Effects of landscape spatio-temporal heterogeneity and of food web structure on biological control for pest regulation

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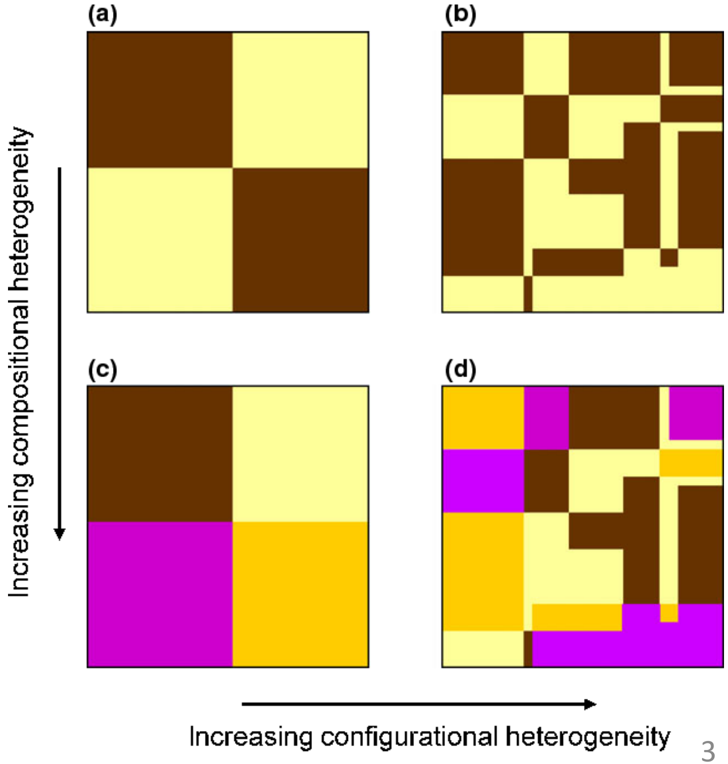
2019-2020

Landscape complexity

Agricultural landscapes vary from **structurally simple** landscapes with **one** or **two** **cropping systems** to **complex mosaics** of **diverse cultivated fields** embedded in a **natural habitat** matrix.

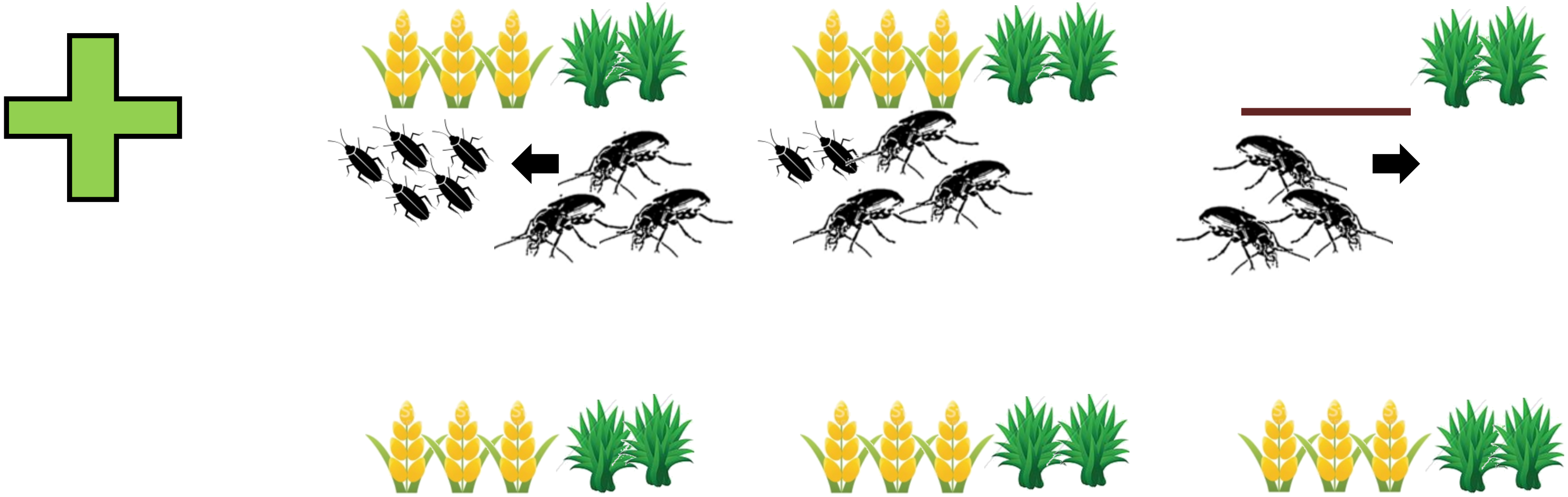
(Power, 2010)

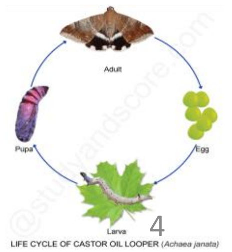
Landscape complexity as Landscape heterogeneity



(Fahrig et al. 2011)

However, the nexus among **agricultural landscape structure** and **the species trophic interactions** is not trivial:

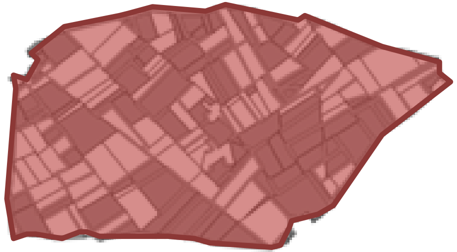




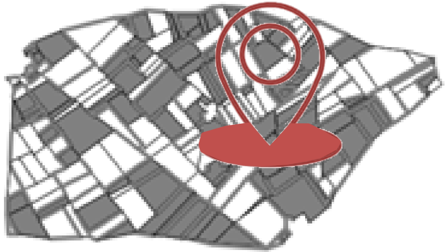
(Rand 2006, Blitzer 2012, Tscharntke 2016)

Objectives:

1) Couple **landscape features** and **species traits** to provide insights **on biological control outcomes** at landscape scale



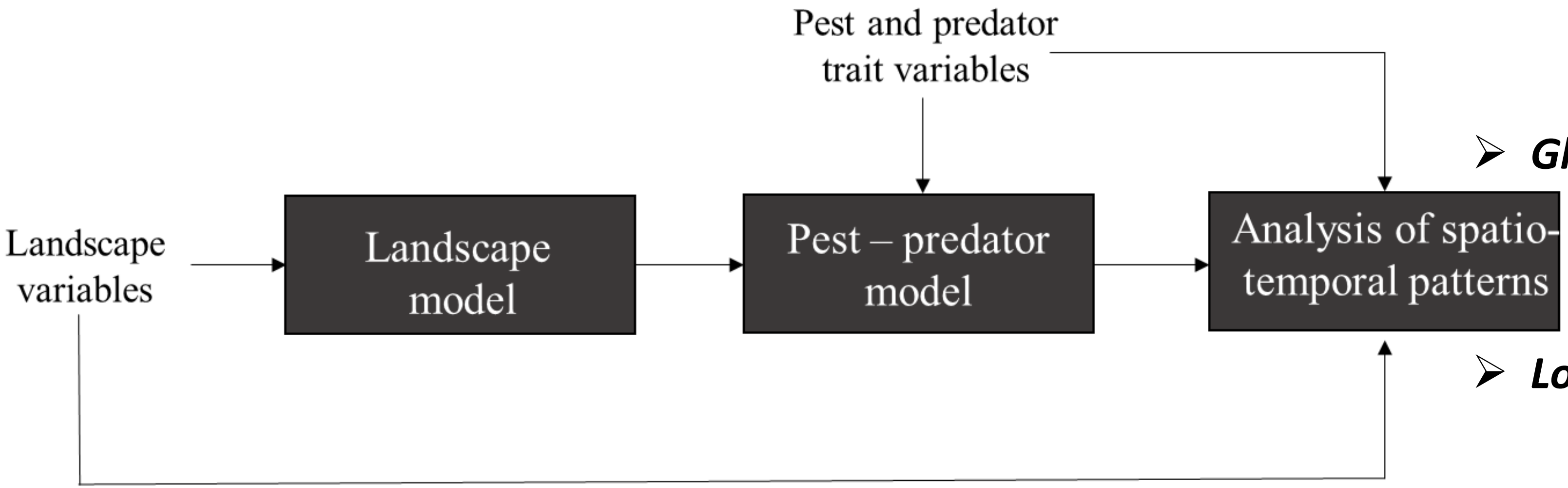
2) To assess how the **lanscape structure** is able to **locally** influence the **pest spatio-temporal** dynamic provding insigth on **biological control**

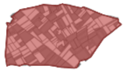


Stochastic-mechanistic prey-predator dynamic model:

- ***Global scale***
- ***Local scale***

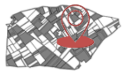
Modelling framework



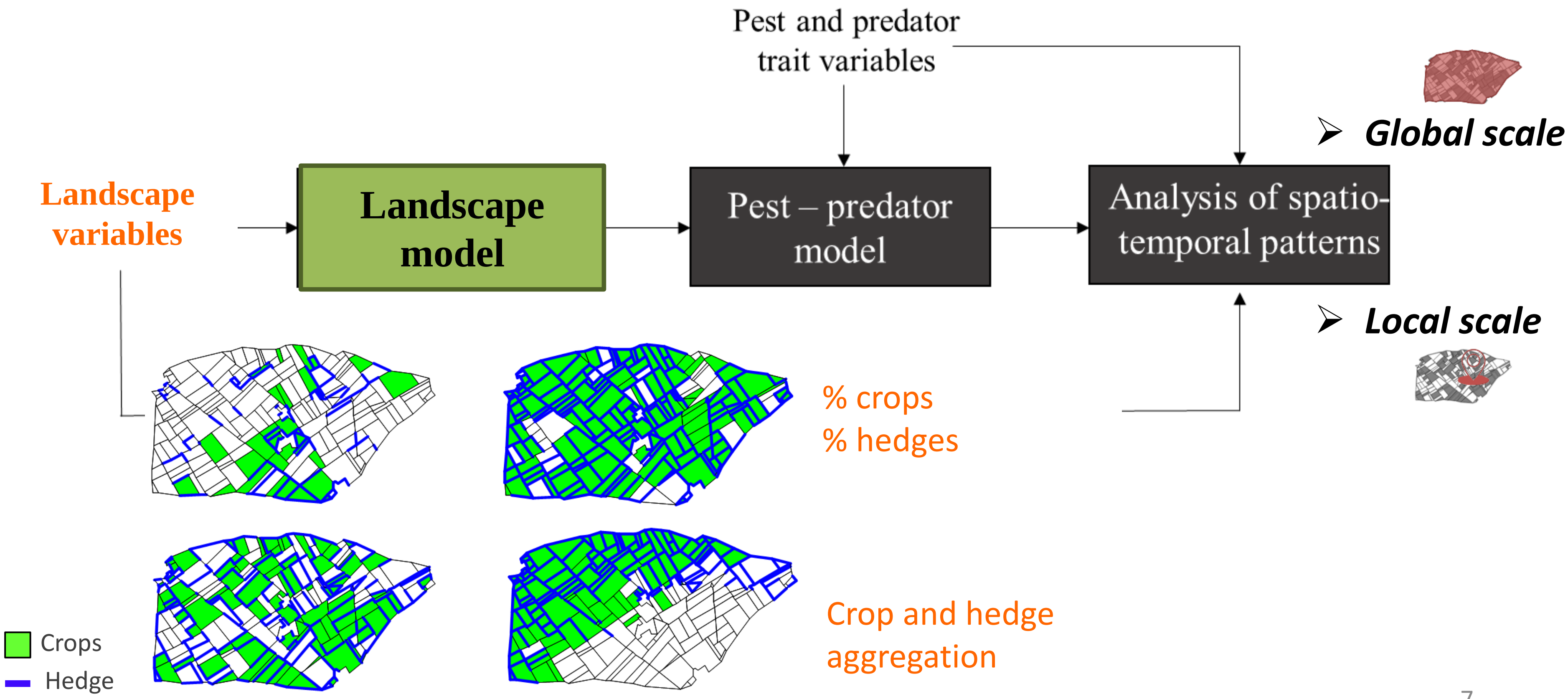


➢ ***Global scale***

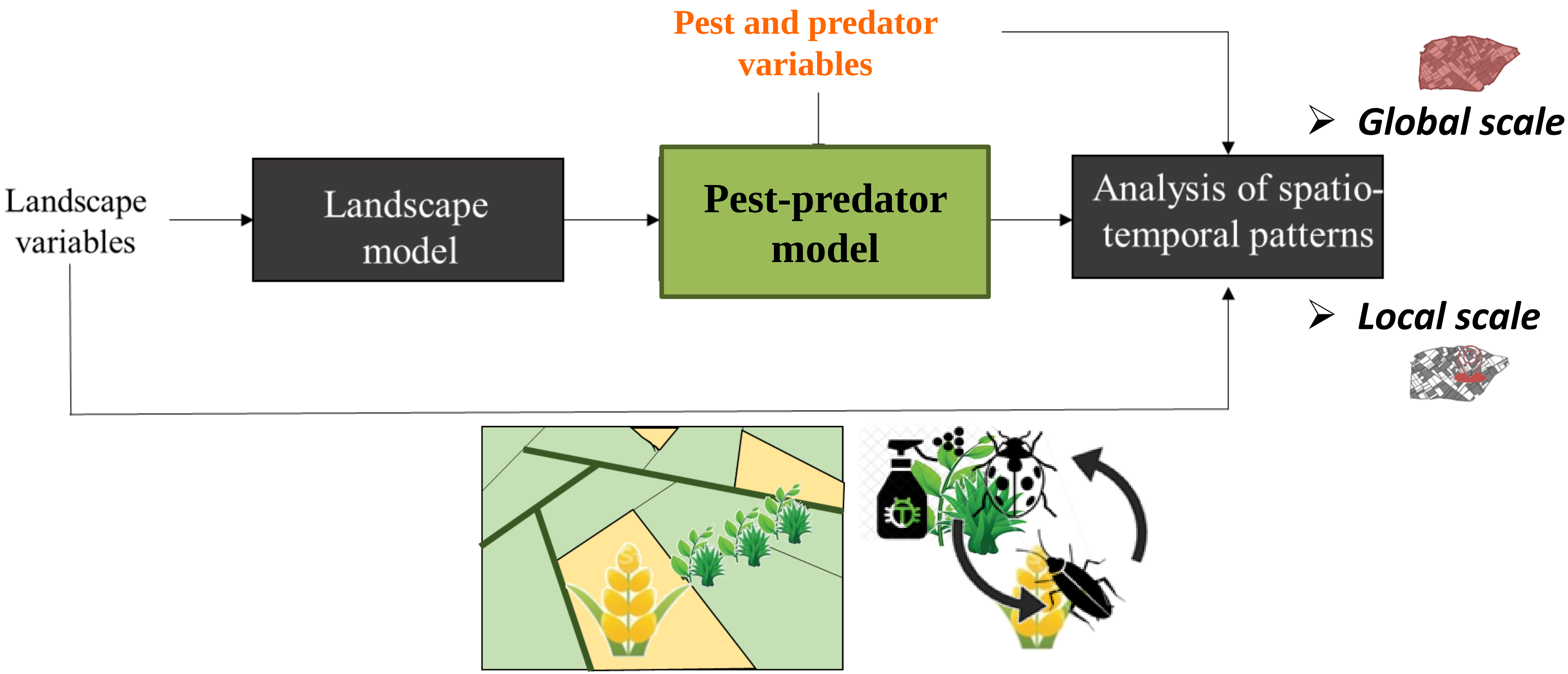
➢ ***Local scale***



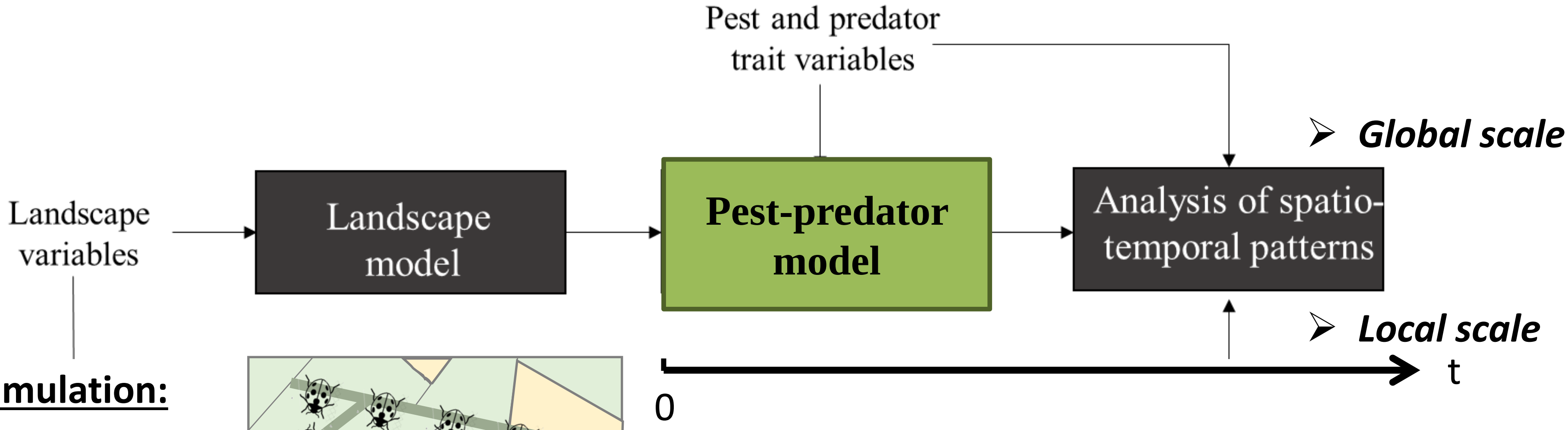
Modelling framework



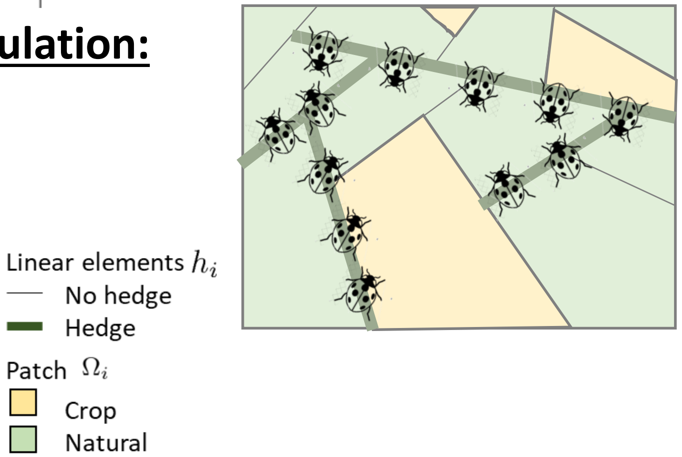
Modelling framework



Modelling framework

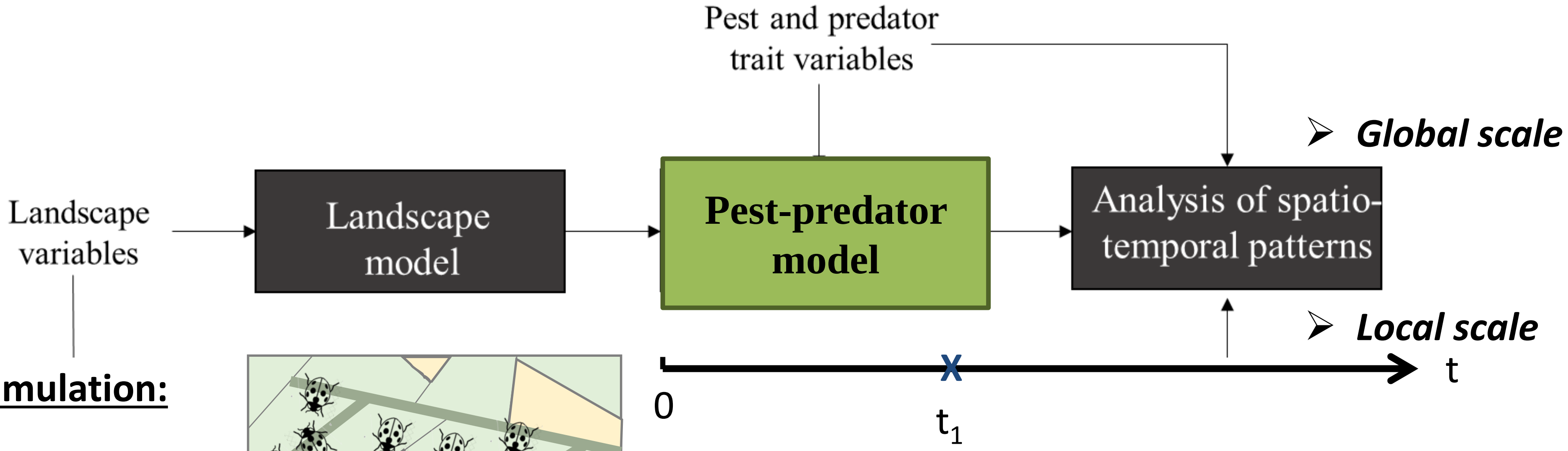


Simulation:

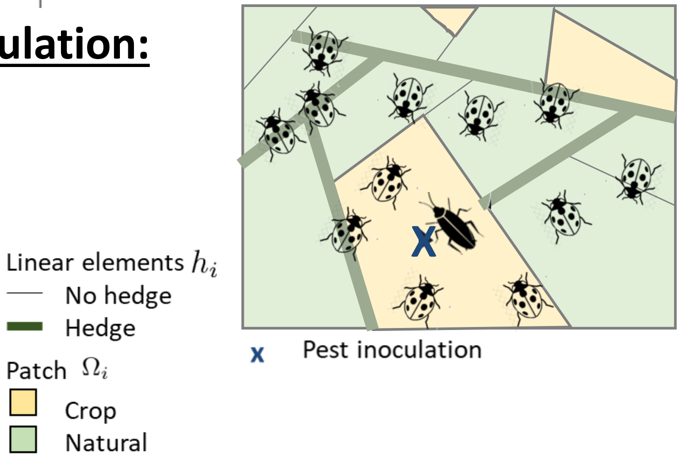


The predator is present in all hedges at carrying capacity

Modelling framework

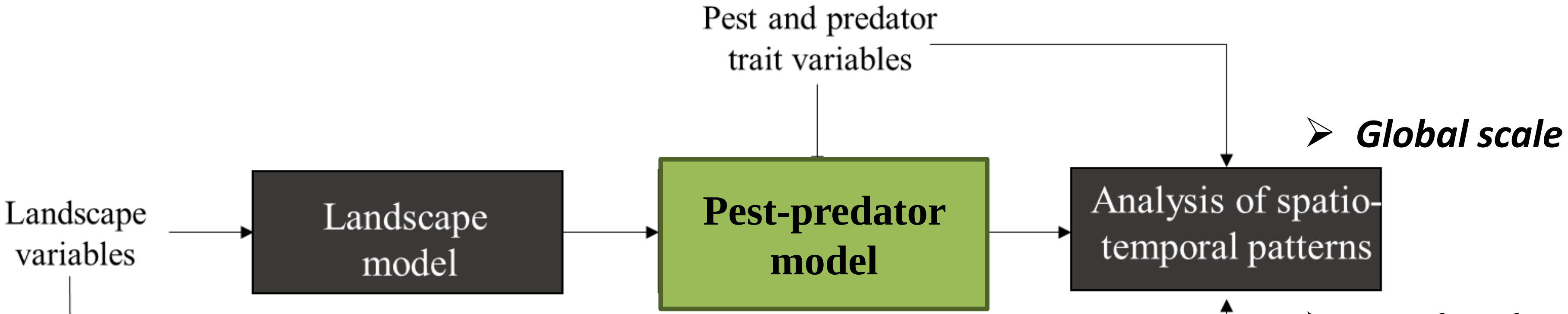


Simulation:

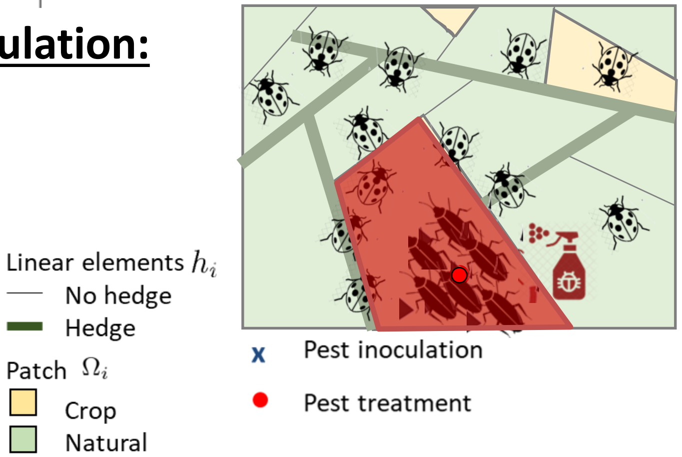


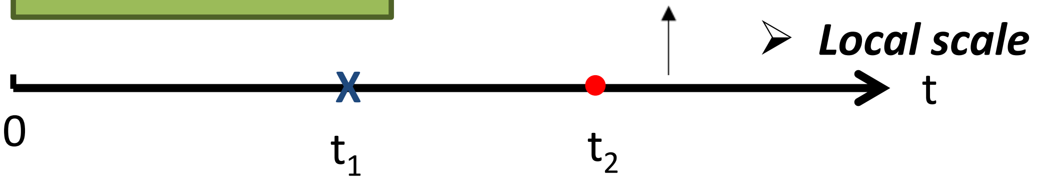
- The pest is introduced randomly in time and space
- The number of introduction in the whole landscape is proportional to crop proportion

Modelling framework



Simulation:

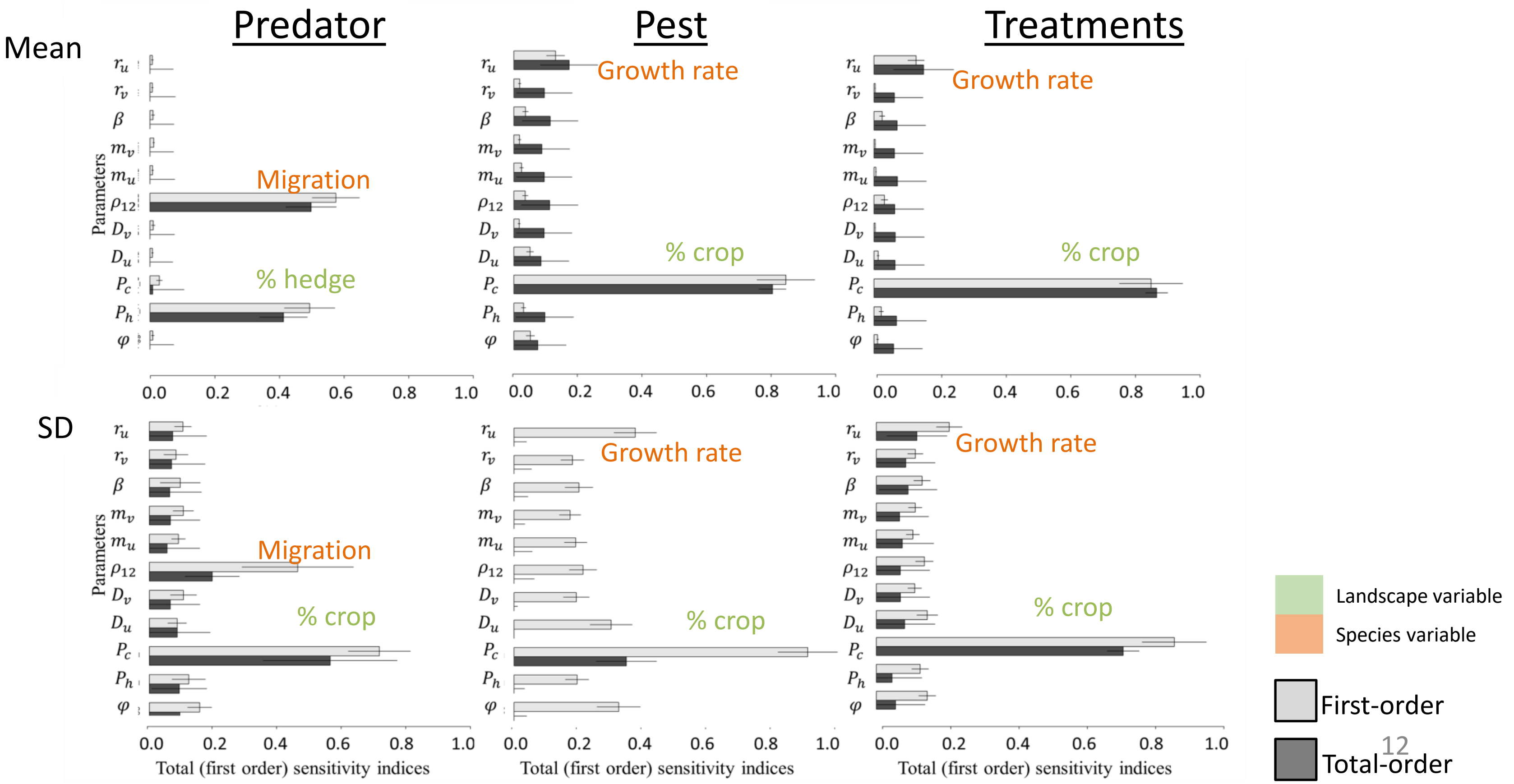




- A **pesticide treatment** is applied to a given crop field when the pest population in that field reach a give threshold

- The spatial location *(x,y)* and the magnitude of pest density at the moment *(t)* of treatment application is identified as output.

Sobol sensitivity analysis



Effects:

	+	−
Predator 	Predator migration % Hedge % Crop AND Hedge % Crop AND Predator migration	% Crop % Hedge AND Predator migration
Pest 	% Crop % Hedge Population growth % Crop AND Hedge % Crop AND Predator migration	Prey diffusion Predator migration Predator predation % Hedge AND Predator migration
Traitements 	% Crop	**# of treatments:** % Hedge; Predator migration **Presence of treatments:** % Crop AND Hedge; % Crop AND Predator migration **Presence and number of treatments:** Pest diffusion; % Hedge AND Predator migration

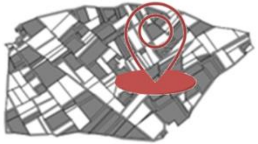
Landscape variable

Species variable

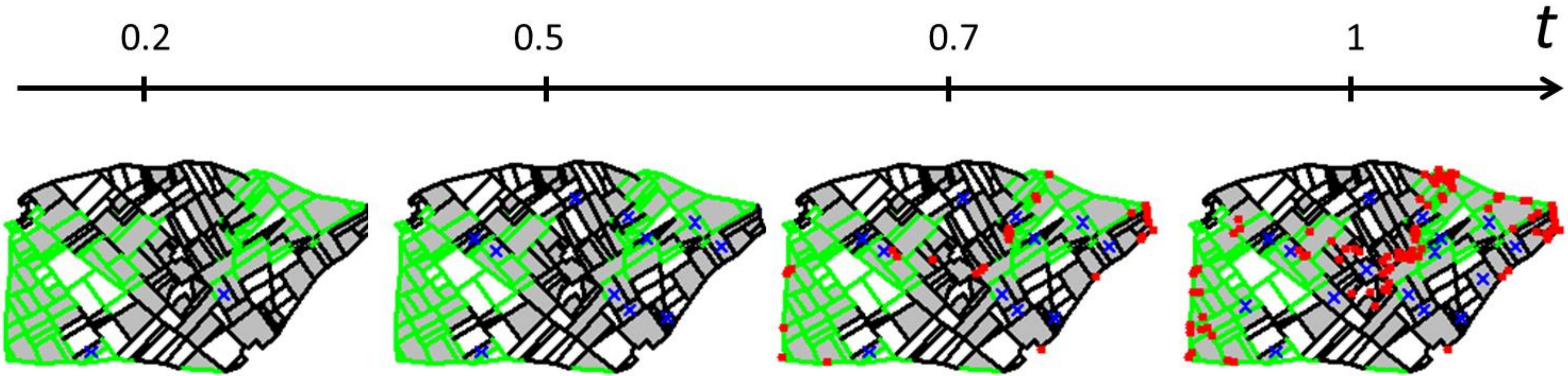
Similar landscapes with the **same number of pest outbreaks**, but with **different spatial distribution of pest density peaks**

% crop = 98%
% hedge = 0.22%
Aggregation = 4.96
N treatments = 10

% crop = 98%
% hedge = 0.35%
Aggregation = 3.22
N treatments = 10



Method:
Point pattern as spatio-temporal point process



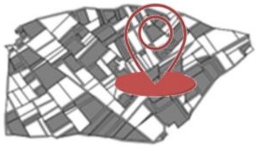
It is a collection ***X*** of pairs (s_i, t_i), $i = 1, \ldots, n$

where s_i, t_i are the spatial location and time of occurrence associated with the *i*th event

We identify the spatio-temporal point patterns:

- x **pest inoculation locations**
- ● **pest peak locations**

Spatio- temporal models in order to LOCALLY **predict**:

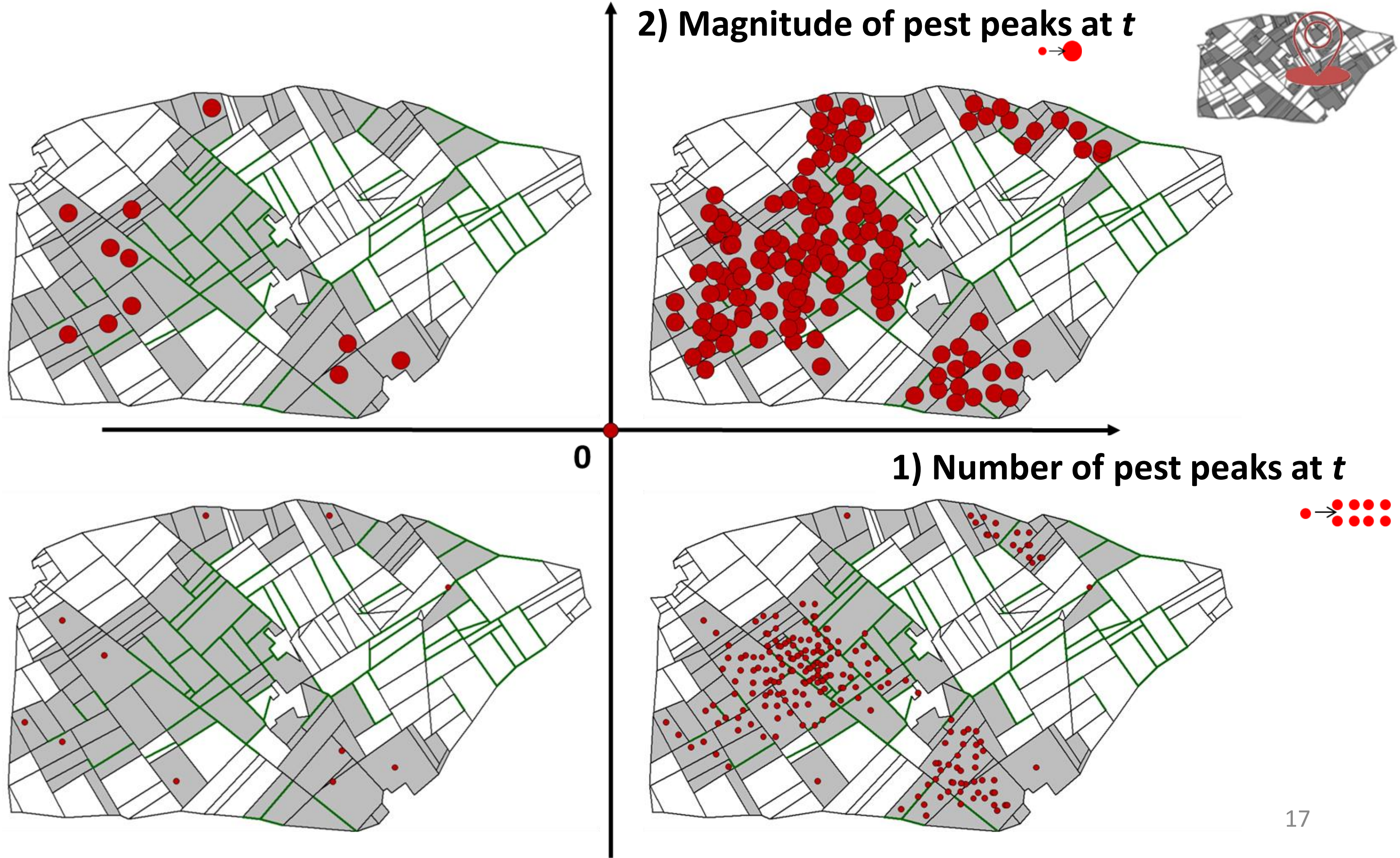


1) Number of pest density peak model $\lambda(s,t)$

$\lambda(s,t) = f($ Spatial covariates , Spatio-temporal covariates , Population dynamic covariates $)$

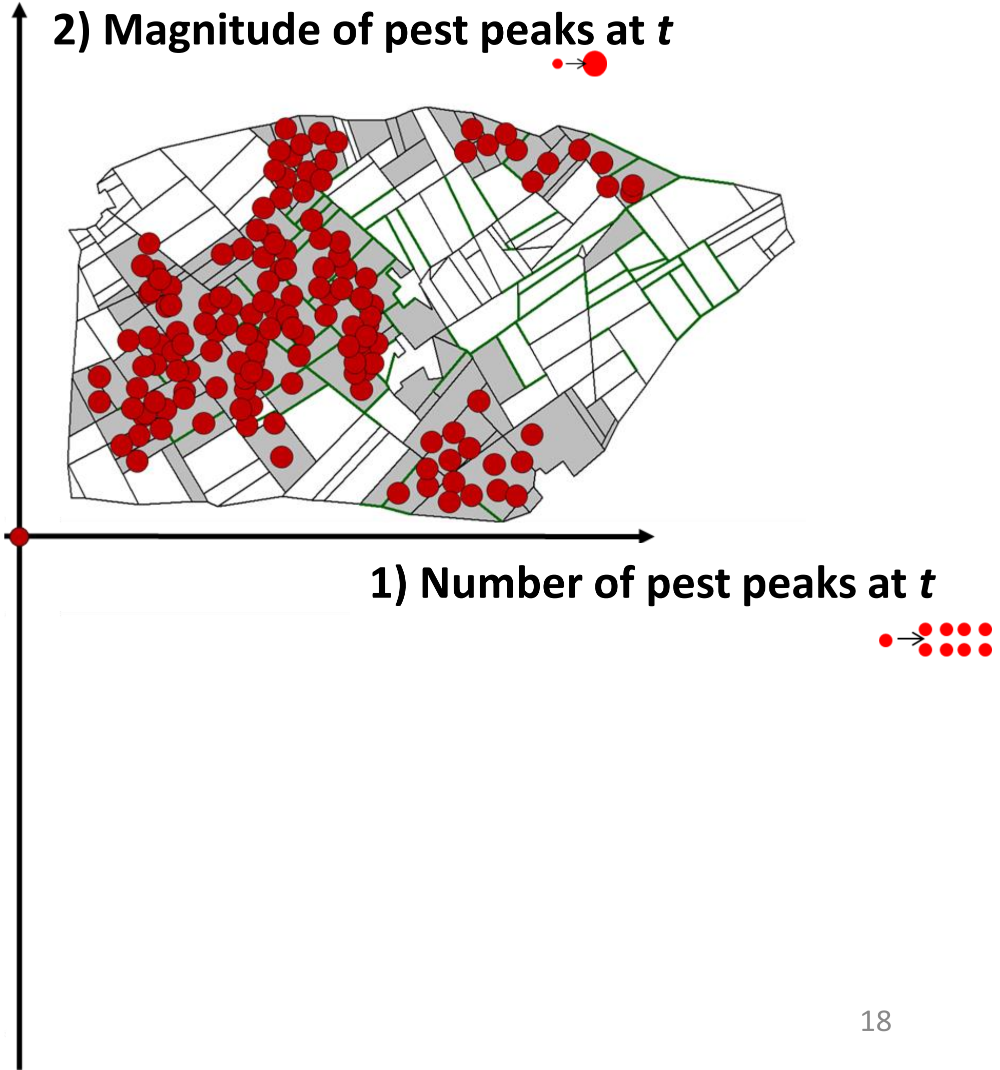
2) Magnitude of pest density peak model $P_{max}(s,t)$

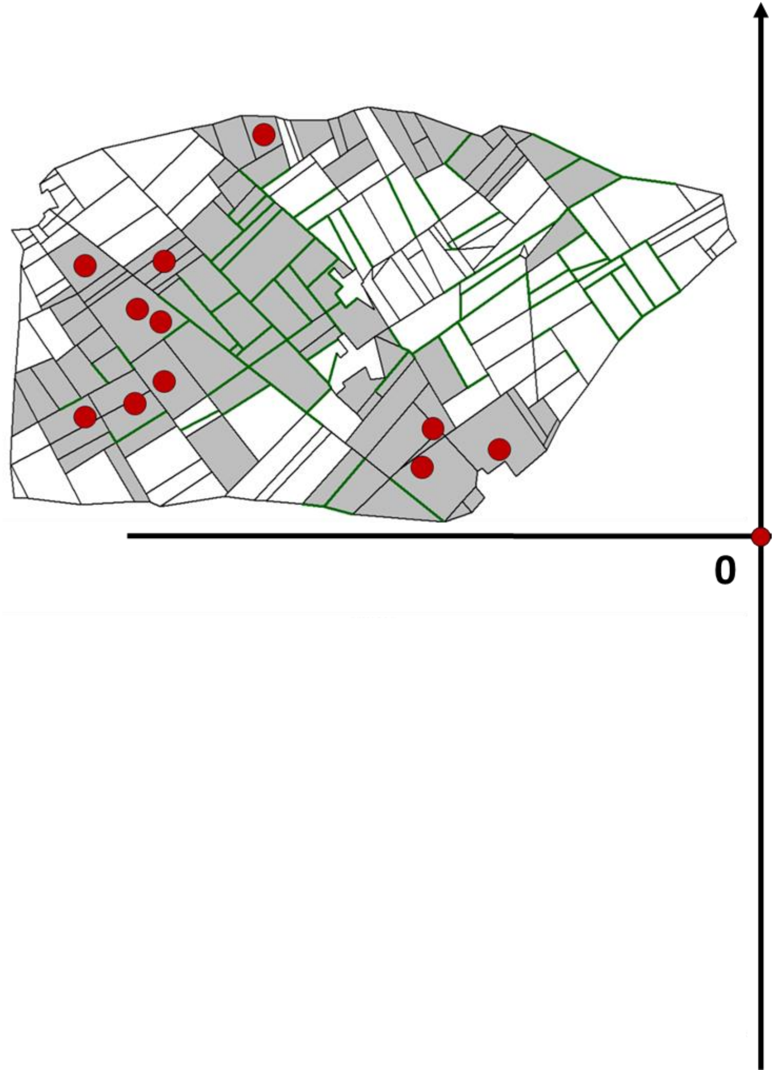
$P_{max}(s,t) = f($ Spatial covariates , Spatio-temporal covariates , Population dynamic covariates $)$


2) Magnitude of pest peaks at t
0
1) Number of pest peaks at t

These variables favour high number of pest peaks with elevated pest concentration.

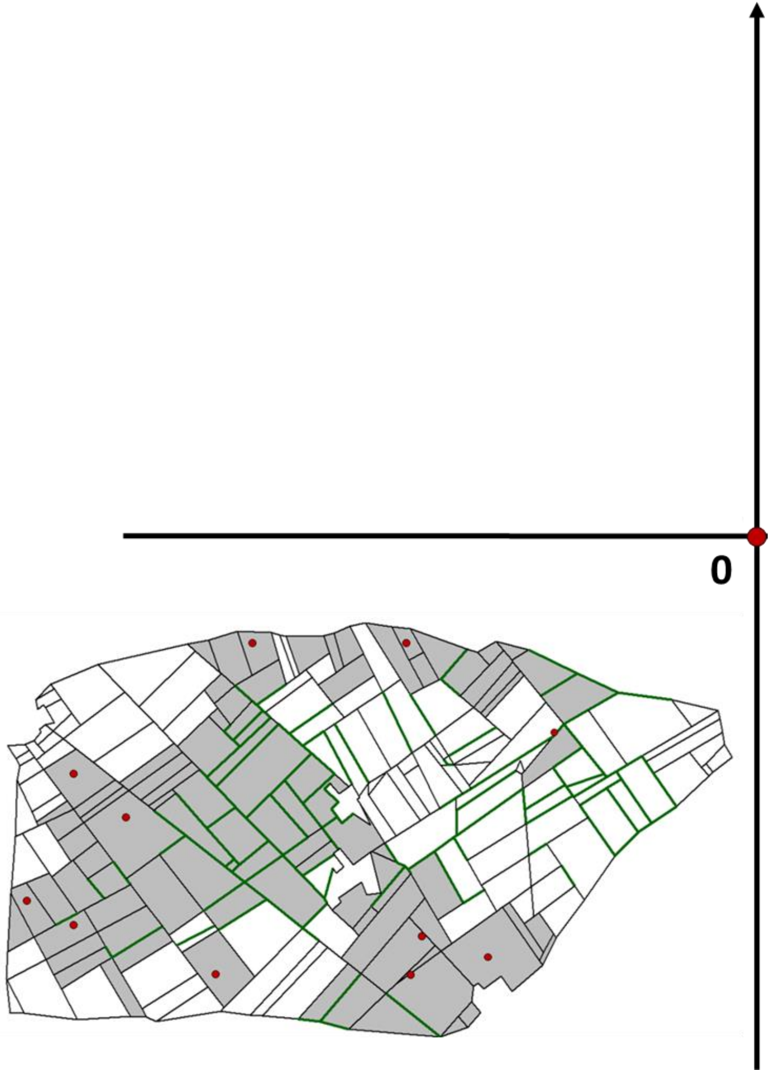
- **Presence of peaks in previuos time steps** in the same position or in the sourroding ones.
    - An **elevated number of pest introductions** in the neighborings
        - **Among two patches**





These variables favour high pest concentration value, but in a low number. This happen when pests are clustered and limited in space, so they cannot diffuse, or they have a fast dynamic.

- An elevated **number of peaks in neighborings** only at one previous time step is not enougth to lead to a high peak number at T.
- In the **middle of the patch** where the inoculation take place.
- Low **% culture**
- **Hedge proportion at landscape scale** can favour the max peak value since predator presence helps to keep pests just under the threshold, but if predators are missing in one spot pest increase rapidly and quickly reach a high density value.
- The **speed of predator spillover from hedge** mostly impact the area close by the hedge.



These variables decrease the number of peaks and also the pest maximum value.

- Application of **pesticide treatments in same loactions or in close ones** at T-1

- The **local** presence of a **high % of hedge** in the buffer highligh a high predator presence in the local area that decrease pest peaks and their density value

- The **diffusion of predator** in culture negatively impact the pest dynamic

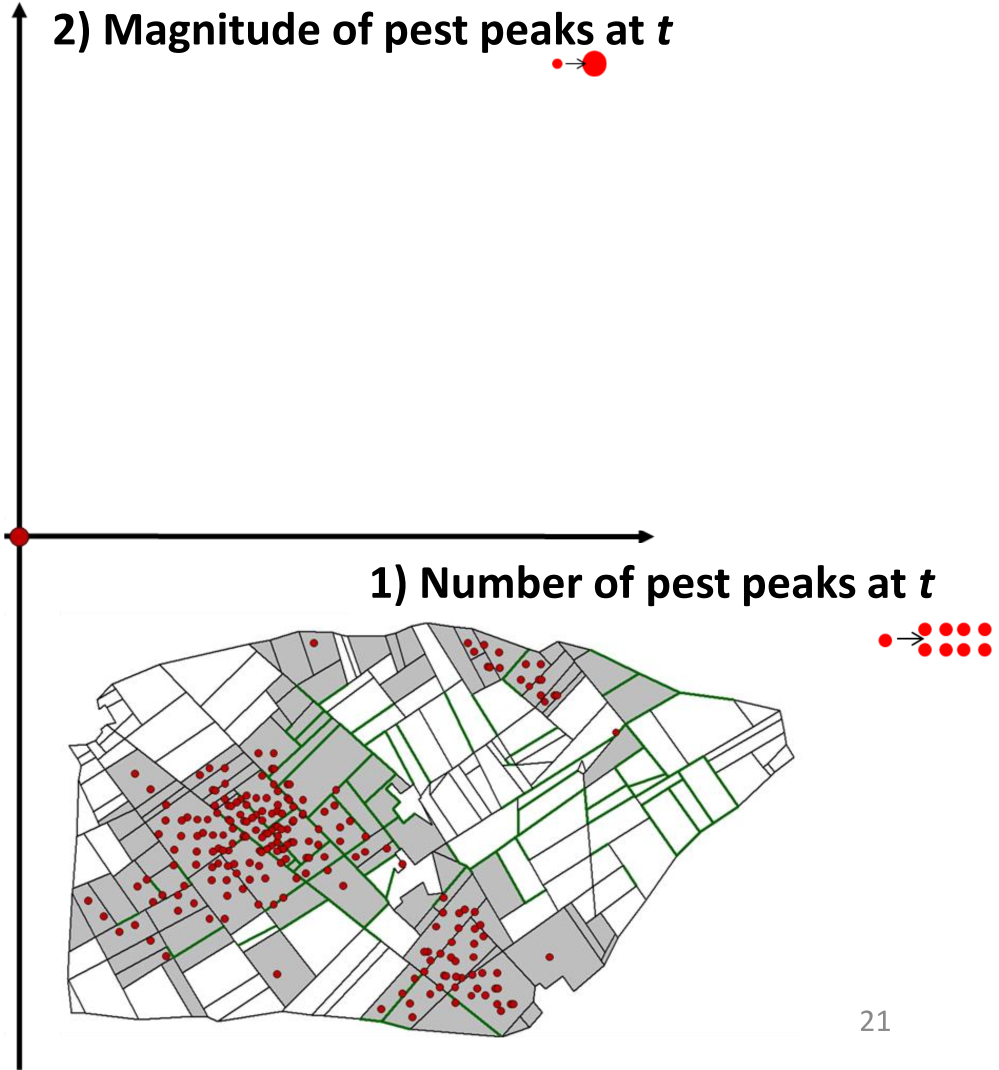
- A **high pest diffusion** favors diluition effect decreasing both peak value and peak number

These variables leads to a high number of pest peaks, but not with an elevated pest value

- **% of crop coverage** that is natural pest habitat, so naturally favors pest peaks. However, those peaks are not characterised by a so high density due to the diluition effect.

- The **crop aggregation** contribute to cause pest spread phenomenon as said before.

- **Cells among more than 3 patches** usually host a high number of pest peaks due to high spillover. The maximum value of pest is negatively influenced since those cell are in the **periphery of the patch.**



Take home messages:

GLOBALLY:

- **Landscape simplification** is the main driver of **pest population abundance** causing the highest number of pesticide treatments;

- The presence of **semi-natural stripes** enhances **predator presence**. However, the main positive effect on predator density results from its **ability of spilling-over from hedge to crop field** leading to an efficient biological control.

- **Different biological control outcomes** are obtained through the **combination** of both **landscape** and **species trait variables**.

Stochastic-mechanistic prey-predator dynamic model

Take home messages:

LOCALLY:

- A well **connected hedge network** could locally reduce pest density and treatment, due to the presence of pest predators;

- Local high **number** of pest peaks (1) is favoured by high pest introduction at previous time steps and situation that are the most suitable for pest dynamics, while they are decreased by dilution effect and predator presence or when treatment are previously applied;

- Local high **magnitude** of pest (2) is favoured by pest introduction and situations that constrain pests in a limited area, pest fast dynamics, low predator presence.

Stochastic-mechanistic prey-predator dynamic model

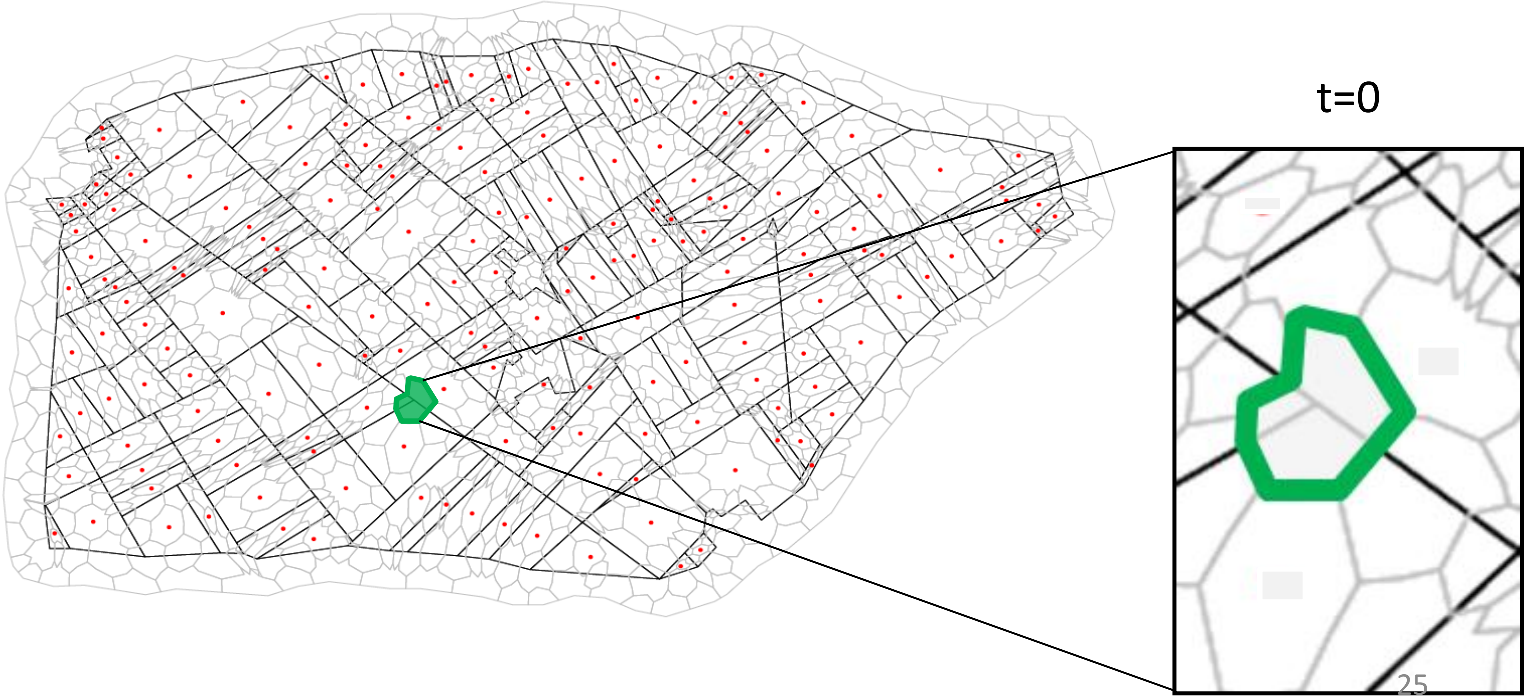
Thank you for your attention!

INRAE BIOSP Biostatistique & Processus Spatiaux

Spatio-temporal point process

The study region is partitioned into cells to capture the local temporal dynamic by models that:

1) Count the **number** of pest peak
2) Consider the **magnitude** of pest peak



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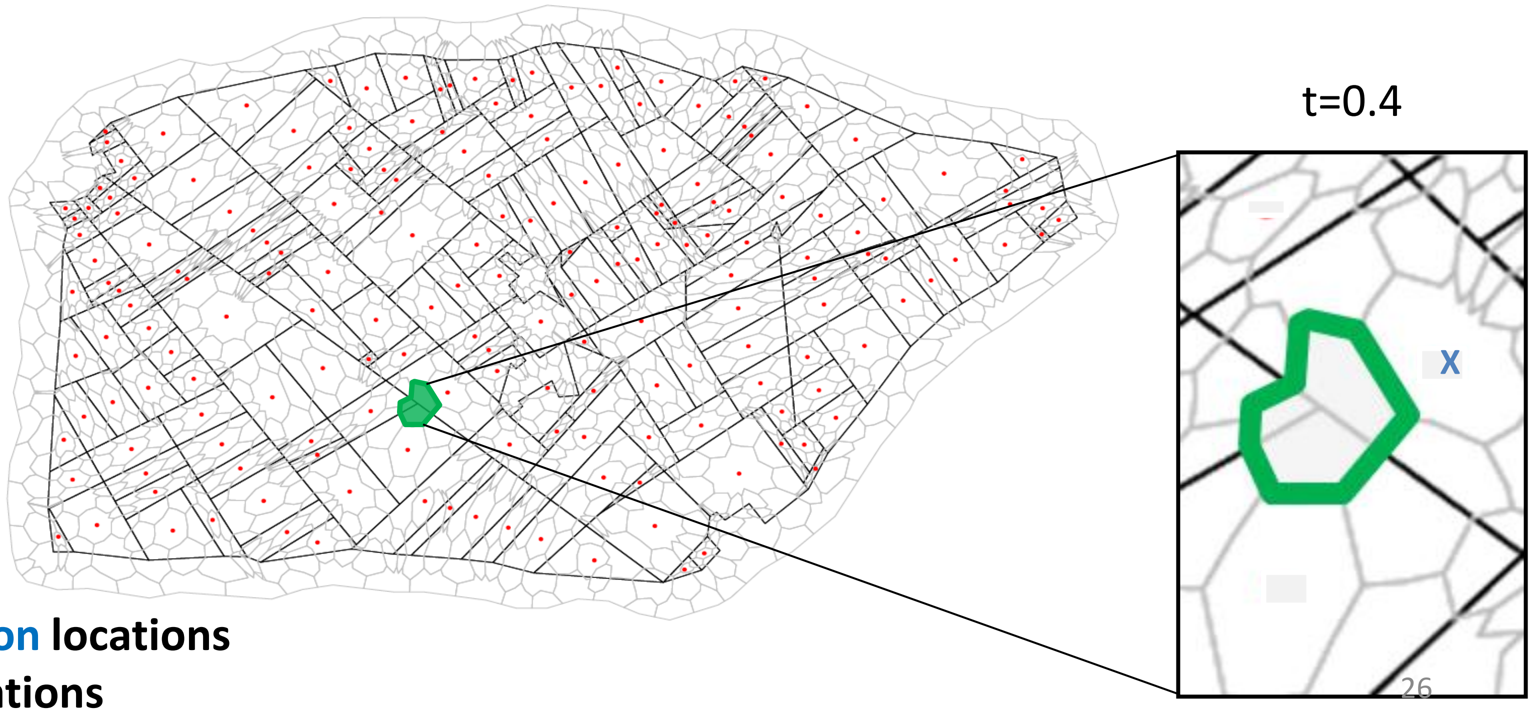

x **pest inoculation locations**

● **pest peak locations**

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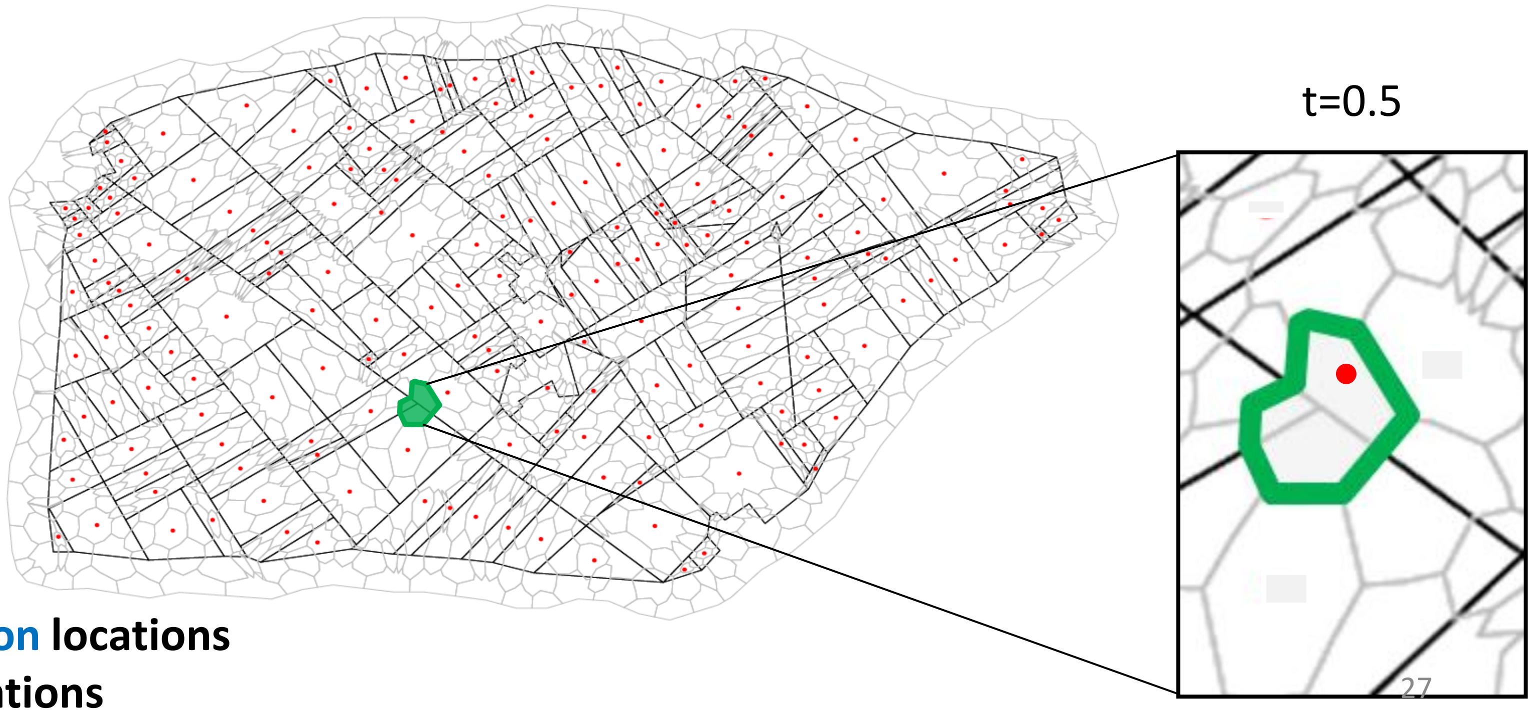

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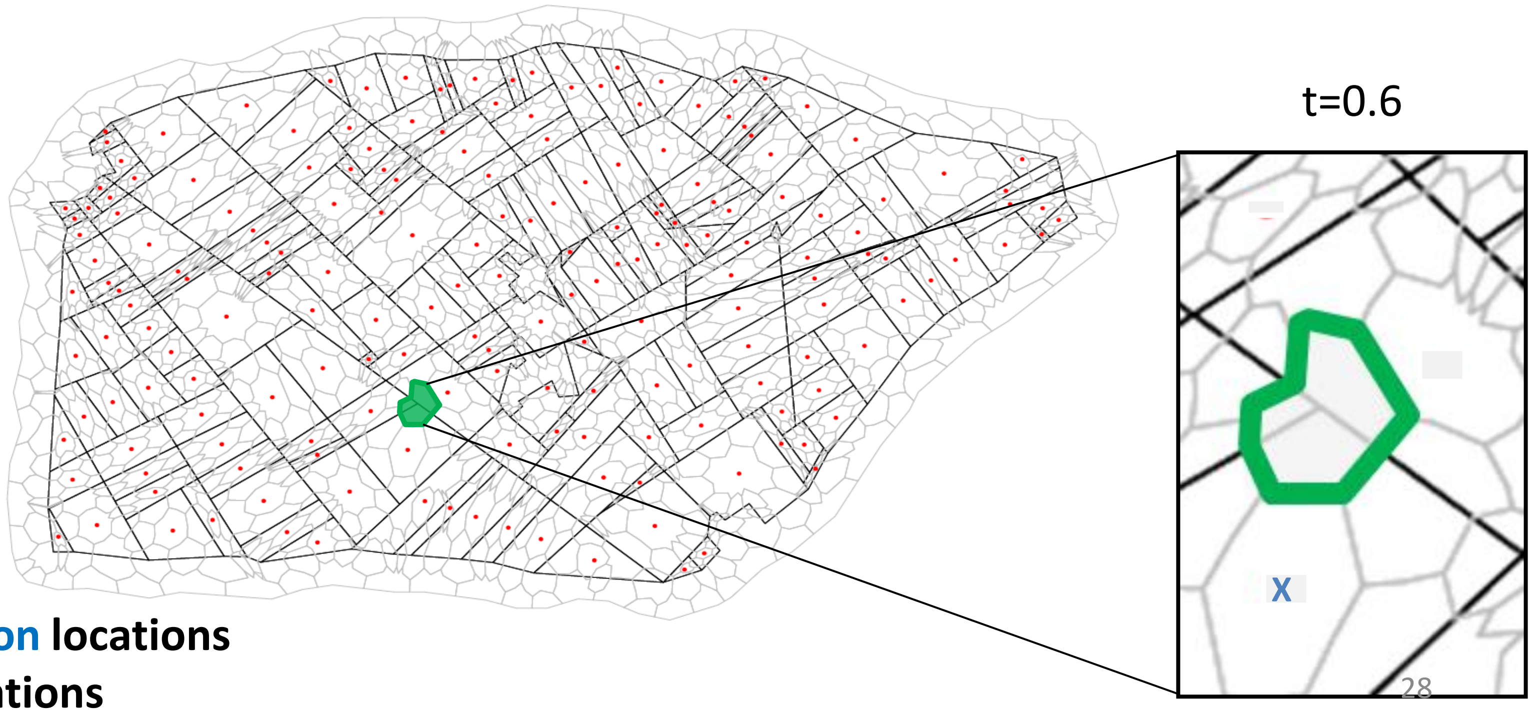

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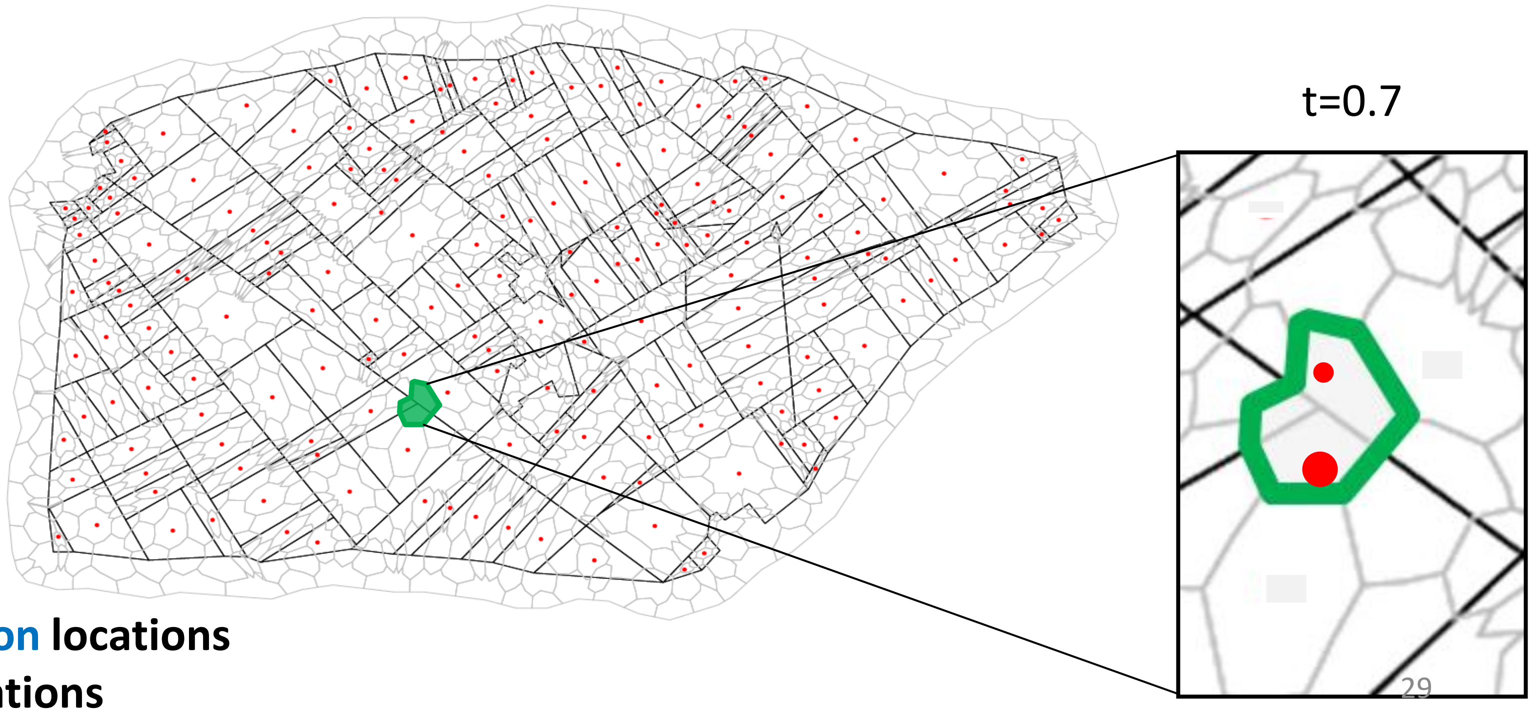
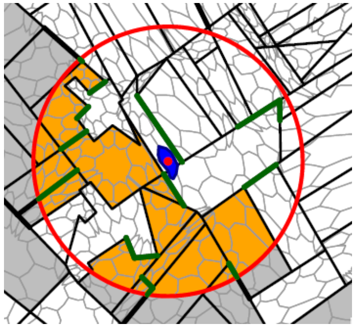


x **pest inoculation locations**
● **pest peak locations**

culture/hedge proportion within the landscape

Cell-patch intersections

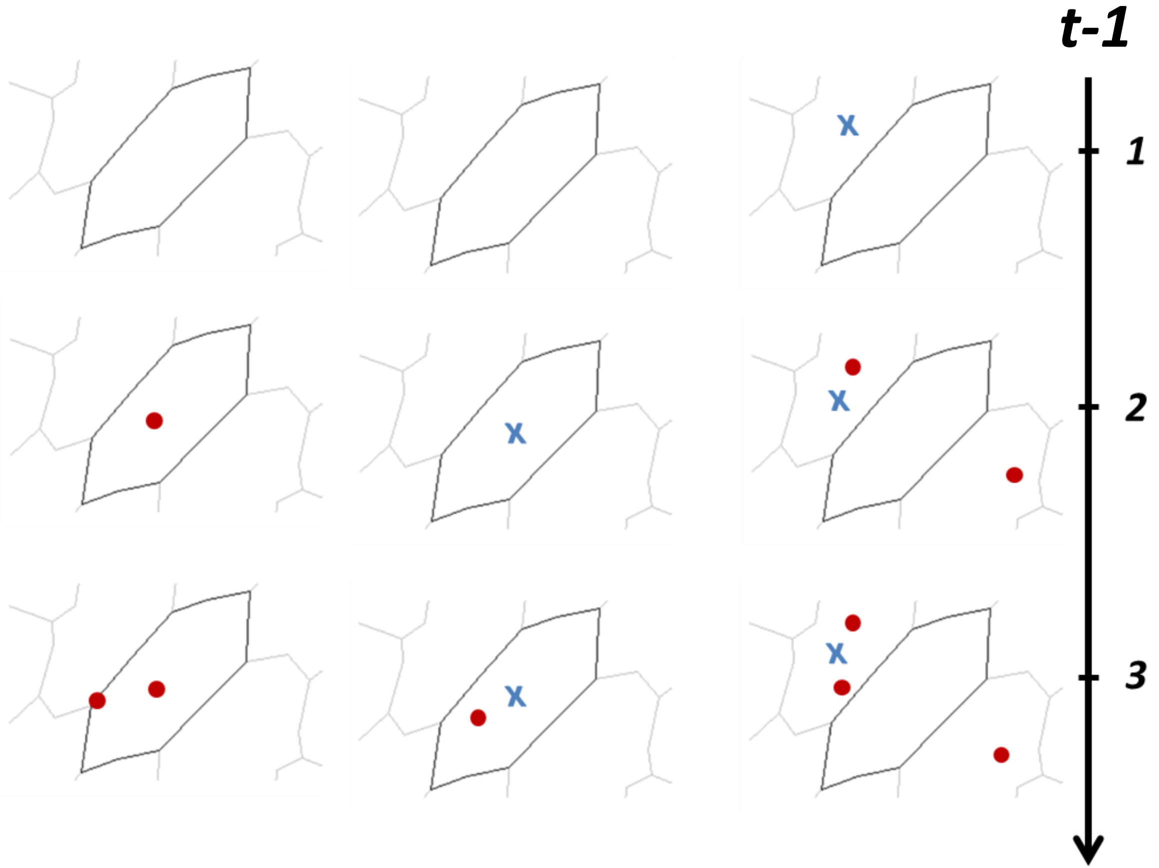
Patch/culture proportion within buffers



Spatial covariates

Spatio-temporal covariates

Population dynamic covariates



a) **Treatments** within the cell;

b) Considering pest **inoculations** and **treatments** within the cell;

c) Considering **treatments** or **inocultations** within neighboring cells.

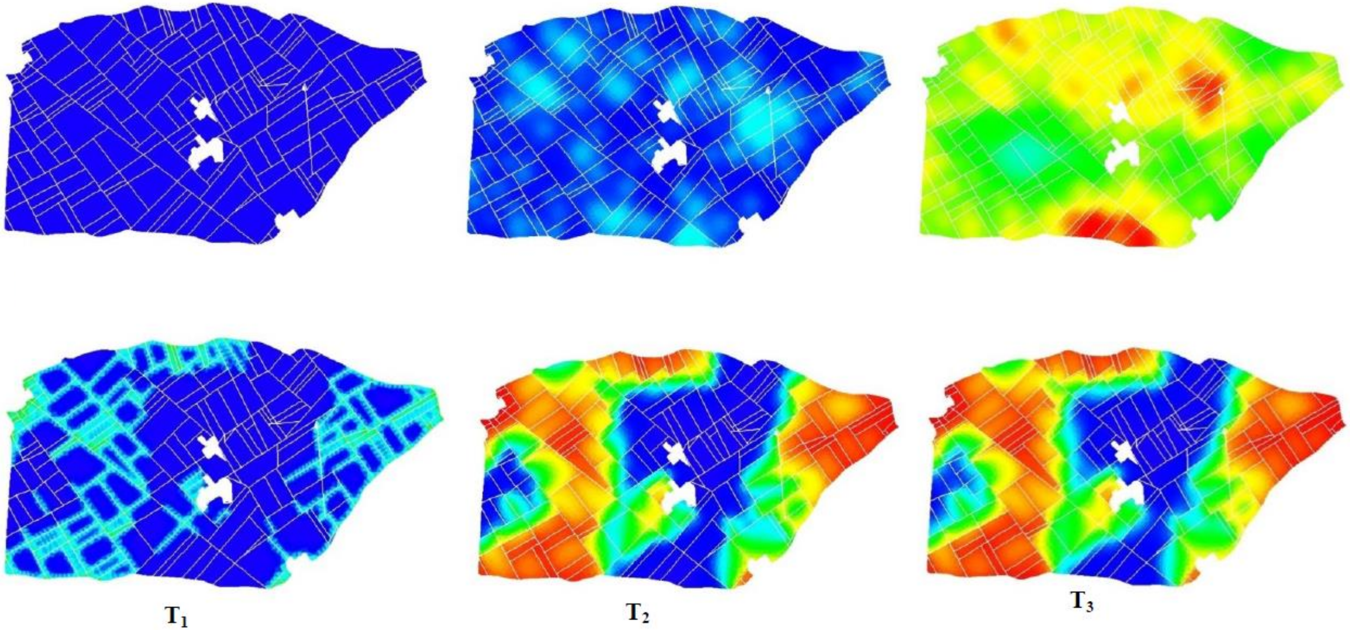
Spatial covariates

Spatio-temporal covariates

Population dynamic covariates

Pest diffusion

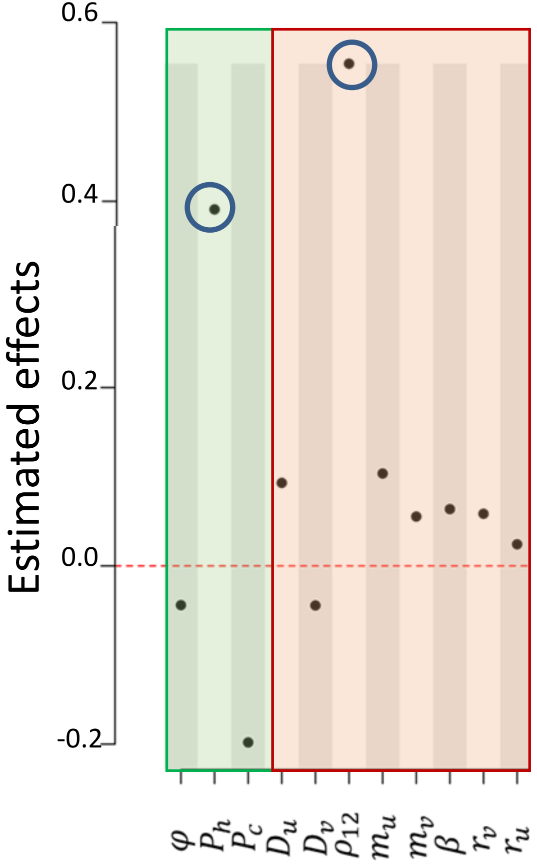
Predator diffusion and spillover from hedge



Spatial covariates

Spatio-temporal covariates

Population dynamic covariates

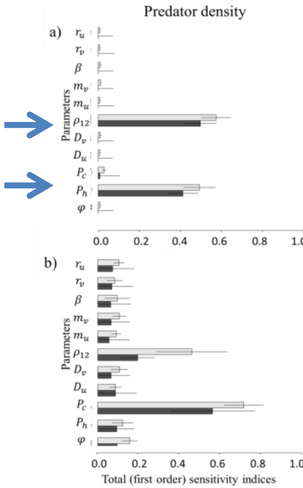


Predator population density

✚

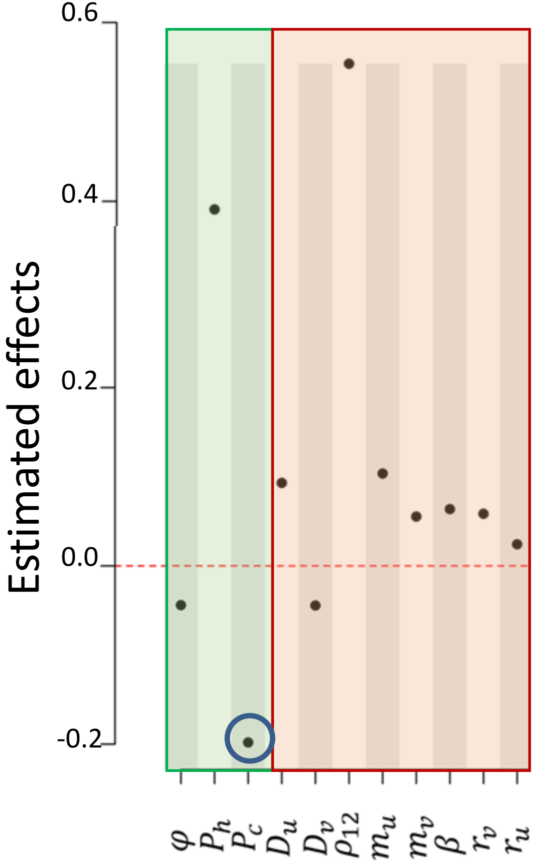
Predator spillover
Hedge proportion

Sobol



Landscape variable
Species variable

Predator population density



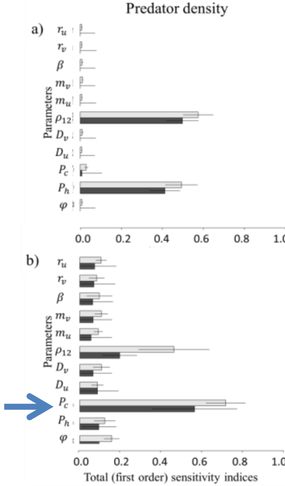
+

Predator spillover
Hedge proportion

−

Crop proportion

Sobol



Landscape variable
Species variable

Predator population density