronted for consistency, and the mechanisms requiring finer descriptions can also be identified. Different scenarios of pest management can then be simulated and the possible consequences of the measures taken assessed. However, spatial dynamics are expressions of multiple and complex ongoing processes, and their modelling at different temporal and spatial scales remains a challenging task. Various approaches have been proposed to address this, including cellular automata, agent-based systems, discrete event systems, system dynamics and geographic information systems, each displaying specific benefits in some domains of application, and weaknesses in others.
In this area of research, we are exploring an approach based on the manipulation of graphs (mathematical object expressing a set of entities, some of which are linked) that are employed here in an innovative way for modelling landscape dynamics. Concepts essential for modellers had to be identified and formally defined. A modelling computer language (called Ocelet) was then developed, together with the grammar and syntax needed to manipulate these concepts, the compiler, and the environment/interface for building models and running simulations. Ocelet is thus both a modelling language and a simulation tool. To illustrate its usage, two case studies possibly pertinent for pest management are presented: 1) the dissemination of a pathogen among neighbouring agricultural plots, and 2) temporary pond and mosquito population dynamics for understanding Rift Valley Fever (RVF) occurrence.

26-An individual-based modeling approach to assess trap cropping management of *Helicoverpa zea* in tomato field

Isabelle Grechi[1], Béatrice Rhino[2], Alain Ratnadass[1], and Philippe Tixier[3]
[1] CIRAD, UR 103, Montpellier
[2] CIRAD, UR 103, Le Lamentin, Martinique
[3] CIRAD, UR 26, Le Lamentin, Martinique
Email: isabelle.grechi@cirad.fr

Farmers in the tropics are faced with crop protection issues such as adverse impacts of pesticides on human health and on the environment, particularly in intensive agrosystems in French overseas islands, or food insecurity and low income due to pest-induced crop losses, particularly in low-input traditional systems in Sub-Saharan Africa. A Cirad-funded « Omega3 » project tackles these problems by studying the effects of the planned introduction of plant species diversity (PSD) in tropical agrosystems, as a potential alternative to conventional practices based on pesticide use.
One of the several study cases the project focused on is the use of sweet corn as a trap crop to control the populations and damages of *Helicoverpa zea* in tomato field in the French West Indies (Martinique). To understand system functioning and improve *H. zea* management, we are developing a spatially-explicit individual-based model at the field scale. The model comprises 3 interacting modules that describe (i) phenology of tomato and corn plants and dynamic of the attractive plant stages for *H. zea* (ii) *H. zea* development, both using thermal units, and (iii) *H. zea* movement and oviposition behavior. More widely, we aim to use this model as a generic tool to improve our understanding of what make the use of a trap crop successful in managing pests among the insect behavioural traits, the crop traits (e.g., relative attractiveness) and the spatio-temporal planting design of the trap and commercial crops. The modeling approach we are currently developing and further issues are presented.