Tracking uncertainties in risk assessment of pest control strategies on non-target species

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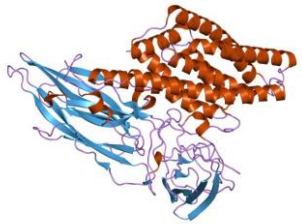
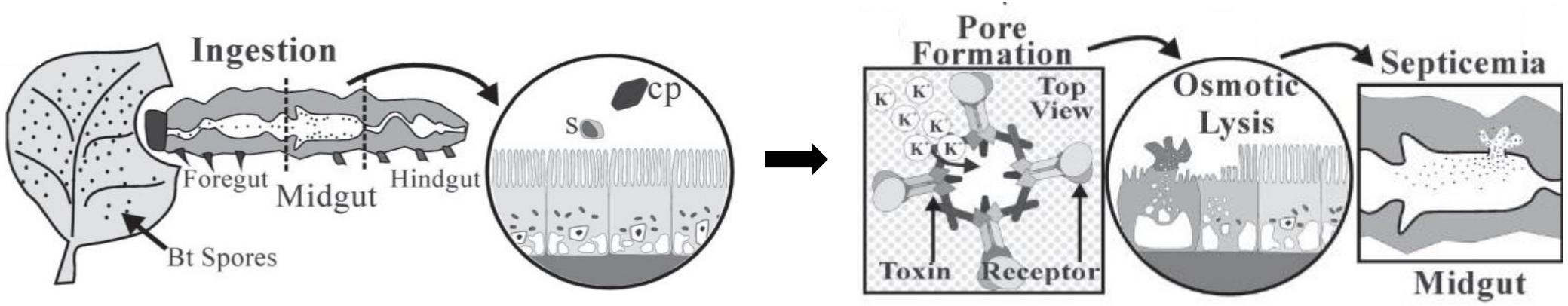
Bt to control pests in crop fields

- **GM** maize varieties producing **Bt Cry proteins** (e.g., MON810, Bt11 and 1507) developed **to control pests**: e.g., European Corn Borer - *Ostrinia nubilalis* Mediterranean Corn Borer - *Sesamia nonagrioides*.

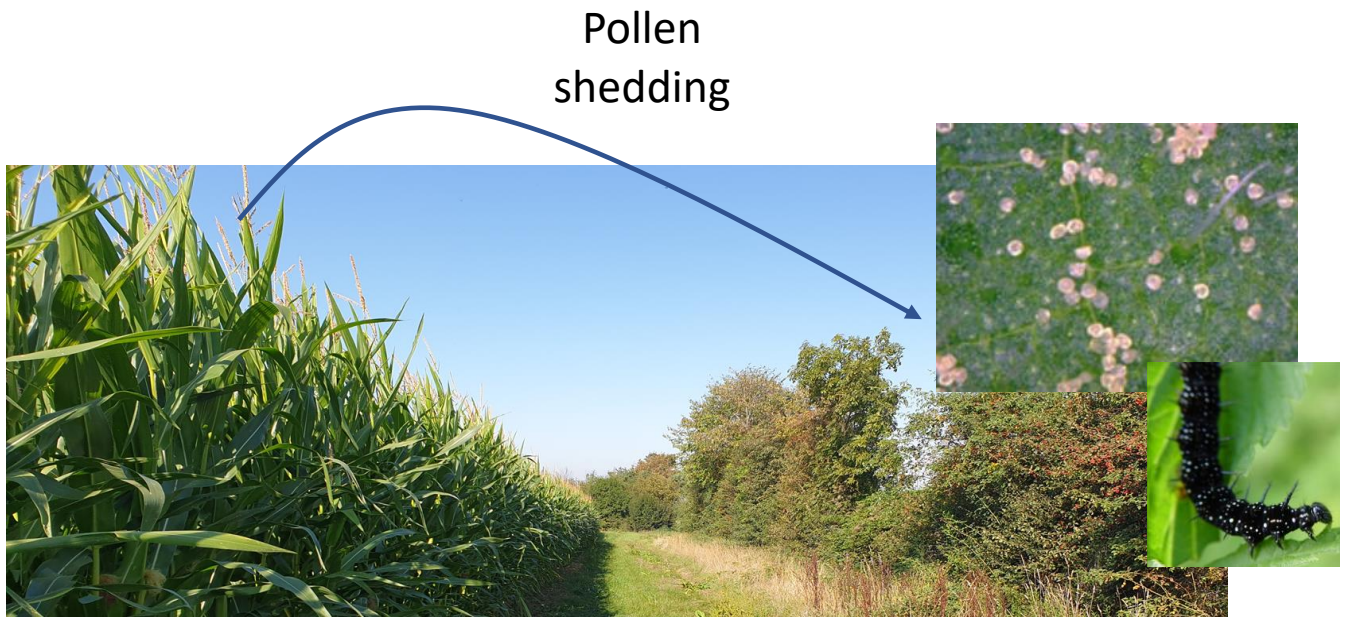


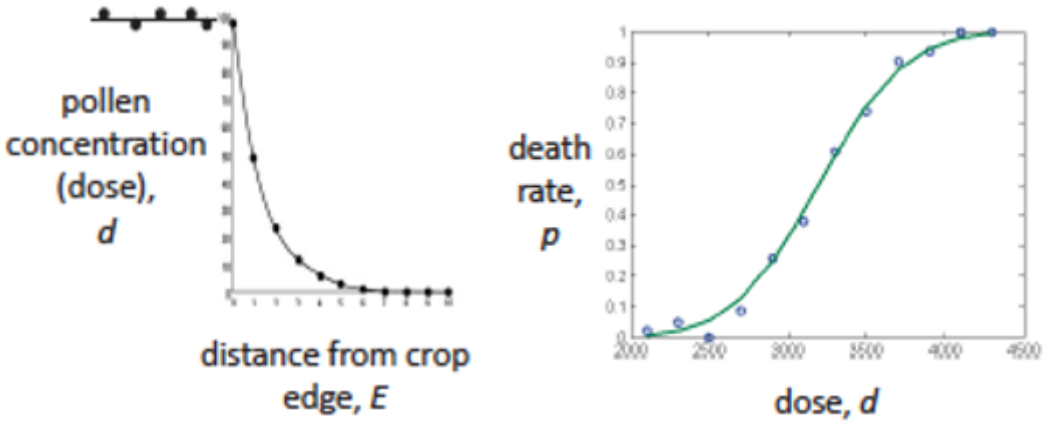


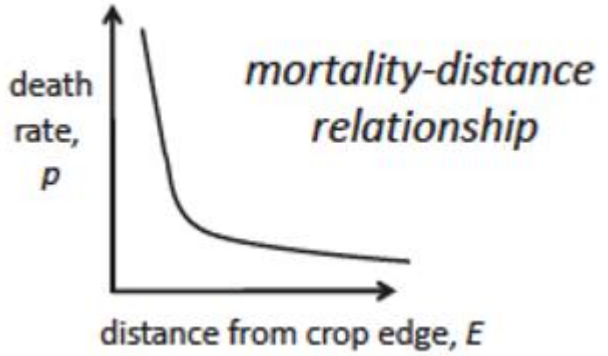
Adapted from: Whalon and Wingerb (2003) *Bt: Mode of action and use*. Archives of Insect Biochemistry and Physiology. 54(4)

Bt on Non-Target Lepidoptera

- Bt toxin is **expressed in pollen,** which is **dispersed by wind** over large distances and can thus **reach habitats of non-target organisms** (NTOs)







Bt on Non-Target Lepidoptera: Assessment Models

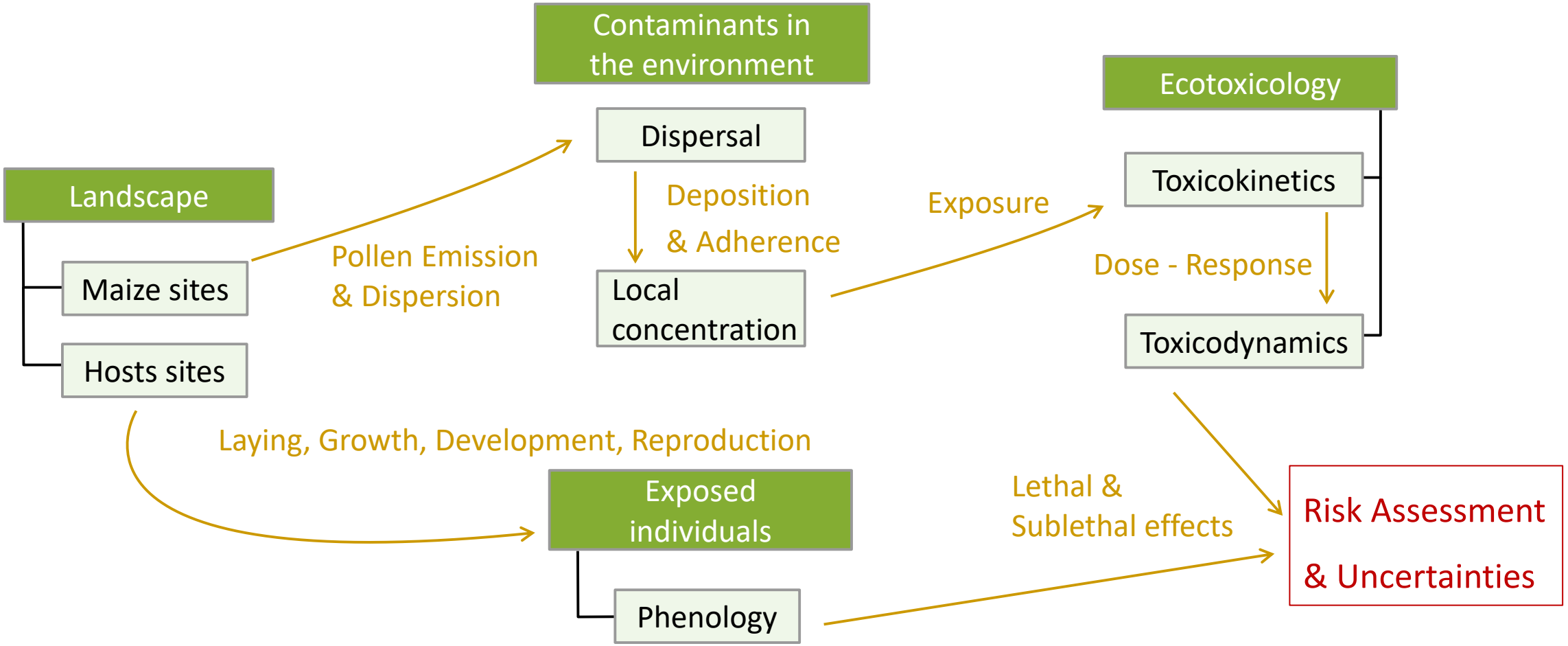
Model	Dose-response	Distance to Bt	Plant distribution	Overlapping larvae/pollen
Perry et al., 2010, 2012	X	X	X	(indirect)
Holst et al., 2013	X	X		Explicit
Fahse et al., 2018	X	X		Explicit

Design a **spatially-explicit generic modeling framework** (Leclerc et al. 2018 and Walker et al. 2019)

- **Landscape structure** of **maize** fields and lepidopteran host **plants**
- Dynamics of **pollen dispersal**: flowering periods, pollen deposition and rainfall host plant washing
- **Phenology** of larvae: laying site, date of emergence, perdio of development
- Toxicokinetics-Toxicodynamics model affecting **mortality** and **sublethal effects** (reproduction and development)

Leclerc, M., Walker, E., Messéan, A. and Soubeyrand S. (2018) Spatial exposure-hazard and landscape models for assessing the impact of GM crops on non-target organisms. Sci. Total Environ., 624, pp. 470-479
Walker, E.; Leclerc, M.; Rey, J.-F.; Beaudouin, R.; Soubeyrand, S. & Messéan, A.(2019) A Spatio-Temporal Exposure-Hazard Model for Assessing Biological Risk and Impact. Risk Analysis, Risk Anal., 39 , pp. 54-70

Bt on Non-Target Lepidoptera: Spatially Explicit Models



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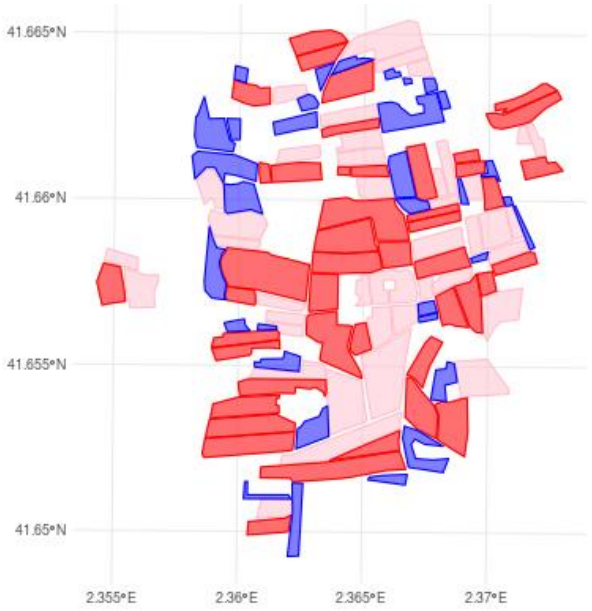
Bt on Non-Target Lepidoptera: Spatially Explicit Models

Landscape



Spatial domain $\Omega \subset \mathbf{R}^2$

N maize fields cells: C_{crop}

M habitat cells: $C_{habitat}$

Maize Fields

GM Fields

Habitats

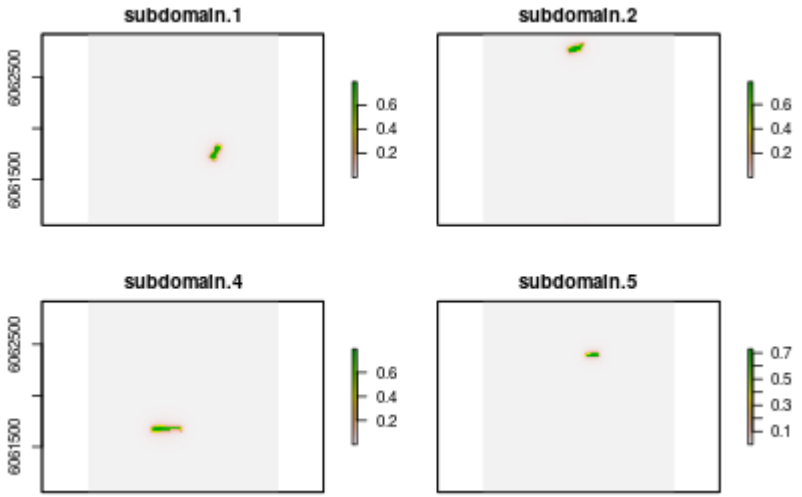
Kernel (Geometric)

Pollen Emission & Dispersion

$$\frac{1}{(\sqrt{x^2+y^2})^{\beta}} \times \frac{(\beta+1)(\beta+2)}{2\pi}$$

$$\beta = -2{,}63$$

for each field

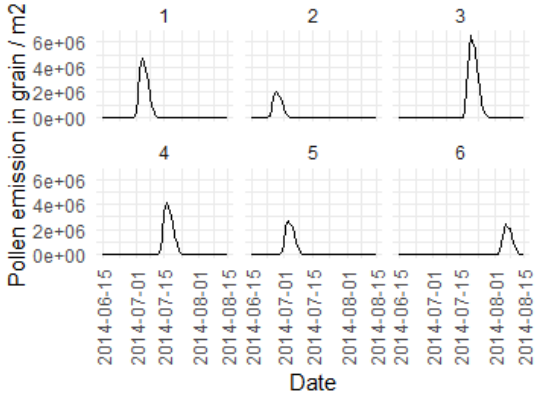


Bt on Non-Target Lepidoptera: Spatially Explicit Models

Contaminants in the environment

Deposition & Adherence

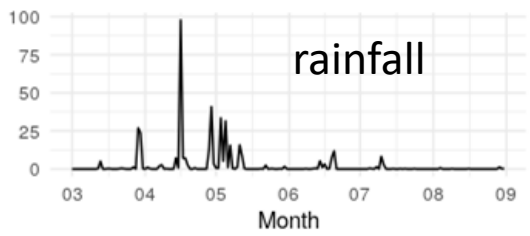
Pollen emission per field

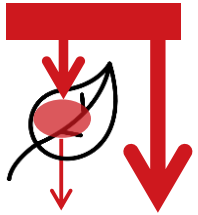


Pollen deposition

$$\lambda_{local}(y,t) = (1 - \alpha(Z(t)))\lambda_{local}(y,t-1) + \beta\lambda_{disp}(y,t)$$

washing adherence





Convolution

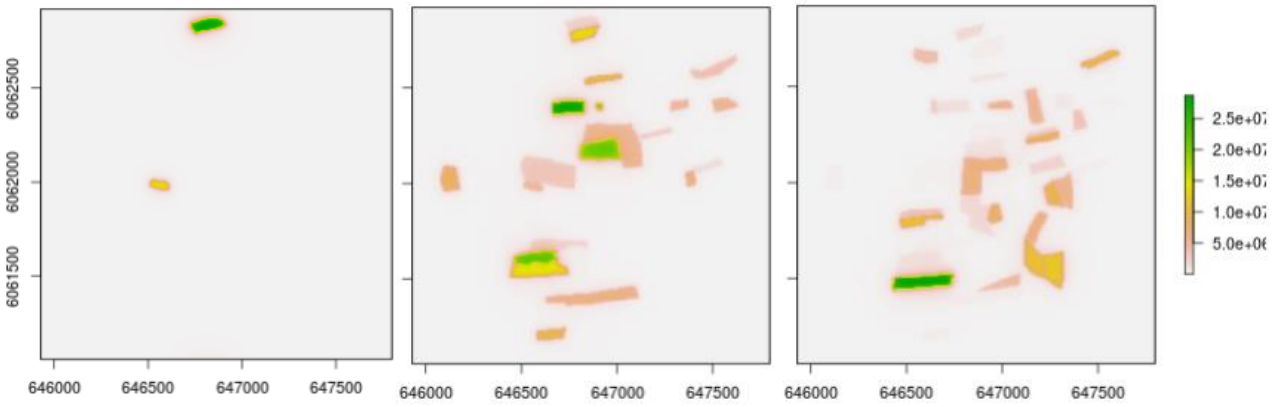
$$\lambda_{disp}(y,t) = \int_{\Omega} \tilde{E}(x,t)K(y-x)dx$$

by Fast Fourrier Transform

$$\tilde{E} * K(y,t) = \mathcal{F}^{-1}(\mathcal{F}(\tilde{E})\mathcal{F}(K))$$

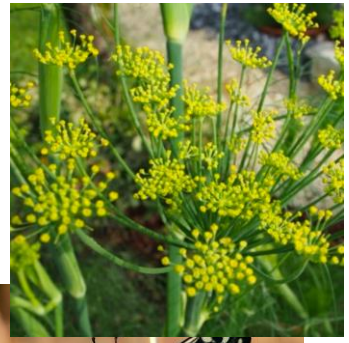
Deposition of pollen on landscape

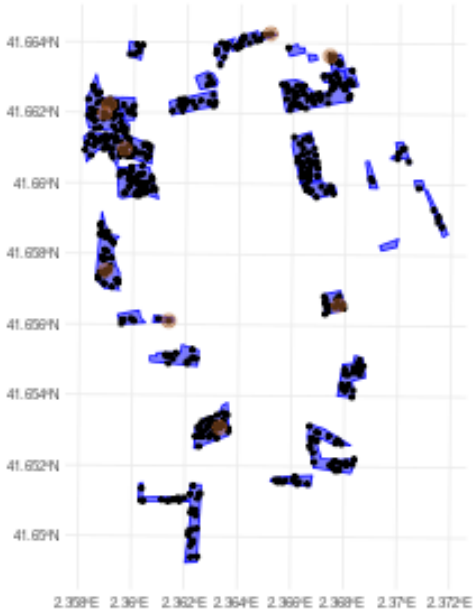
Unit: pollen /m^2



Bt on Non-Target Lepidoptera: Spatially Explicit Models

Exposed individuals

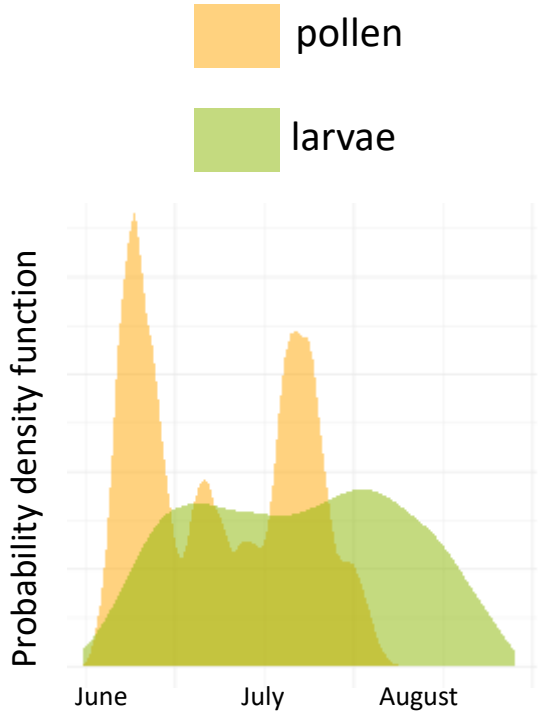




$N_{layingSite}$ distributed in habitats $C_{habitat}$

- Laying sites
- Habitats

Matching between pollen deposition $\lambda_{local}(y,t)$ and occurrence of a larvae

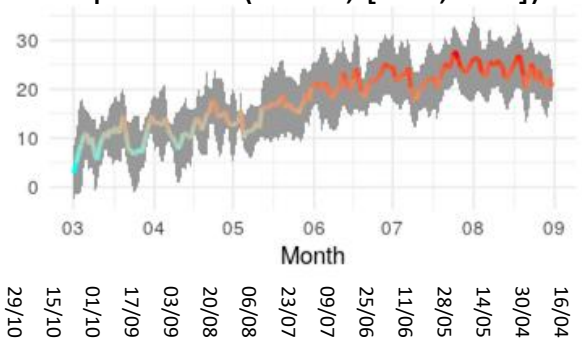


Degree day model

$$\delta_0(T) = \exp(\rho T) - \exp\left(\rho T_{max} - \frac{T_{max}-T}{\Delta}\right) + \lambda$$

- $r(T)$: development rate
- T : temperature
- T_{max} : upper survival temperature
- ρ, Δ, λ : other parameters to fit

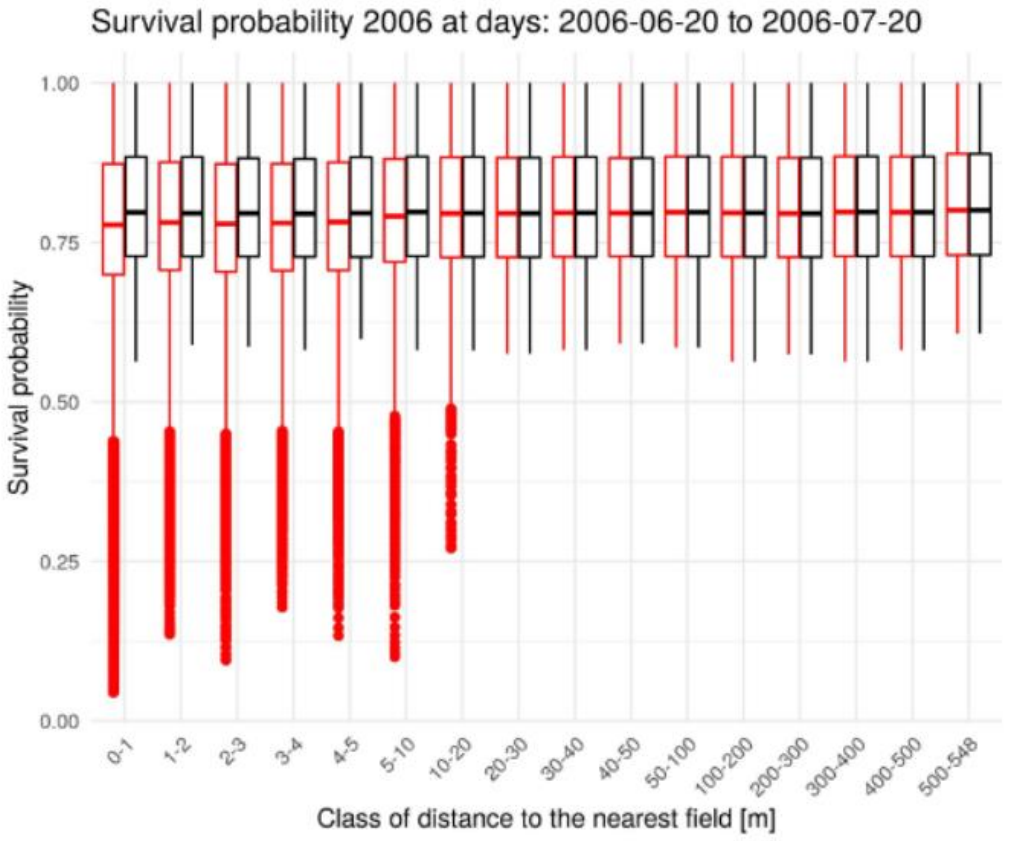
Temperature (mean, [min,max])



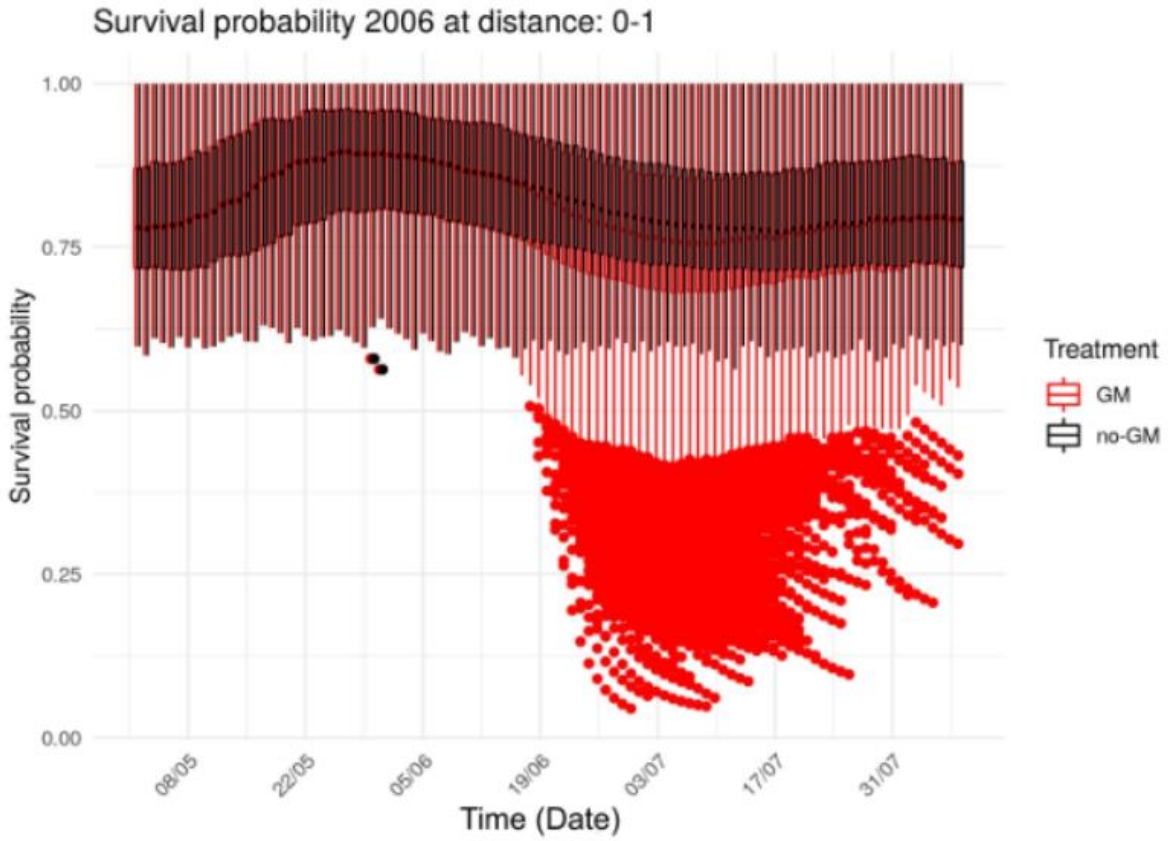
Bt on Non-Target Lepidoptera: Spatially Explicit Models

Ecotoxicology

(a) - Survival along class of distance.



(b) - Survival along time at closest distance.



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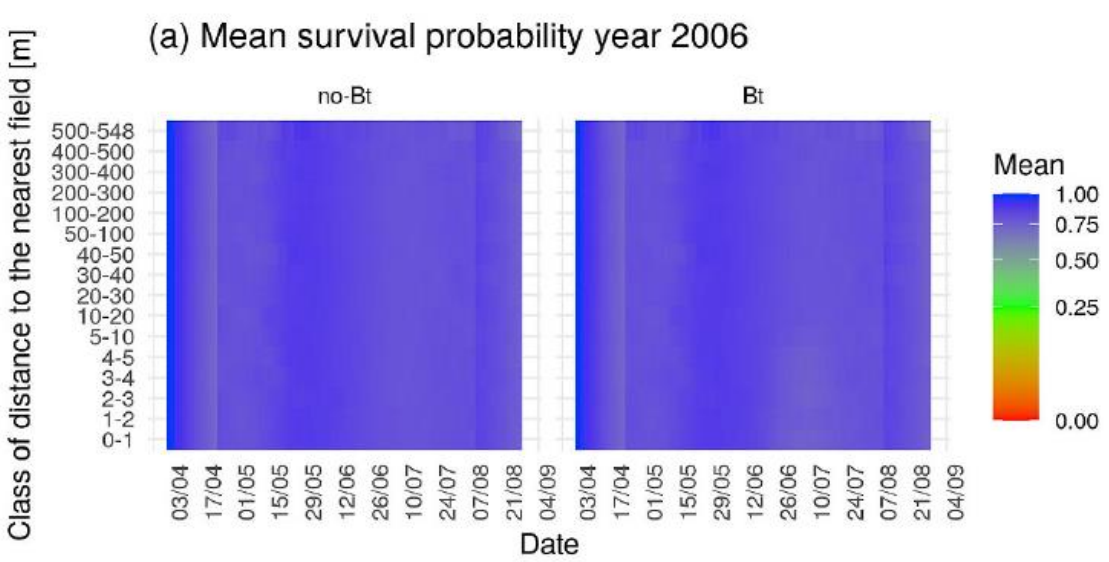

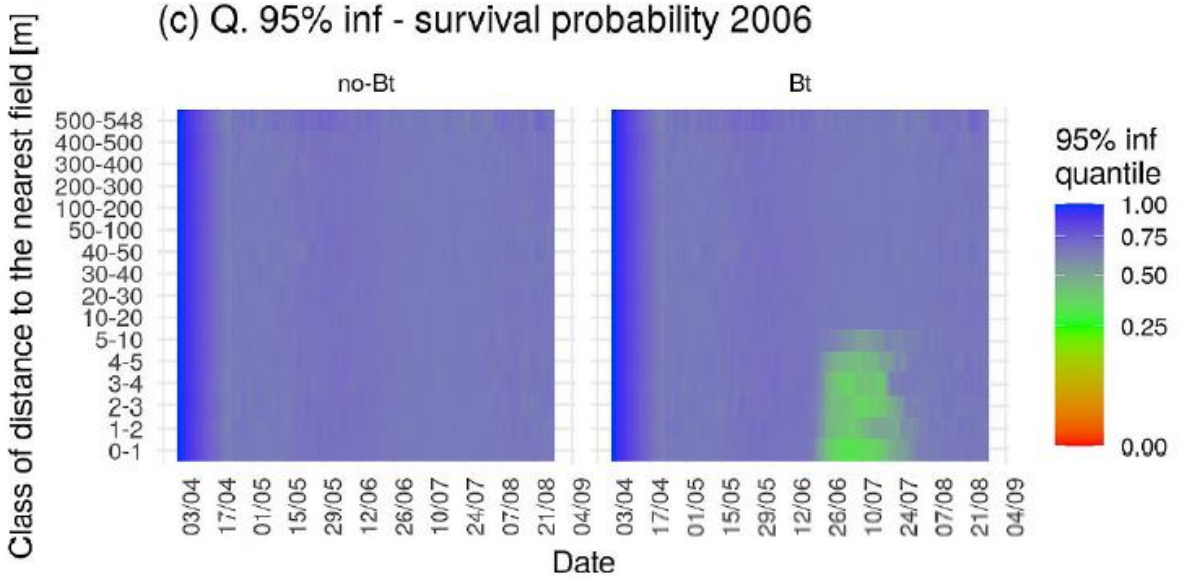

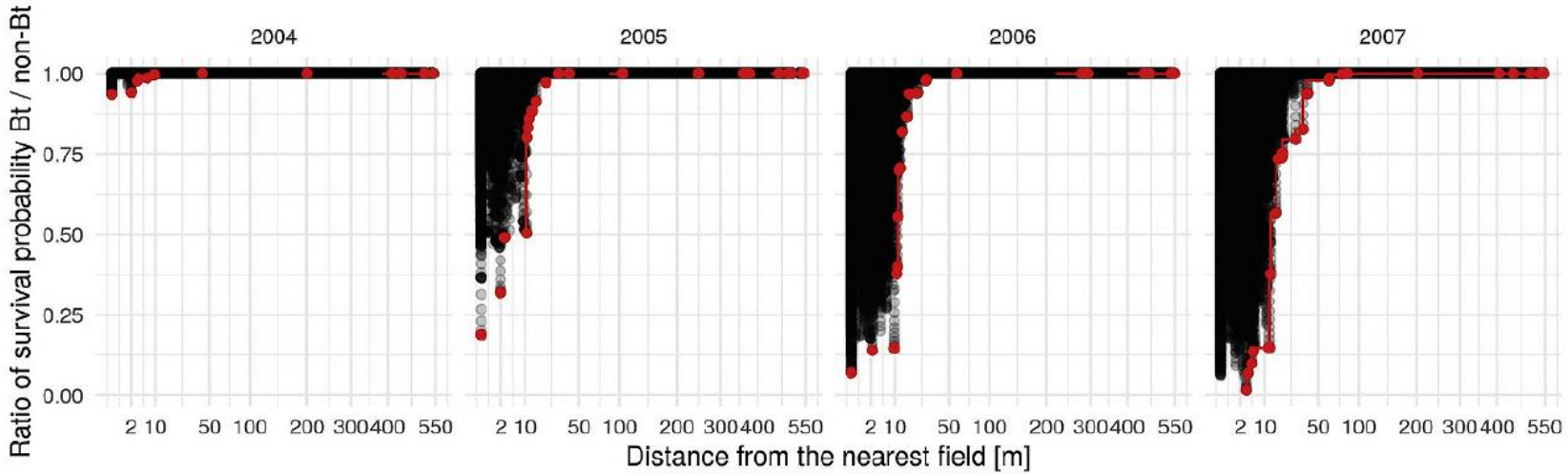

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Conclusion

So then: Risky or Not Risky to grow Bt-Maize for *Papilio machaon*?

There is a narrow line between diverging conclusions:

- **no risk by only looking at the average regional effect** of Bt on NTLs survival
- **a significant threaten** when **considering the variability of individuals mortality** and **sub-population level** (e.g., a mortality higher than 40% within the 10m for the 10% most Bt-sensitive individuals).

… Still more uncertainties considering:

- **Thousands of chemical products** chronically constraining the life cycle of Lepidoptera
- Additional **agri-ecosystem complexities**: land-use, local weather, species interactions as predation, parasitism, competition, and behavioral traits such as oviposition preference, propensity of migration.

BÜROLANG

INRAE

Thank you

Biostatistique BIOSP & Processus Spatiaux

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