Agricultural landscape modelling for the simulation and analysis of processes

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Introduction

Using spatial models in prospective: objectives, advantages and drawbacks

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Keywords: Scenarios, Spatially explicit and dynamic simulation, Validation, Plausibility

This theoretical paper presents a state of the art on the use of spatial models dedicated to prospective studies. The first part summarizes the converging interests of foresight studies and geography. The second part gives helpful insights to answer the question of how choosing an appropriate model for exploring the future of territories/landscapes. The third part is dedicated to the question of models validation as means to improve the plausibility of scenarios. These methods are not exhaustively described but rather illustrate that the geoprospective consists in a community of practices and tools with a common objective: better exploring the future to improve current decision making. It aims at highlighting the contribution of models for such purpose and helping possible users (geographers, agronomists, modelers, prospectivists, etc.) to choose a convenient model. It attempts to clarify some misunderstanding and confusions that already exists when combining scenarios and models.

Session 1

Landscape representation

Multiple Point Statistics: simulating and assessing uncertainty of complex spatial models

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Keywords: Stochastic simulations, training image, non-parametric statistics, patterns reproduction

In many applications, modeling bi- or three-dimensional fields is necessary to solve physical processes. For instance, a permeability field is required for computing fluid flows. Moreover, most often only few data are available, which implies uncertainties. In this framework, simulating random fields allows for several scenarios and assessment of uncertainty regarding predictions. Parametric random field generators based on a covariance function (or variogram) often failed to produce complex spatial features. Multiple Point Statistics (MPS) is a non parametric geostatistical method, relatively recent (introduced by Guardiano and Strivastava (1993), first efficient implementation by Strebelle (2002)), and able to overcome some limitations of classical parametric techniques. The basic principle is to start from a training image (conceptual model) from which non parametric statistics are derived on pattern occurrences. Those statistics control the generation of random fields which are able to mimic realistic structures present in the training set. While the algorithm is pretty obvious, it allows simulating a broad range of random processes, for examples: simulation of porous medium, geomorphology of braided rivers, rainfall time series, or multivariate satellite images.

OpenFLUID: A Software platform for modelling and simulation of integrated landscape functioning

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Keywords: landscape, spatio-temporal, modelling, coupling, software platform

Landscapes are complex systems in which many processes interact in space and time. Landscapes are also the suitable scale for the evaluation of many ecosystem services. Such evaluations involve integrated landscape modelling that requires i) an accurate representation of the spatial variability of landscape elements and properties across the study area, ii) the efficient interactions of models simulating the spatial processes to take into account, ii) a set of tools and methods for analysis of simulations results.

The OpenFLUID platform proposes a software environment for spatio-temporal modelling and simulation of landscapes functioning, mainly focused on fluxes, with the ability to integrate many types of local or spatial processes (hydrology, pollutant, agronomy and decision …).

The OpenFLUID basic principles rely on i) a multi-scale digital landscape representation (DLR), ii) the coupling of models simulating the landscapes dynamics, iii) the real-time observation of simulations results for data analysis.

The DLR is based on a multi-scale graph approach for representation of the landscapes elements, their properties and their connectivity. The modelling of processes is performed by simulators (models) plugged and automatically coupled in the platform. Using this system, a user can build the landscape model that matches his scientific questions by reusing existing simulators or creating new simulators.

The above-evoked concepts and functionalities are integrated in the OpenFLUID software framework which is the base of the platform. Additionally, OpenFLUID proposes various users interfaces (command line, graphical interface), a ROpenFLUID package for management and analysis of simulations from within the R environment, and a development environment dedicated for simulators development.

OpenFLUID is also a collaborative support that can be shared in workgroups for development, capitalization, distribution and reuse of models and simulations.

The presentation will give a quick overview of concepts and functionalities of the OpenFLUID platform, illustrated with examples of scientific applications, and will propose a live demonstration of the software.

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http://www.openfluid-project.org/

Landscape representation and connectivity management:
organisation and algorithms of the OpenFLUID-landr library

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Keywords: Graph, connectivity, geometry, landscape objects, discretization

Among the different landscape discretization approaches for modelling complex landscape systems, there is one which uses graphs where the nodes are equivalent to the landscape objects (areal, line or point) and where the edges are equivalent to the connectivity between these objects [1,2]. This is the approach chosen by the OpenFLUID software [3,4]. The creation of the graph representative of the space can be done by expert knowledge, but also through advanced geomatic operations which are applied to numerical spatial data. In this way, the OpenFLUID software includes the OpenFLUID-landr library which offers a collection of spatial algorithms specialized for the landscape modelling (space discretization into landscape objects, connectivity computation ...). The OpenFLUID-landr library is a set of landscape oriented thematic features, which range between generic spatial operations and modeller needs. OpenFLUID-landr offers simple bricks for i) the integration of several formats of spatial data (vector and raster), ii) the verification and modification of geometrical characteristics, iii) the discretization of space into objects and iv) the computation of objects connectivity. Thus, using combinations of these basic operations, modellers can create their own operation tools corresponding to their own landscape representation. OpenFLUID-landr functionalities can also be enhanced with supplementary developments or by using external libraries. The methods developed by the modellers can be used as independent programs, OpenFLUID simulators, or through OpenFLUID graphical plug-ins. The use of the OpenFLUID-landr library will be illustrated with an example of a plug-in specifically developed for the distributed hydrological model MHYDAS [5]: the concepts of landscape discretization and specific connectivity computation related to this hydrological model have been implemented in a plug-in which leans on the OpenFLUID-landr library components. This plug-in is reachable through a graphical interface (Geo-MHYDAS) for the OpenFLUID software. The simulated landscape will be available for simulations with the MHYDAS model. The genericity of the OpenFLUID-landr library allows modellers to develop their own landscape representations and various connectivity computations.

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For a theoretical study of landscapes

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Keywords: rural landscape, modelling, formal grammars, graphs, complexity

A landscape, whether it is studied for what it is in itself or for the ecological processes that it fosters, is a dynamic object still misunderstood. Landscape ecology seems to be one of these disciplines in which applications have caught up with, or even overtaken, the theoretical reflections. Yet, the return trips between experimentation-theory-models so praised in other scientific disciplines would be undeniably beneficial to these landscape studies [1]. This presentation hopes to promote a return to theory, to held better understand what a landscape is, basically.

Landscapes change, grow and develop, similar to an old plant on which new branches replace old ones, without changing its overall shape. Mathematical tools exist to formalize these types of dynamics, and such formalizations bring as much a simplified as a renewed understanding of the object of study. Indeed, to put into the form of equations a landscape complex enough to form an agricultural mosaic, allows synthesising its structure and its dynamics into a few symbols only, as this has successfully been achieved in other disciplines in living sciences.

I proposed in the past to base ourselves on a graph representation of the landscape, which would materialize the interactions with its neighbouring constituents, and a grammatical formalization of its dynamics, which would synthesize the changes that it fosters [2]. Beyond the possible universality of such a « landscape language », a great interest of this linguistic is to take into account the history of the object, as well as its undeniable multi-scale functioning. Through concrete examples taken from temperate as well as tropical landscapes, either natural or managed, made up of parcels or linear, I will show the relevance of such a theoretical framework. The latter remains to be tested through other case studies and other collaborations.

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Unclassified satellite imagery as an alternative representation of landscape for estimating biodiversity indicators

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Keywords: remote sensing, NDVI, habitat, model, birds

Remote sensing offers several ways to represent the habitat structure of biological organisms. One that predominates is to discretize the landscape in homogeneous spectral units to establish land cover maps that are considered as habitats. Spatial descriptors can then be calculated to explain the presence or abundance of some species.
Although widely used, this approach requires making choices about the types of land cover and their level of detail. It therefore introduces *a priori* human perception of landscapes which can be very different from the real habitat perception of species. In addition, the discretization removes landscape features which may be sensitive species. Therefore, the modelling of relationships between landscape patterns and biodiversity indicators may be biased.
An alternative approach offered by remote sensing is to consider a continuous landscape representation. It is based on the direct linking of continuous descriptors based on the reflectance of the raw images with biodiversity indicators. The reflectance of the raw data (or derived indices) reflects functional or physical properties of habitats. It can therefore potentially explain the presence or richness of studied species.
In this work, we assess the effect of landscape representation obtained by remote sensing on bird-habitat models. First, we compare the performance of models integrating two different representations of habitat patterns at a given time: discrete representation (CORINE Land Cover) *versus* continuous representation (vegetation index, NDVI). Then we compare the results of these models with other models integrating a functional representation of habitats. This representation is obtained from a temporal classification through NDVI time-series data reflecting the vegetation phenology.
Bird data were obtained from the STOC national program (French Breeding Bird Survey) from which several response variables were calculated (several species richness and functional metrics). The used images correspond to 16 days syntheses NDVI obtained with the MODIS sensor (250m spatial resolution). Generalized linear models were then computed to link bird and NDVI data.
The first results show a significant impact of landscape representation on model performances. Unclassified images (i.e. continuous representation) always offer a higher explanatory power than classified data (explained deviance difference of 10-15% depending on the date of the image and the response variable considered). Unclassified satellite imagery appears as a relevant source of spatial data to predict patterns of bird communities over large areas and at a low cost.

Session 2

Data mining and virtual landscape initialisation

Modelling of land use with a fine scale

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Agricultural activities exert considerable pressure on environmental resources and quantifying the environmental impact of agriculture production poses challenging task, in particular for large and heterogeneous regions. We use a Bayesian approach to infer the spatial distribution of land use by making best use of two survey data sets. This allows us to model the spatial distribution of land use within distinct areas being homogeneous in terms of environmental conditions within our geographical area of interest (Pan-Europe). The first data set, a point-based field survey of land use/cover, allows for estimating the prior distributions of the model parameters. The second survey data set of land use shares within administrative regions (i.e. NUTS3) is used for investigating the posterior distributions. We aggregate the models up to the same scale of available observations of land use shares. Due to the large number of explicit scales, we made the assumption of independence among explicit scales in order to get analytical posterior distribution. An optimal constrained Bayesian estimator is applied to get consistent predictions of land use within the fine, explicit scale of homogeneous units. The simulations of the model show the effectiveness of our approach demonstrated through the application over France.

Simulate the rotation of a landscape by reproducing local structures

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Keywords: crop rotation, graphs, constraints solving, logic programming

The development of tools for the simulation of virtual agricultural landscapes is an important issue for the study of interrelationships between landscape, biophysical processes and their actors. The approach followed in this work is inspired by GenExp-LandSite, a neutral approach of landscape simulation. Our approach simulates "realistic" agricultural landscapes by reproducing collocations of cultures that characterize the organization of a real landscape.
We propose the following approach to simulate landscapes: 1) a representation of the actual agricultural landscape by a graph of plots, 2) a characterization of a real digital landscape by a frequent pattern mining method and 3) a reconstruction of "realistic" rotations using logic programming (Answer Set Programming).
We hypothesize that an agricultural landscape is characterized by the local structures (or collocation) of cultures that compose it. A grove landscape is structured by small patches of grassland separated by hedges, while an open plains landscape rather be structured by the collocations of large plots of cereals without hurdles. Such collocations are the landscape characteristic we would like to reproduce when generating a rotation. The generation is performed for a given date, regardless of the temporal succession of rotations.
An agricultural landscape is represented by a graph (a set of nodes connected by edges) where each node represents a plot and where edges encode the adjacency of two parcels. This representation highlights the interfaces between cultures. We use a pattern mining tool to extract frequent collocations of cultures, *i.e.* the "characteristics" of a real landscape.
The heart of our proposal is the use of a logic programming tool (ASP - Answer Set Programming) to generate a realistic crop rotation from an empty landscape. We assume that the geometric boundaries of parcels are given.
The proposed approach offers the possibility to generate a rotation whose organization captures local structures previously extracted. Moreover, it is possible to control the generation of the rotation through rules and constraints of composition. It is, for example, very easy to express that « Not any corn parcel must be close to a river », or that « the total grassland surface must be beyond 5000 ha ».
The presentation will attempt to present the results for the generation of agricultural landscapes and will show the expressiveness of constraints.

Learning and generating hedgerows in a landscape: an approach coupling adaptive Hilbert curves and Markov chains

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Keywords: Markov chains, Hilbert-Peano curves, Hedgerows

Space filling curves can be used in order to linearize spatial information, especially the Hilbert-Peano curve that relies on a simple pattern. However, classical regular curves are not suitable when the spatial information under study is irregular, with both low and high density zones. Using a curve that locally adapts to the information is then a better solution: an example of such a curve is the so-called adaptive Hilbert curve (AHC); an algorithm is described by Quinqueton et Berthod [1]. Besides, Markov chains are frequently used in many applications, as machine learning tool as well as generation tools, for example to simulate land-use successions in a given landscape [2].

Our proposition is to couple AHC and Markov chains in order to collect spatial characteristics of hedgerows structures in two contrasting agricultural landscapes, in Brittany and in Durance low valley. Each landscape was cut into cells that were clustered according to their number of linear elements [3]. An adaptive curve was defined over the centroids of hedgerow segments in each cell. The curves were then used as input data for Markov chains learning. Three models were learnt, one for the waiting periods between centroids (or distance on the curve), one for the hedgerow lengths (data were discretized within 6 classes), and one for the hedgerows orientations (6 classes). The three variables were considered as independent. The results obtained over all the cells allowed constructing model libraries.

The learnt models were then used to generate hedgerows landscapes. We defined a specific algorithm, that performs a regular course on an empty cell according to an average Hilbert curve; then it successively generates the hedgerows parameters (centroid, length, orientation) according to Markov models that are randomly chosen from those corresponding to the appropriate cell class. A post-processing is then performed to remove segment crossings and other defaults. Eventually, based on the various parameters, various landscapes can be generated and used to test scenarios on hedgerows lines planning.

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RLITE AND FIELD PATTERN GENERATION

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Keywords: field pattern, tessellations, simulation, estimation

RLiTe is an R package devoted to random T-tessellations [1]. It will be shown how to use RLiTe for generating field patterns.
First one selects a stochastic model of tessellation. The simplest model to be considered is the completely random model. However, due to the high variability in field size and shape yielded by this model, landscapes generated by the completely random model are not realistic.
Generally, one prefers alternative models defined by an energy function that penalizes non-realistic patterns. Simple examples of energy functions controlling the relative orientations of field boundaries and the variability of their areas, implemented in RLiTe, will be presented.
In practice, once a parametric family of energy functions has been chosen, one needs to select numerical values for the model parameters. Empirical explorations of the parameter space can be performed based on intensive simulations. Alternatively, one may start from observed field patterns and try to determine the parameter values of the model able to generate observed data. In other words, one may try to estimate the model parameters from observed field patterns. It will be shown how to perform such estimation with RLiTe where pseudo-likelihood inference has been implemented.
Next it will be shown how to simulate given models of T-tessellations. The iterative algorithm implemented in RLiTe is of Metropolis-Hastings type. Based on practical examples, we will see how to determine the length of the burning stage and how to select a sampling period in order to obtain samples of field patterns.

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Designing a functional landscape typology for territorial modeling of water and atmospheric nitrogen flows

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Keywords: landscape typology, nitrogen cascade, hidden Markov model, segmentation, mining heterogeneous data

To model the nitrogen cascade at macro-territorial level, it seems convenient to segment the territory into relevant landscape units in respect of water and atmospheric nitrogen flows. The recognition of these landscape units leads us to propose an approach to constructing a landscape typology from heterogeneous data. Among the methods to segment territories into homogeneous units, we assume that the hidden Markov models (HMMs) are appropriate to the recognition of landscape units from heterogeneous data combining variables of different types. ARPENTAGE is a toolbox of data mining programs that rely on the theory of HMMs for segmentation and analysis of spatial and (or) temporal data. In the case presented, ARPENTAGE takes as input landscape variables related to land relief, land-use, landscape features such as hedgerows and wetlands, and the spatial arrangement of these elements. The result of segmentation with ARPENTAGE is a probabilistic classification where classes are represented by distributions of observations; an observation is a tuple consisting of a sequence of n terms corresponding to the selected landscape variables. This approach has been applied on the Grand Morin watershed in Seine-et-Marne, France (1200 sq km). Preliminary data mining results are encouraging, but their interpretation is difficult because of the large number of observations that describe a class. To improve the interpretation of the classes, we implemented a number of procedures : (i) the Kulback-Leibler divergence that measures distance between two distributions in order to make it possible to merge classes that are close to each other and to increase the number of classes in the typology in order to obtain less noisy classes ; (ii) the Apriori algorithm that allows searching frequent items of different lengths and thus promotes rapid interpretation of classes ; (iii) the algorithm MBD-LLBORDER that seeks emerging items whose frequency increases significantly from one class to another and thus can extract the differences between classes to better characterizing them ; (iv) the D3 JavaScript library for the development of a website that provides, from ARPENTAGE results, an interactive visualization of landscape types at the same time as their most common landscape elements. The generic aspect of this approach will be tested on two other territories of close extensions but of contrasting landscape features.

Crossing expert knowledge and databases to model the cropping systems of an irrigated area

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Keywords: territory, spatialisation, participation, agricultural practices

This work is the first step of a design-and-assessment project for the spatial management of water. We present the collaborative construction of a spatially explicit, agent-based simulation model which represents interactions between the institutional, hydrological and agricultural domains of the territory. One of the challenges was to describe the spatial distribution of cropping systems in the territory.

We aimed at localizing and describing the cropping systems exhaustively on the 12,000 field blocks of the studied territory, the downstream part of Aveyron catchment (840 km^2). A cropping system is defined by the crop sequence and by the management system of each crop. We modelled the crop management systems by formalising the decision rules of the farmer instead of fixed dates because the sequence of technical operations is highly variable from one field to another depending on farm level labour organization and climate. Those rules are based on the observation of the farmer agent environment. In order to represent all cropping systems on all 12,000 field blocks, we iteratively crossed local expertise with quantitative and georeferenced information on yearly crop surfaces available from the "Land Parcel Identification System" (LPIS) database. This was possible through continuous interactions with about forty actors. Participative mapping workshops allowed us to specify and locate the crop rotations, while semi directive farmer interviews enabled us to capture the farmer strategies associated to crop management systems.

At the end of this work, we are able to attribute a cropping system (rotation and management systems of each crop of the rotation) to each of the fields of the downstream Aveyron catchment. We describe about 30 crop management strategies (sets of decision rules) using 17 crop types including 7 maize cultivars. This set of cropping systems is integrated to the multi-agent model for simulating irrigation withdrawal dynamics from each field and in all water resources of the territory (dams, aquifers, rivers). This stage of co-representation of the territory was crucial because it allowed to familiarize the actors with our participative modelling approach and aroused their curiosity for the continuation of the process which aims at designing and evaluating alternatives of spatial distributions of cropping systems to minimize the occurrence of water management crises.

Session 3

Landscape characterisation and dynamic simulations

Importance of spatially explicit and farm-based modelling in designing and assessing agro-environmental policies: the cases of biodiversity conservation and lignocellulosic biomass supply

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Keywords: spatial modelling, mathematical programming, micro-economics, agro-environmental policy, agricultural supply

This thesis tackles the difficulty of designing public policies that allow for an effective spatial distribution of agricultural activities from an environmental point of view, in the fields of the production of biomass for energy purposes and the conservation of biodiversity. The models developed herein to design and assess such policies account for changes in agricultural activities and practices as well as their location. This is achieved by considering spatial features, decision making at the farm level, and detailed modelling of farming systems.

In the first part, we place ourselves upstream from policy design so as to determine if lignocellulosic biomass production complies with sustainability criteria or if there is a need to implement a policy to do so. We have developed a spatially explicit regional supply model with a county sub-level for agricultural and forest lignocellulosic biomass. Spatial aspects are accounted for in terms of agropedoclimatic context as well as transportation distances and costs from counties to bioenergy facilities. We have applied this modelling approach to the case of the French Champagne-Ardenne region, to analyse biomass supply and its impacts when facing an increased demand for lignocellulosic feedstock. Our results highlight the potentially problematic competition for the most fertile agricultural land between food and energy crops.

In the second part, we address the issue of designing a cost-effective agro-environmental policy which generates a non-aggregated spatial distribution of fields enrolled in a programme aimed at Tetrax tetrax conservation in the Plaine de Niort, France. We have developed a spatially explicit and detailed farm-based optimization model that accounts for the agropedoclimatic context as well as the relationships between the field, farm and landscape levels. Moreover the model is coupled with a relevant spatial pattern index. We compare the budgetary cost and effectiveness of different policy instruments.

Treating both the spatial aspects and decision-making at the farm level in mathematical programming models makes it possible, on the one hand, to more accurately assess compliance costs and, on the other hand, to highlight and analyse the tradeoffs between the cost and the environmental effectiveness of public policies. This modelling approach therefore provides the means to better design and assess environmental policies in the agricultural sector.

Impact of livestock systems management on ecological continuities: a modeling-simulation framework proposition.

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Keywords: Livestock farming system, Ecological continuities, Spatial Modelling, Scenarios

Green-way policies usually focus on ecological continuities between semi-natural elements of landscape (hedgerows, permanent grasslands, woods). These policies consider that other agricultural landscape elements have a negative impact on biodiversity or no impact at all. Recent works have shown that the amount of crops in fields and continuities between different crops within a landscape could also have a positive impact on biodiversity. These landscape patterns are directly linked to farmers' decisions about the choice of crops they cultivate and their allocation on the fields of the farm. In livestock farms these decisions are related to animal management.
Thus the aim of the work we present is to analyse the impact of animal management systems, particularly the choice of animal production and the choice of feeding management, on the variability of landscape composition and structure. To realize that analysis, we developed a five steps method:

1. Analysis of cropping plan and crop allocation decisions based on a survey in a diversity of Britain livestock farms (dairy, swine and poultry farms, farms combining several livestock productions)
2. Modelling of farmers decisions for different production systems
3. Model validation by face validation: the farmer himself validates the model based on simulations realized on his farm with his rules
4. Simulation of contrasted scenarios: we combined two landscapes (contrasted on the length of hedgerows) and different proportions of production systems (dairy with grass or corn as a main forage and swine without on-farm feed production)
5. Analysis of simulated landscapes on the basis of landscape features that potentially explain biodiversity

Simulation modelling of organic waste management on a territory scale

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Keywords: simulation, systems dynamics, representation of action, logistics, organic wastes

The strong increase in the world's population, namely in urban areas, renders necessary to produce more food as well as to deal concurrently with an increased waste production. In this context, recycling organic waste products in agriculture contributes to improve its sustainability, namely by reducing its environmental impact by substituting those wastes for mineral fertilizers applied to crops.

Devising agricultural production systems based on the recycling of organic wastes organized on a territory scale needs the use of numerous and heterogeneous pieces of knowledge both on these systems' biophysical (organic wastes, soils, crops, environment) and human (farmers' management practices, collective organization) components.

In this perspective, we develop dynamic simulation models enabling this knowledge to be integrated with the aim of representing these systems as sets of spatially distributed production and consumption units. These models allow one to simulate waste products management scenarios both at the farm and territory levels and to assess their agronomic and environmental performances.

The two main aspects of the waste recycling issue will be presented: configuration of waste production and consumption unit networks; synchronization of waste supply and demand flows. The Action-Flow-Stock ontology and formalism designed to make dynamical simulation models of these systems will be described. The use of these models will be illustrated on a few cases.

Changes in agricultural landscapes and beekeeping: a complex overlapping of management entities and functional units

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Keywords: agriculture, beekeeping, management entity, landscape, socio-ecological system

Modern bee-keeping has progressively transformed a leisure activity into a commercial one with an increasing interaction between honey bees and crops. Three contrasting situations set up the scene in France: crop farmers provide specific nectar-rich plants to bee-keepers producing a labelled honey (i.e. wheat-lavender farming systems), crop farmers require pollination from honey bees (i.e. fruit trees), and beekeepers take profit of oilseed crop's nectar (i.e. raps and sunflower cropping systems). These situations raise a specific landscape dynamics modelling issue because these two stakeholders do not plan their management at the same time and space scales. Moreover, the farmer management entities are topologic while the beekeeper ones are center-periphery.

A participatory research is undergoing to encourage farmers and beekeepers to collaborate and cooperate through a companion modelling process in which a landscape dynamics model is used as a boundary object between both stakeholders. The model simulates the agricultural landscape dynamics and its impact on the dynamics and productivity of beehives to support understanding and discussing the complex interactions between bees and crops. The three mentioned socio-ecological systems are represented by a virtual landscape, representative of crops types and plot and farm size, representing a typical agricultural landscape adaptable to specific contexts of agricultural practices (organic vs conventional, with or without hedgerows, exclusive cash cropping vs cash cropping and livestock rearing). The agricultural landscape dynamics is driven by the cropping plan and crop rotation rules enacted by the farmers, and the beehives dynamics is driven by the location and maintenance decisions taken by the beekeepers and according to the impact of agricultural practices on bees' health.

The issue of the overlapping of farmers and beekeepers management entities and bees functional units is discussed. The problem of time shifts between landscape changes and their impact on the functioning of the socio-ecological system is underlined. The way theses interactions are simulated by means of an agent-based model is presented.

ATLAS: an agricultural landscape dynamics simulator for the study of the interactions between the landscape and insect population dynamics through a multi-agent approach.

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Keywords: Agricultural Landscape, Crop rotations, Phenology, Simulator, GAMA

In the context of pesticides reduction in agricultural landscapes, the solicitation and favouring of regulative ecosystem services, especially via natural enemies of crop pests, represent an alternative solution. This lead needs to be further analysed in terms of the efficiency of different possible scenarios of application.
Agricultural landscapes are particular ecosystems with high spatial-temporal variability. Crop rotations and crop phenology define a dynamical patchwork in the landscape that can highly influence the life cycles of the pest and their natural enemies.
In order to test scenarios of spatial-temporal organizations of the landscape in the aim of favouring pest regulation, we developed on a multi-agent platform the ATLAS (AgirculTural LAndscape Simulator) model. This model simulates the dynamics of the landscape in a simple and generic way. It relies on the attribution of a crop rotation to each cultivated field of an agricultural landscape and takes into account crop phenology through sowing periods and thresholds of development based on degree-days. The spatial data needed as an input are based on the covers observed during an initial year. According to user-defined rotations, the model will assign a rotation to each field based on the initial cover defined in the spatial data and a statistical method.
The ATLAS model was validated on a landscape part of the LTER zone (LongTerm Ecological Researcg Site) of the Coteaux de Gascogne, in the south-west of France. Validation was done by comparing the spatial-temporal patterns of the simulated covers to observed data.
The ATLAS model allows the simulation of a dynamical agricultural landscape in which both crop rotations and crop phenology are taken into account. Both of these can directly influence the population dynamics of pests and their natural enemies. Coupled with population dynamics models, ATLAS can be a great tool to test the interactions between the landscape and these populations. It could also be used to test the effects of different scenarios such as spatial-temporal landscape management scenarios (cover placement), agronomical practices scenarios (sowing dates), climate change scenarios (based on weather data) and their effects on pest regulation.

Session 4

Landscape influence on biotic and abiotic processes

Exploring pest regulation in the context of dynamic agricultural landscapes

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Keywords: Landscape dynamic model, population dynamics, biological regulation, fragmentation, spatio-temporal heterogeneity

Given nowadays understanding of pesticides harmful effects on the environment, alternative control methods against pests are to be assessed. Among these, biological regulation by natural enemies appears as a potentially strong means of action. For example, it is commonly admitted that densities of most pest natural enemies in fields are strongly linked to the presence of non-crop habitats [1]. Furthermore, the physical environment and/or farming systems involve many types of patches (such as crop fields, woodlots, etc.) which impact the survival of pests and their natural enemies.
Therefore, in order to study the role of landscape fragmentation or/and crop rotation on pest regulation, we explored pest distribution at the landscape scale through *in silico* experiments by combining a dynamic landscape model with a population dynamics model. The spatially explicit component of our agricultural landscape model was based on a Gibbs measure which enabled us to control the landscape configuration. We allowed four land-use possibilities to be attributed to the fields, namely: semi-natural habitat, crops with no insecticides use, crops lowly treated (moderate use of insecticides) and conventional crops (excessive use of insecticides). The landscape configuration was defined by the proportion of each land use and its index of fragmentation [2]. The landscape evolution over time was modelled as a Markovian process defining patch rotations. Coupled to this landscape model, the population dynamics model essentially relied on a Lotka-Volterra system simulating the dynamics of pests (preys) and their natural enemies (predators).
Based on these coupled models, we investigated the impact of landscape spatio-temporal heterogeneity on a function of pest density which we used as a proxy for pest regulation.
This work is part of the ongoing PEERLESS ANR project whose aims consist in assessing the economic acceptability of alternative agricultural practices and conducting a cost-benefit analysis of given policies to control insect and weed pests.

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Simulation of a borders and fields model, application to pest control on landscape

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Keywords: partial differential equations, population dynamics, biological pest control, simulation, multidimensional coupling

The recent study [1] deals with the influence of a line (1D) on a two-dimensional (2D) biological invasion. The authors propose a model where the two-dimensional environment includes a line on which fast diffusion takes place while reproduction and diffusion only occur outside this line. They establish the line can accelerate the 2D invasion.
We propose here to adapt this model to agricultural landscape geometries. This allows us to study the influence of field borders on the efficiency of natural predators in order to control a biological pest.
For this purpose, we simulate a spatialized Lotka-Volterra model on two types of habitats: some 2D fields and some 1D field borders. Each geometrical element is associated with a particular dynamics. These dynamics are connected with some fluxes. The originality of this work consists in coupling 2D and 1D partial differential equations to model the global population dynamics. We have developed a software to simulate this model based on a geometrical description of the landscape. We compare different strategies of pest control. Based on these simulations, we show the efficiency of field borders to control a pest population.

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Modelling the trajectories of Lepidopterans within a heterogeneous landscape

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Keywords: stochastic landscapes, individual-based model, trajectories, Lepidopterans

The understanding of the spatio-temporal dynamics of populations (pests, auxiliaries, species of heritage interest...) at the landscape scale is crucial to design efficient management strategies of these populations. Within highly anthropised systems such as agro-ecosystems, the habitat of organisms is generally fragmented and heterogeneous. As the structure of the landscape can impact, for instance, biological dispersal, the apprehension and the prediction of population dynamics at a regional scale can be challenging.
In the particular case of Lepidopterans we can generally distinguish between elements of the landscape that are attractive (areas where nectariferous and/or host plants are present) and elements which are repulsive, or, which have a barrier effect (hedges for some species). Here, we present a modelling framework for simulating trajectories of Lepids within a heterogeneous agricultural landscape that influences the movement of individuals. We begin by presenting an individual-based model, built with a system of stochastic differential equations that describes the movement of particles among a force field. Then, we propose a methodology for i) simulating landscapes within attractive and/or repulsive areas located in field margins, and, ii) build a force field among which Lepids move. To finish with, we show results from simulations in order to illustrate how this modelling framework could be used to investigate the effects of the structure of agricultural landscapes on the spatio-temporal dynamics of organisms such as Lepidopterans.

Comparison of statistical frameworks to study the relationship between landscape features and pest insects abundance

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Keywords: landscape metric, simulation model, generalized linear models, random forests

Pest management is an important issue for agriculture. There is an increasing ecological concern about the systematic use of chemical products, urging the scientific community to develop new pest management strategies. According to current knowledge, the structure and the composition of the landscape have an impact on the dynamic of pest populations, notably by providing more or less resources or habitat to pest. In order to be able to use landscape management as a tool for pest management, effects of agricultural landscape features on these populations need to be assessed. This purpose raises some methodological questions as the estimation of the scale of effect [1], the choice of the appropriate statistical methods or the definition of relevant metrics to describe the landscape [2]. This study focuses on the oilseed rape/pollen beetle (*Meligethes aeneus*)/parasitoid (*Tersilochus heterocerus*) system, known to be under a great landscape influence [3], and for which there are both observation data [4] and a simulation model [5]. Based on the classification of the land cover, we tested a set of landscape metrics describing the landscape in terms of proportion of a cover or shape and configuration of patches. Statistical frameworks establishing the relationship between insect abundance and landscape metrics were applied on simulated and observed data: mainly, the generalized linear models with several variable selection procedures, an approach of multi-model inference and the random forest approach. Working on a simulated dataset enables to analyse if, and to what extent, the detected effects match the expected signal. The main effect validated by all the methods, is due to the proportion of woody area in the landscape. The metric of class area proportion is also validated as a relevant metric to explain pollen beetle abundance. Moreover, this metric is easy to calculate and interpret, unlike metrics describing the shape or the configuration of patches. This work is part of the COPACABANA project (funded by the INRA SMaCH meta-program) whose purpose is to establish the influence of landscape features on the genetic structure and on the dynamic of pest populations.

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PODYAM and MODPEST
Tools for modelling the population dynamics of several pests at the landscape scale

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Keywords: model, epidemiology, population dynamics, natural pest control, multi-pest

Integrated Pest Management (IPM) requires that several control methods be combined in order to control simultaneously several pests. Many models have been developed to predict disease epidemics and insect pests' population dynamics and to help design control strategies for a single pest on a single crop. But it is difficult to design IPM strategies based on these models because of the lack of common formalisms or even common state variables between the different models. As a result, it is not possible to simulate the effects of cropping practices on the pest profile of a given crop, nor the unintentional effects of control methods applied to a given crop on the other crops in the rotation or in the landscape. Here, we propose a set of tools to help modellers build simulation models for any set of pests (weeds, diseases, insect pests) or natural enemies in order to predict the effect of the spatial configuration of control methods on all the main pests in an agricultural landscape. MODPEST is a database that contains equations and parameters that can be used to represent the processes in each pest's life cycle as well as biological traits of these pests. The database already contains equations obtained from the analysis of 37 models from the literature. PODYAM is a modelling framework that can be used to combine these processes into a working model and run simulations. In PODYAM, space is represented as a hierarchy of pixels of several sizes, allowing representing each species at a relevant scale. The population of each species is divided into several compartments representing either the development stage (e.g. for insects), the different forms (e.g. for fungal diseases) or the different organs (e.g. for plants). The life cycles of all organisms, as well as crop management, are represented by generic processes that modify the abundance matrices (pixels x compartment) of the different species, and that use different interchangeable functions for different species, with parameters also depending on the species. A graphical user interface can be used to guide the user through the different steps needed to define his own model, or to modify existing models. In order to demonstrate the genericness of the approach, three existing single-pest models working at the landscape scale were adapted within the framework: a model of brown rust of wheat, a model of blackleg of oilseed rape and a model of pollen beetle of oilseed rape.

Fragmentation, habitat instability and evolutive process in landscapes: individual-based modeling of dispersal syndromes

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Keywords: dispersal, evolutionary ecology, landscape ecology, indidivual-based modeling

Dispersal is a central process in a number of areas in ecology and evolutionary biology (e.g. Clobert et al. 2012). It is also one of the main process linking landscape structure, dynamics and population functioning. In the current context of global changes, dispersal is particularly crucial by allowing individual and species to locally buffer changing environmental conditions, or to follow the geographical shift of their niche (e.g. Travis, 2003). Thus, it is an important priority to gather information on the links between landscape and dispersal, so that we can anticipate the effects of global changes on species distribution, community composition and ecosystemic services. Dispersal has long been considered as a fixed trait in population and species, but a growing number of evidence suggest that it is in fact both a plastic and evolving trait (Clobert et al., 2004).
Using and individual-based model (IBM) simulating the movements and the evolution of a species in a fragmented and dynamic landscape, we study the evolution of different dispersal parameters with the characteristics of landscape, in the context of the cost/benefits balance associated with movements. We use this model as a case-study of the effects of evolutive feedbacks happening during landscape management and conservation ecology process, with the example of the creation of ecological corridors.

Impact of elementary landscape patterns on the fine-scale spatial genetic structure

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Keywords: landscape patterns, landscape genetics, spatially-explicit dynamic modelling, point pattern process

One of the goals of agroecology is to provide alternatives to the use of pesticides through new strategies of pest management, for example, based on modifications of the spatial organization of cropping systems [1]. Rational developments of such new strategies require estimating the effects we may expect from the landscape structure and composition on the demogenetics of populations. Yet, typical studies in landscape genetics [2] infer the effects of landscape structure from the spatial distribution of genetic variation using real and complex landscape data and samples from populations. This assumes that genetic and demographic variations over the landscape arise from its spatial structure. In this work, we proposed to investigate how elementary landscape patterns impact the fine-scale spatial genetic structure (SGS) and understand its spatial distribution. To answer this question, we built a spatially explicit and individual-based model associating landscape, genetics and population dynamics. We focused on 3 landscape patterns that differ in concavity of the structuring element inside a suitable habitat and easiness to be bypassed: a barrier, a widely studied pattern in landscape genetics and landscape ecology, a square representing an archetypal agricultural field and a cross to evaluate the effect of convex pattern. As controls, we used an empty landscape (leading to the isolation-by-distance situation) and a panmictic model. In our simulations, we make the resistance and the proportion of the structuring element varied and we observed their impact on point process indices as well on two genetic indices: the *Sp* statistic, used to quantify the SGS [3], and the linkage disequilibrium index $\bar{r}_d$. After 400 generations of reproduction in those landscapes the studied patterns can be indirectly inferred using the indices. However, for some resistance values and proportion of the structuring element, patterns with nearby concavities cannot be disentangled. Patterns hardly contrast when the overall resistance increases except for $\bar{r}_d$. Values of *Sp* and $\bar{r}_d$ both increase with the resistance of the proportion of the structuring element. The main mechanism we identified to shape the genetic diversity arose from the fact that the stronger the structuring element is in the landscape, the less breeding individuals exchange with the most distant individuals. In conclusion, we showed that landscape patterns have significant impacts on fine scale genetic structure, and thus can be inferred from spatial genetics when relevant indices are used.

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Mechanistic modelling of atmospheric dispersal of biotic and abiotic particles at landscape scale

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Keywords: Fluid mechanics, Landscape, Pesticide, Pollen, Dust

Many environmental and ecological issues appear at landscape scale in relation to agricultural practices: what is the impact of landscape heterogeneity on particle fluxes? How to organize better the landscape? etc. These issues fall within the context of (1) the integrated production, i.e. to limit the use of phytosanitary inputs based on environmental resources, while maintaining the quantity and quality of production, and (2) the adaptation of farming systems to extreme events such as drought. In both cases, it is required to control the development and spread of diseases (spores, microbial aerosols), invasion of crops by weeds (gene flow), the loss of soil nutrients (mineral dust), the pest outbreaks, etc.., and this while preserving biodiversity (gene flow). Atmospheric dispersion processes play a fundamental role in the flow of these biotic and abiotic particles between the different compartments of the ecosystem and between ecosystems. These processes are highly dependent on air flow at these scales, which is all the more complex as the landscape is heterogeneous.

The Environmental Mechanics team of UMR ISPA has in recent years developed a set of numerical tools to simulate with high details the flow dynamics in the lower atmosphere (from the plant to the region scale), the vegetation-atmosphere interactions, and the turbulent dispersal of gaseous or particulate compounds. These tools, now available, well suited for various landscapes for which they can explicitly represent heterogeneities, can renew the way to investigate some ecological and environmental issues in which the air flow plays a key role. These models have been applied-adapted in heterogeneous conditions for the dispersal of (1) maize pollen in the context of coexistence between GMO and non-GMO crops, (2) pesticides over vineyard in the context of limiting their environmental dissemination, or (3) mineral dust in the context of limiting soil erosion by wind and therefore the loss of soil nutrients. These mechanistic models are interesting tools, complementary to field measurements that can be helpful to develop simple statistical approaches, for operational or finalized use, incorporating the heterogeneity of the landscape.

Impact of landscape structure on hydro-sedimentary transfers. Approach by multi-agents systems

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Keywords: multi-agents simulation, run-off, landscape, hedges, ditches

The hydro-sedimentary transfers on the slopes have a significant impact on environmental watershed resources (soil erosion, diffuse pollution, reduced fertility, flood ...). Understanding the spatial dynamics of runoff from the agricultural parcels to the watershed outlet is a major challenge of water systems management. In absence of obstacles, slopes guides flows from the initiation zones to the stream. However, in hedgerows landscape, anthropogenic linear patterns such as hedges and ditches, complicate this purely topographic dynamic and modify the routing of flows on slopes. This is a cause of hydrological disconnection between the agricultural parcels and the streams.

This communication aims at presenting a model for runoff dynamics reconstruction adapted to hedgerow landscapes. To understand the effects of landscape structure on the flow surface processes, we propose an approach based on a multi-agent system, able to highlight the role of linear elements (local) on the hydrological functioning of watersheds (global). Based on very simple iterative processes, simulations can reproduce the complexity of flows trajectories induced by the landscape structure. For this, the dynamic process (flow) is discretized in several agents having the ability of moving in the simulation environment following topographic parameters derived from a digital terrain model as well as hedges and ditches entities. Simulations allow not only identifying the individual trajectories in the landscape of each of the agents but also building spatial indices characterizing the effect of the landscape roughness (visualization of input and output points in linear networks, localization places to changes in flow behaviour, impacts of linear elements on flows time transfers ...). All simulations were validated by several filed checks on the experimental watershed in Calvados (Lingèvres 15km ^{2}).