CBGP Seminar Presentation

Modelling the dispersal of invasive species using landscape variables

Pedro Mourato Catela Nunes

Index

1. Personal Background
2. Introduction of Invasive Biology & Dispersal Modelling
3. Model Species
4. Article 1 – Local scale Least-cost path model
5. Article 2 – Large scale diffusion model
6. Article 3 – local scale epidemilogical celular based model
7. Post-Doc Overview

Pedro Mourato Catela Nunes

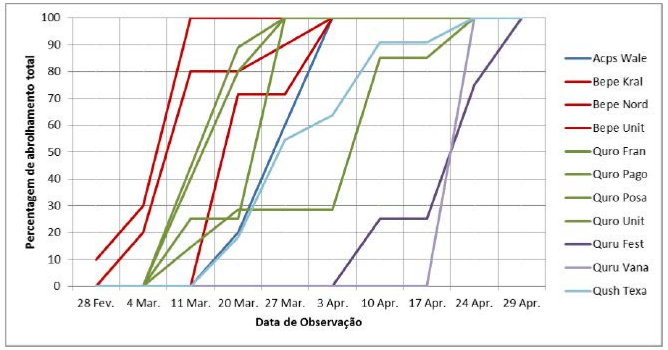
2011 to 2014 - Bachelor in Biology

University of Lisbon (ISA)

Final Project: "Comparing the herbivory between native and exotic forest species found in two arboreta from the REINFFORCE international network"

2 – Leaf phenology

Figura 1. Evolução da percentagem dos indivíduos de cada espécie-proveniência que chegaram ao nível fenológico das folhas de abrolhamento total na Tapada da Ajuda.



Legenda: Wale – País de Gales, Kral – Eslováquia, Nord – França (Norte), Fran – França, Pago – Espanha, Posa – Croácia, Unit – Reino Unido, Fest – França (Este902), Vana – Espanha (País Basco litoral), Texa – EUA (Texas).

2 - Damage assessment

Quadro 2 – Quadro com os tipos de estragos estudados baseado no protocolo "Damage assessment – a field guide", do projeto FunDivEUROPE.

Tipos de Danos	Descrição	Imagem
Defoliadores (CH)	Defoliadores são insectos que conseguem consumir a maior parte do material foliar destruindo a lâmina foliar inteira (apenas restando veias mais rigidas centrais) ou consomem porções distintas da folha como buracos circulares cortados apartir da margem da folha ou pequenos buracos espalhados aleatoriamente pela folha	
Mineiros de Folhas (LM)	Insectos que se alimentam pelos tecidos suculentos, enquanto escavam túneis dentro da folha. Em Latifoliadas, estes insectos alimentam-se entre a superficie superior e a inferior da folha.	
Formadores de Galhas (Gall)	Insectos que induzem a formação de galhas nas plantas e alimentam-se do seu tecido.	
Esqueletizadores (SK)	Insectos que consomem todo o tecido foliar expecto as nervuras das folhas.	
Enroladores de Folhas (LR)	Inclui os enroladores de folhas que se enrolam dentro de uma folha formando um tubo com formato de um prisma circular servindo de abrigo e os dobradores de folhas que dobram a folha inteira para se esconderem lá dentro. Outra variante são insectos que ligam duas ou mais folhas juntas formando também um tubo que serve como abrigo e para alimentação.	
Sugadores de Seiva (SF)	Insectos que têm um armadura bucal especializado para sugar fluidos dentro das folhas, deixando marcas da sua actividade como pontos descolorados, deformações e locais foliares mortos.	
Necroses (NEC)	Pontos nas folhas causadas por actividade fúngica, sendo estes pontos normalmente amarelos, castanhos ou pretos.	

3 – Statistical Analysis

Compare leaf herbivory between Trees Species and Proveniences

GLM analysis

Pedro Mourato Catela Nunes

2014 to 2017 – Master in Natural Resources Management and Conservation

University of Lisbon (ISA) and University of Évora

Hinc Patriam Sustinet
INSTITUTO SUPERIOR DE AGRONOMIA
Universidade de Lisboa

UNIVERSIDADE DE ÉVORA

Class: GIS and Remote Sensing Applied to Natural Resources Management

Thesis: "Honeydew producers in eucalypts and associated native fauna"

Honeydew producers in eucalypts and associated native **fauna** [PDF] utl.pt
PMC Nunes - 2017 - search.proquest.com

Pedro Mourato Catela Nunes

2018 to 2023 – PhD in Forestry Engineering and Natural Resources
University of Lisbon (ISA)

INSTITUTO SUPERIOR DE AGRONOMIA
Universidade de Lisboa

Modelling the dispersal of invasive species using landscape variables

Pedro Mourato Catela Nunes

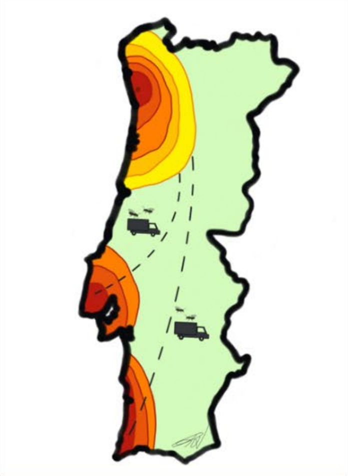
SCIENTIFIC ADVISORS:
Ph.D. Manuela Rodrigues Branco Simões
Ph.D. José Carlos Franco Santos Silva
Ph.D. Hervé Jactel

THESIS PRESENTED TO OBTAIN THE DOCTOR DEGREE (Ph.D.) IN FORESTRY ENGINEERING AND NATURAL RESOURCES

Chapter 1. Introduction

Chapter 2. Modelling *Monochamus galloprovincialis* dispersal trajectories across a heterogeneous landscape to optimize monitoring by trapping networks

Chapter 3. Modelling the invasion dynamics of the African citrus psyllid: The role of human-mediated dispersal and urban and peri-urban citrus trees



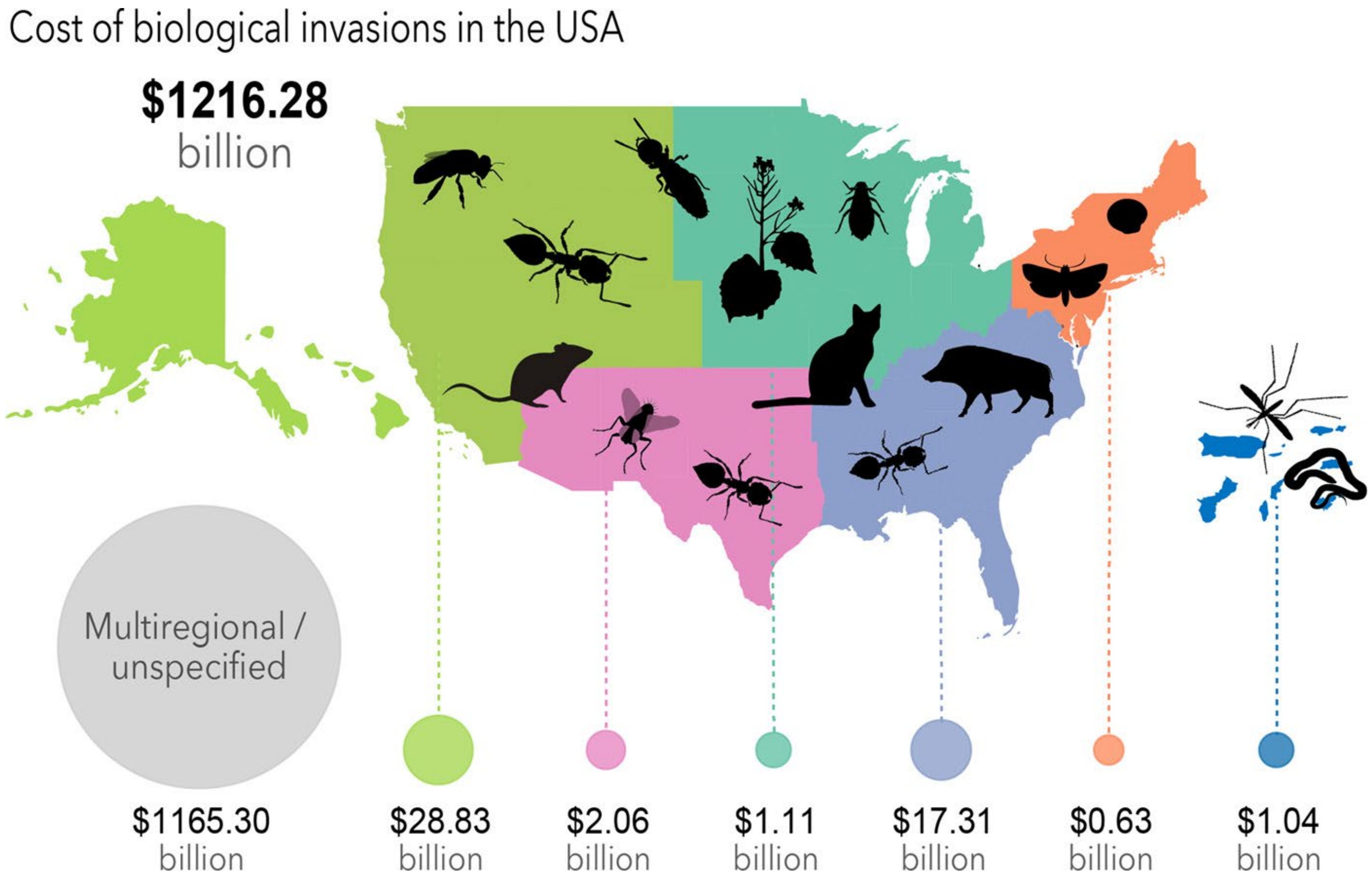
Chapter 4. Patterns of invasibility in agricultural landscapes: are spatio-temporal epidemiology approaches helpful?

Chapter 5. Conclusions

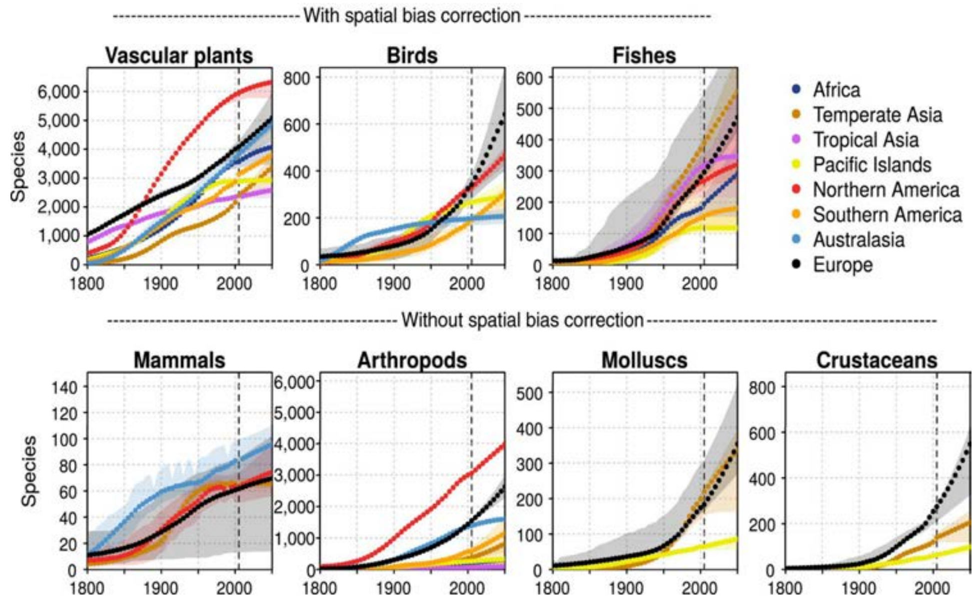
Introduction

Biological Invasions

A threat to biodiversity and human welfare



Alarming rising trend of Biological Invasions!!

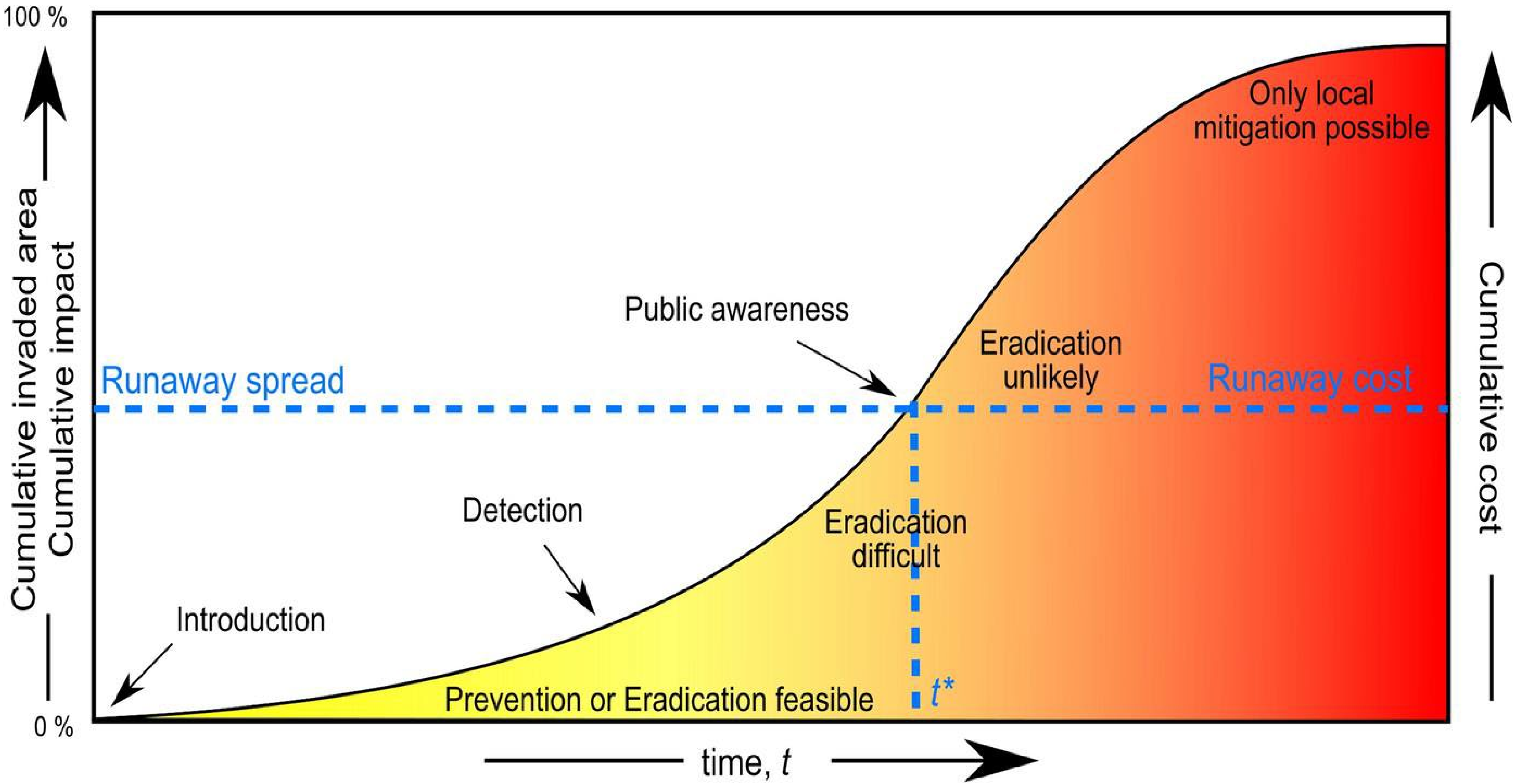


Introduction

Invasion curve and management strategies

Invasion Steps

1. **Introduction**
2. **Establishment**
3. **Expansion**
4. **Saturation**



Introduction

Dispersal of Insects

Motivated to improve fitness

Active Dispersal

Passive Dispersal

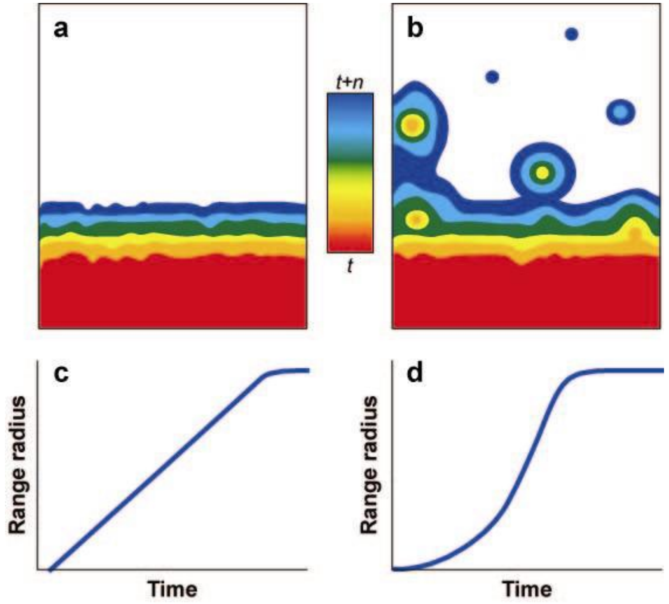
Introduction

Dispersal of Insects

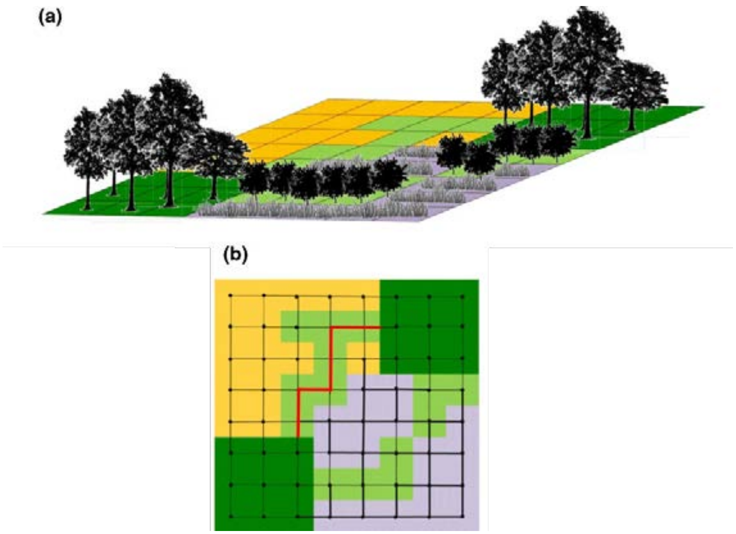
Landscape Heterogeneity

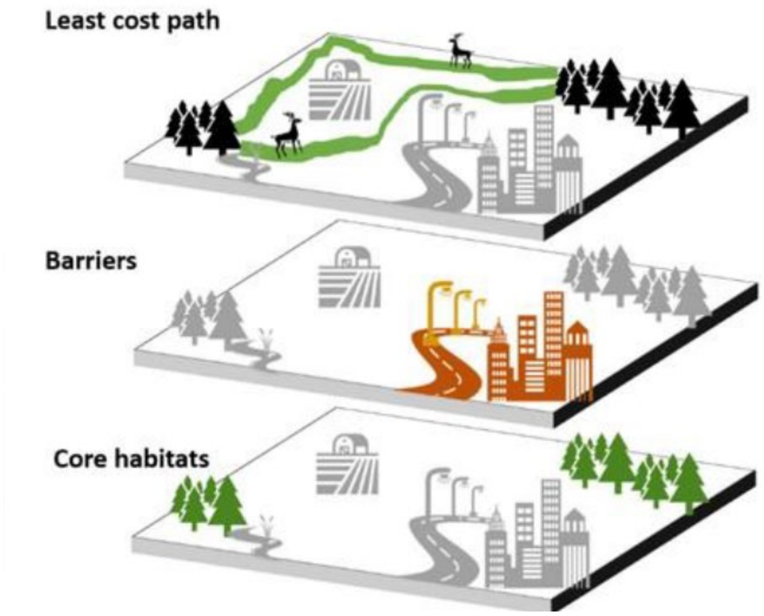
Continuous spread x Stratified spread

Habitat Variability



Liebhold AM, Tobin PC. 2008.
Annu. Rev. Entomol. 53:387–408

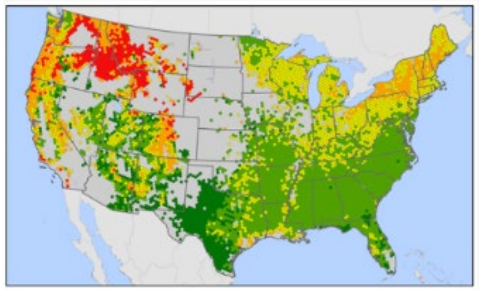




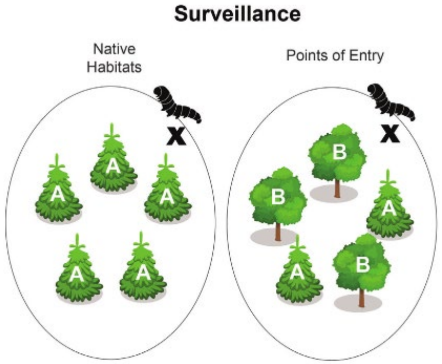
Introduction

Dispersal modelling aims at improving the understanding of the dispersal mechanisms of invasive species

Risk Analysis



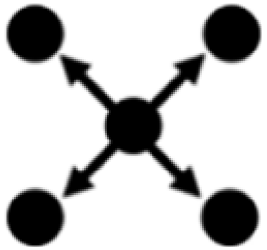
Early Detection



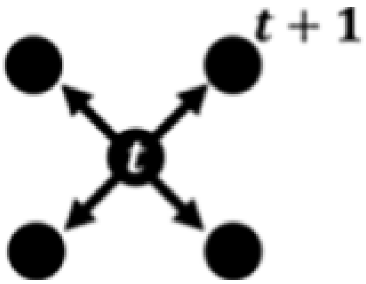
Control

"SLOW THE SPREAD"
A National Program to Contain the Gypsy Moth

Reaction diffusion models



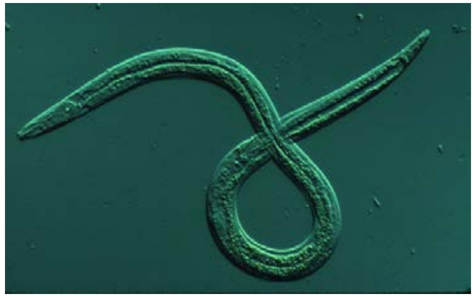
Integrodifference equation models



Introduction

Two Model Invasive Species

Pine wood nematode



Monochamus Galloprovincialis

Trioza erytreae

Citrus Greening disease
Huanglongbing (HLB)

Candidatus
Liberibacter

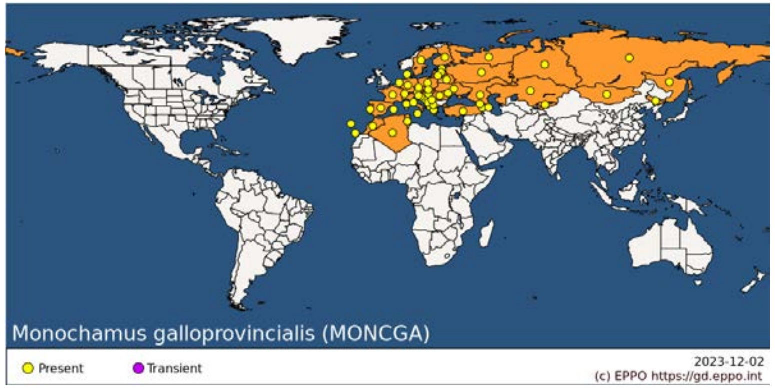
Introduction

Monochamus galloprovincialis

Native species to Europe and Asia

Pine Trees host plants

Vector of the Pine wood nematode

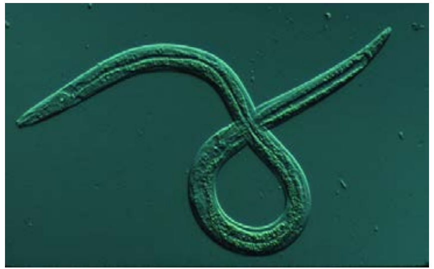


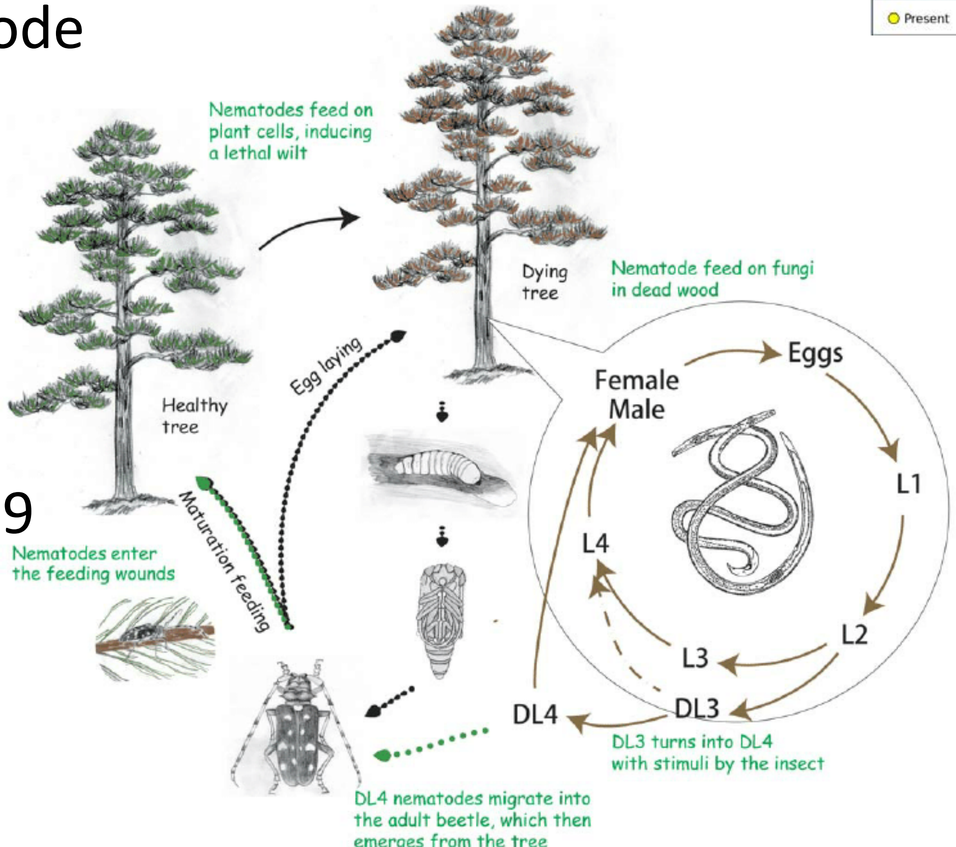
Pine wood nematode

American native species

Invasive in Asia and Europe

First detected in Portugal in 1999





Pine wilt disease

Introduction

Pinewood nematode represents a great threat to Europe

Monitoring trapping grids are currently mandatory for all European Union country members

(Commission Implementing Decision 2012/535/EU of 26 September 2012)

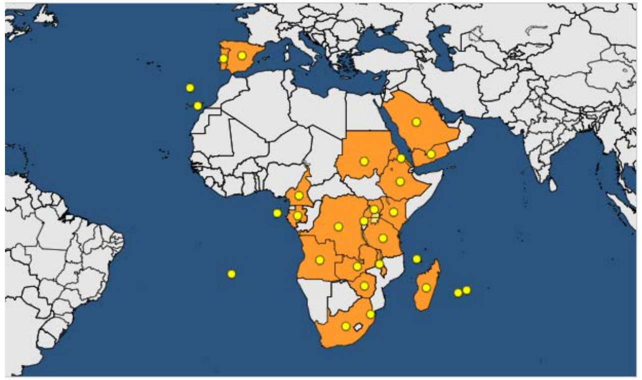
Important to improve the understanding of the vector's spread pattern in the landscape.

Map 1- Demarcated areas for the containment/eradication of PWN outbreaks in th

Introduction

Trioza erytreae

- Exotic species from Tropical Africa
- Citrus host plants
- Vector of the **greening disease**
- Can settle under a variety of ecological conditions such as in equatorial, arid, and warm temperate climates
- High fecundity and dispersal capacity
- Reported in the mainland of Spain and Portugal in 2014 and 2015 respectively.



Introduction

Greening disease

Why is it so important?

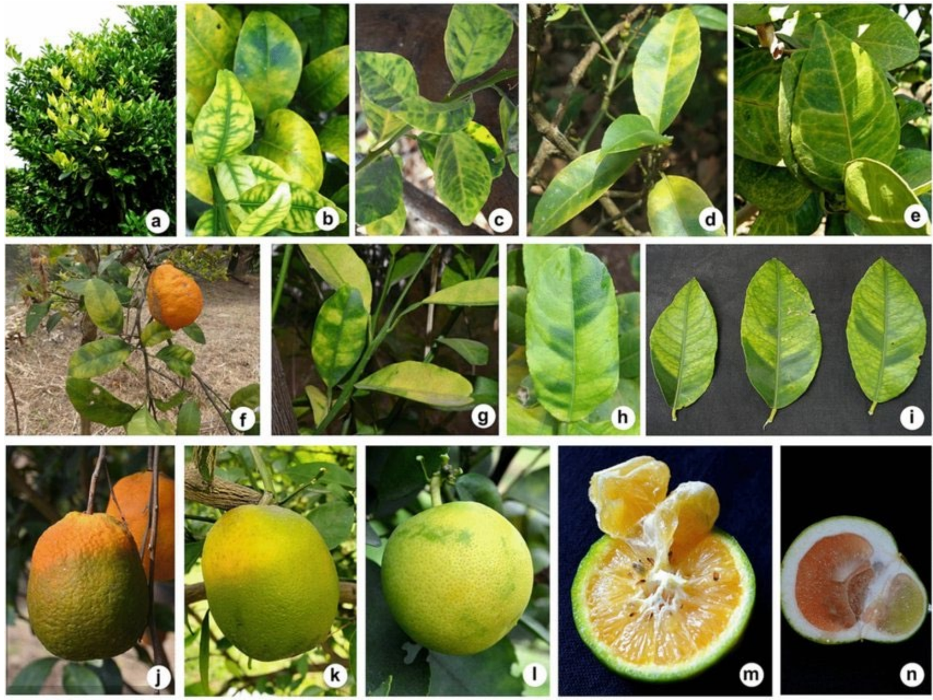
Considered to be the **WORST** citrus disease worldwide, no cure

Disease caused by the transmission of the *Candidatus* Liberibacter bacteria

Diaphorina citri

Responsible for the loss of 74% of the citrus production in Florida from 2005 to 2019

Cryptic symptoms



Das et al. 2021

Local Scale Least-cost Path Model

Modelling *Monochamus galloprovincialis* dispersal trajectories across a heterogenous forest landscape to optimize monitoring by trapping networks

Published in *Landscape Ecology*, *36*, 931-941.

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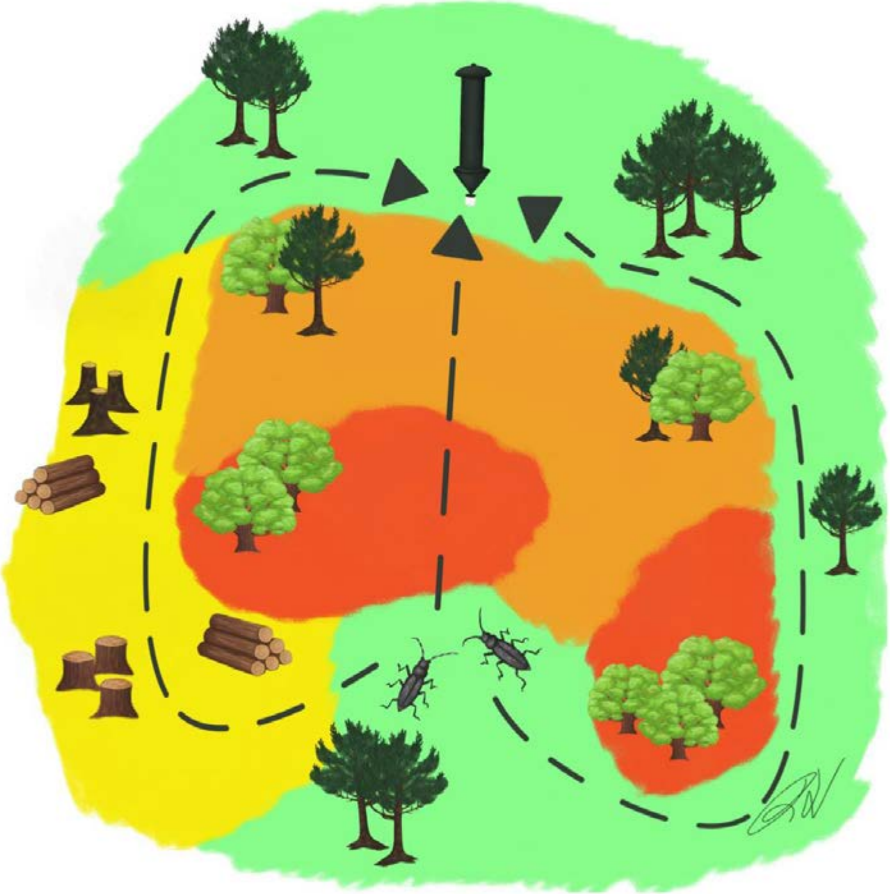


Monochamus galloprovincialis

Objectives

Analyze the effect of landscape heterogeneity on the vector's dispersal

Develop a method to locate the origin of captured insects in a systematic network of pheromone traps

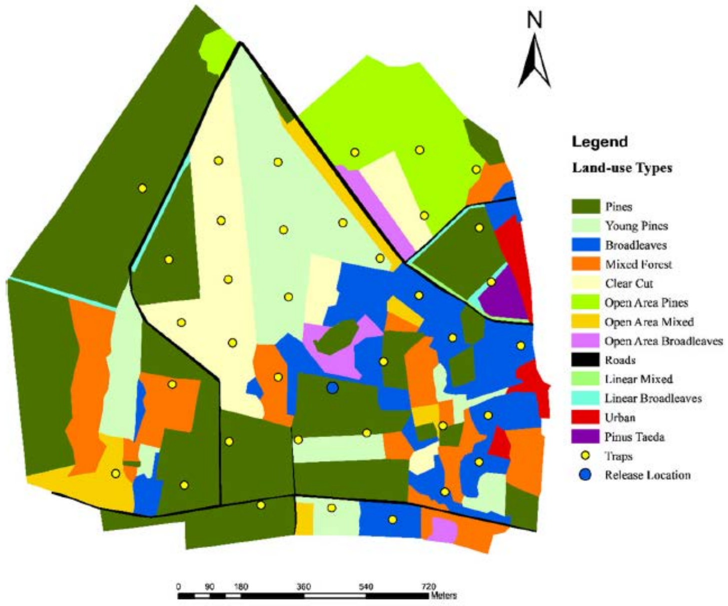
Methods

Mark-Release Recapture

Landes de Gascogne forest in Bordeaux

Release of 2747 marked individuals

Placement of 36 baited traps
heterogenous landscape



Vane Type baited Traps

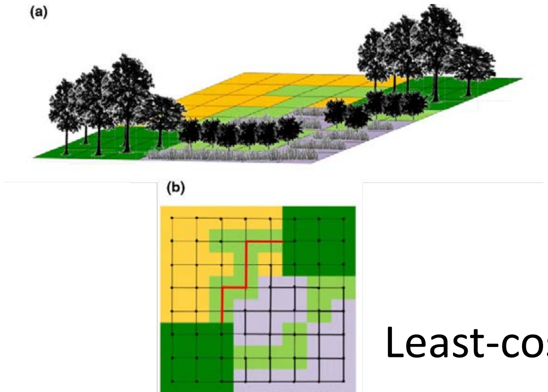
Methods

1. Calculate the friction values of each land-use type in the landscape using LCP analysis

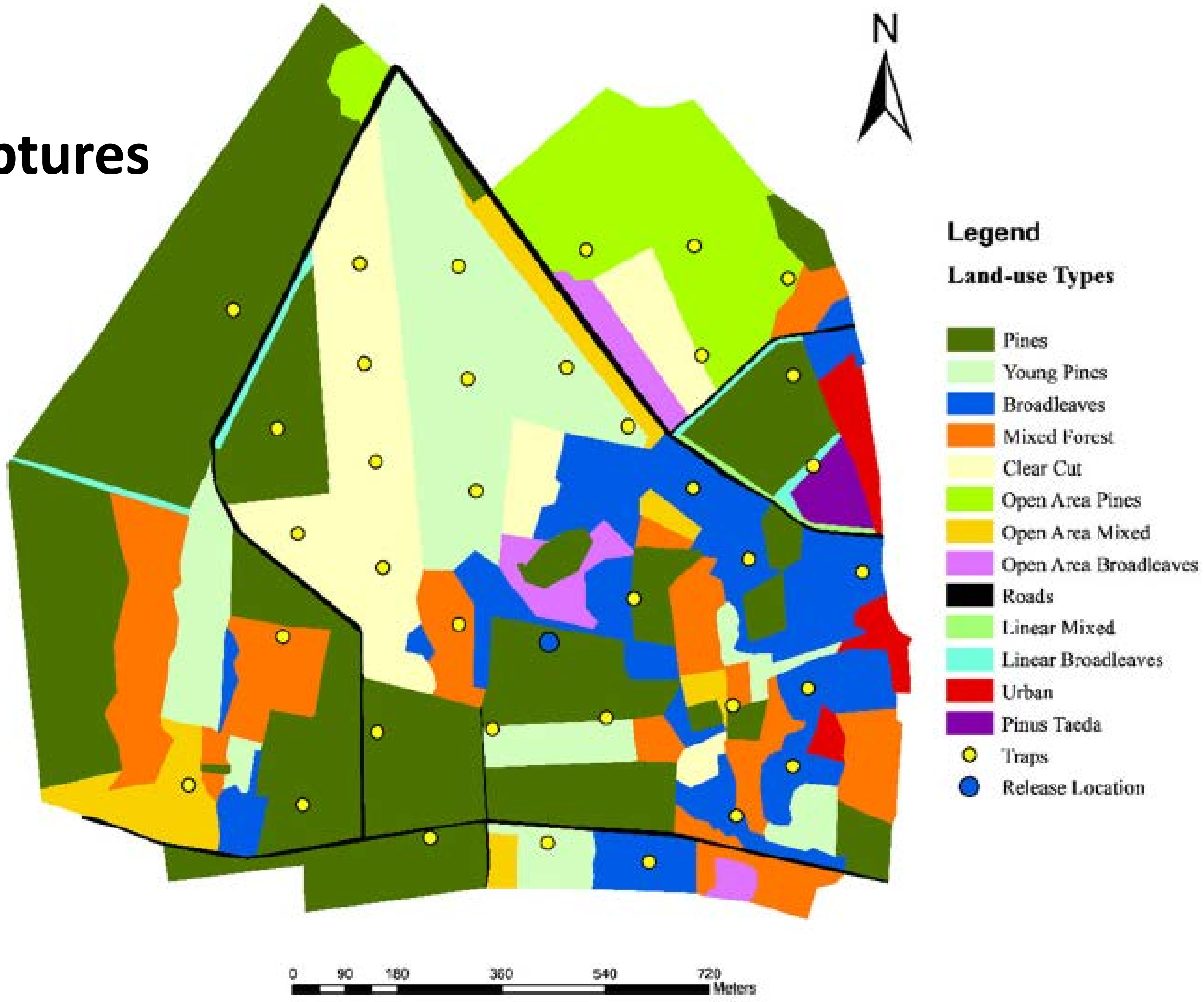
Correlation between least-cost paths and recaptures

Land-use Types	Control	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13
Pines	1	4	1	1	1	1	1	1	1	1	1	1	1	1
Open Area Pines	1	1	4	1	1	1	1	1	1	1	1	1	1	1
Open Area Mixed	1	1	1	4	1	1	1	1	1	1	1	1	1	1
Open Area Broadleaves	1	1	1	1	4	1	1	1	1	1	1	1	1	1
Roads	1	1	1	1	1	4	1	1	1	1	1	1	1	1
Young Pines	1	1	1	1	1	1	4	1	1	1	1	1	1	1
Clear Cut	1	1	1	1	1	1	1	4	1	1	1	1	1	1
Broadleaves	1	1	1	1	1	1	1	1	4	1	1	1	1	1
Mixed Forest	1	1	1	1	1	1	1	1	1	4	1	1	1	1
Pinus Taeda	1	1	1	1	1	1	1	1	1	1	4	1	1	1
Urban	1	1	1	1	1	1	1	1	1	1	1	4	1	1
Linear Broadleaves	1	1	1	1	1	1	1	1	1	1	1	1	4	1
Linear Mixed	1	1	1	1	1	1	1	1	1	1	1	1	1	4
R^2	0.263	0.073	0.184	0.232	0.252	0.252	0.311	0.289	0.359	0.300	0.263	0.263	0.268	0.267

Iterative optimization process (Highest R^2)



Least-cost path analysis



Methods

2. Estimate the barycentre of the infestation

Barycentre Equation:

$$X_B = \frac{\sum_{i=1}^{n} x_i}{n} \quad Y_B = \frac{\sum_{i=1}^{n} y_i}{n}$$

X & Y Coordinates

Euclidean Distance Barycentre:

$$X_B = \frac{\sum_{i=1}^{n} x_i . w_i}{\sum_{i=1}^{n} w_i} \quad Y_B = \frac{\sum_{i=1}^{n} y_i . w_i}{\sum_{i=1}^{n} w_i}$$

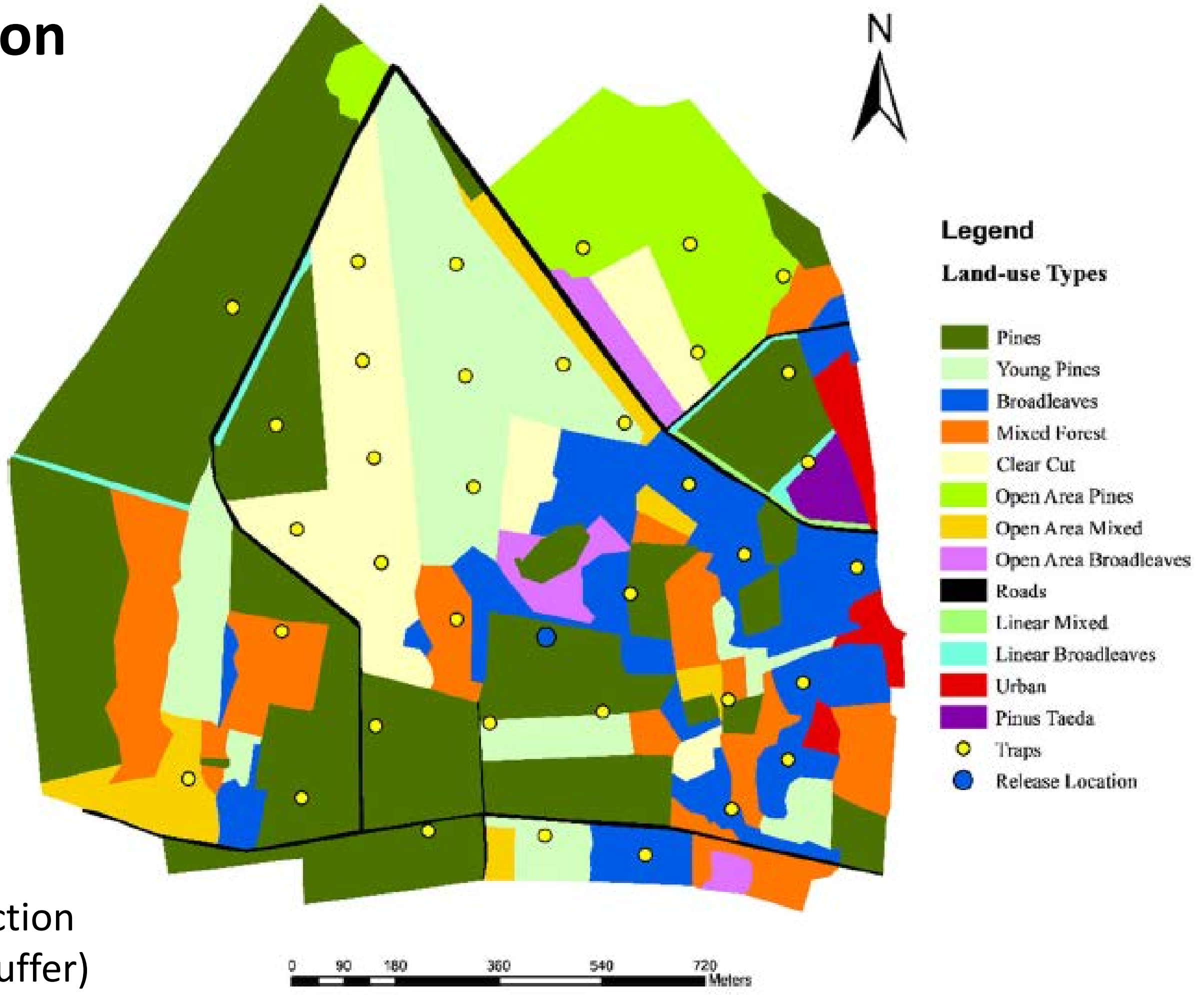
Weighted by Recapture Values

Least Cost Path Barycentre:

$$X_B = \frac{\sum_{i=1}^{n} x_i . w_i . F_i}{\sum_{i=1}^{n} w_i . F_i} \quad Y_B = \frac{\sum_{i=1}^{n} y_i . w_i . F_i}{\sum_{i=1}^{n} w_i . F_i}$$

Weighted by surrounding friction values (100m buffer)

Study site in the Landes de Gascogne forest in Bordeaux



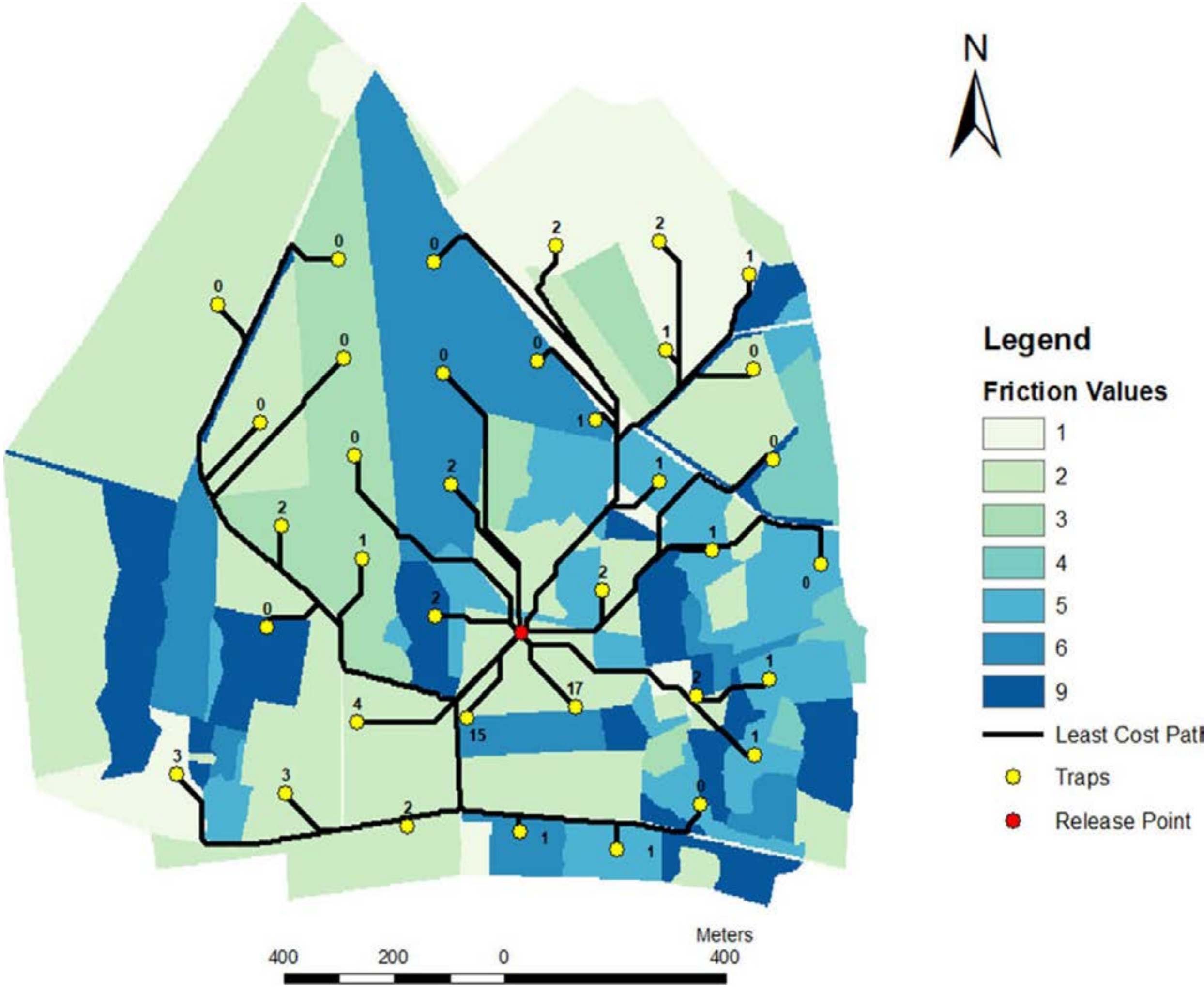
Landscape classified into 13 land-use types

Results

68 out of 2747 marked insects were recaptured

Land-use Friction Values:

1 - Open areas
2 - Pines
3 - Clear cut
5 - Broadleaves
6 - Young Pines
9 - Mixed Forest



Landscape classified into Friction values

Results

Invasion Barycentre Estimation

Euclidean

Paths and recaptures

$R^2 = 0.263$

Accuracy = 31m

Least-cost path

Cost paths and recaptures

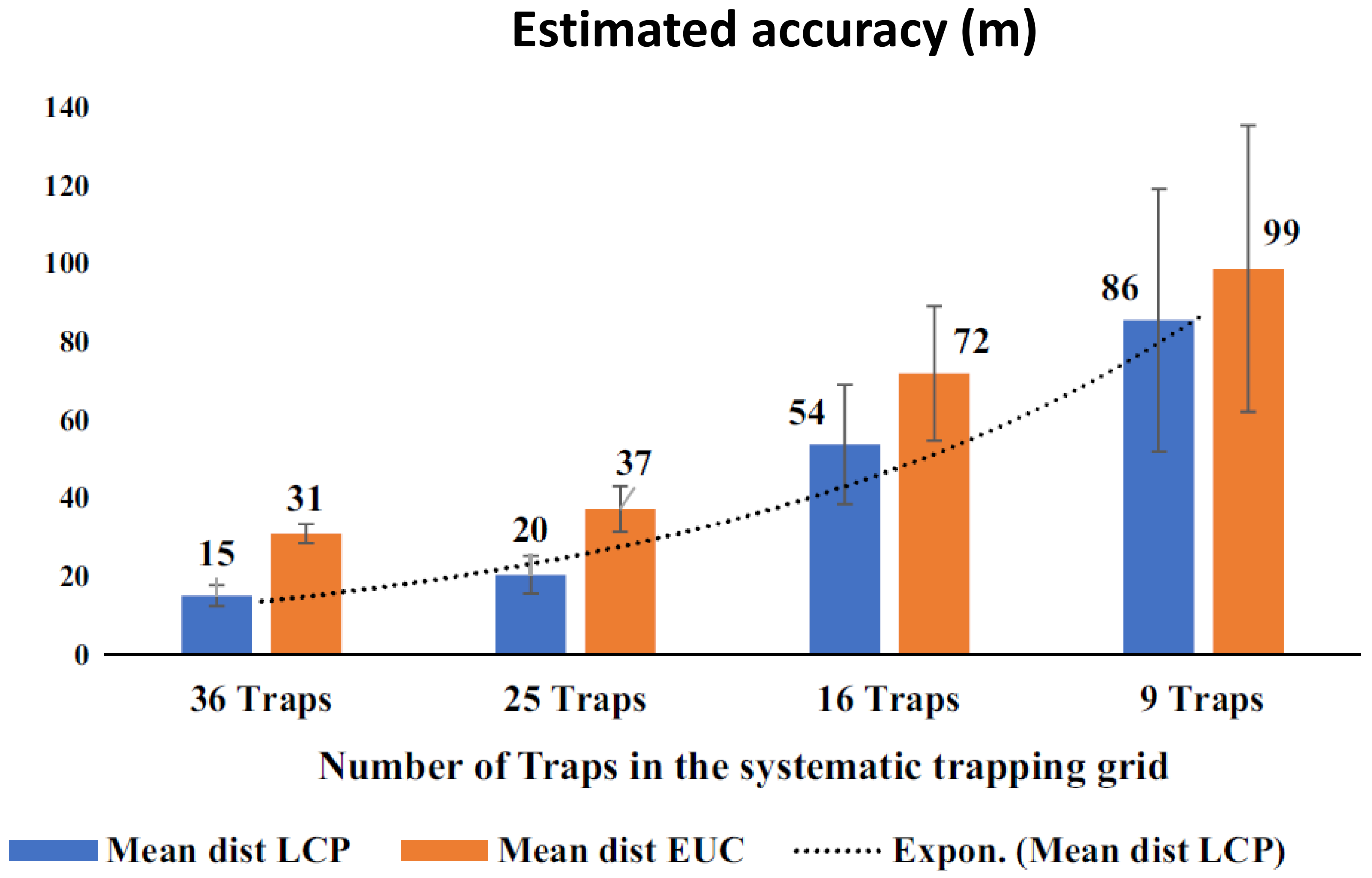
$R^2 = 0.627$

Accuracy = 15m

Results

Grid size effects (36, 25, 16 and 9 traps)

36 Traps N = 36
25 Traps N = 2049
16 Traps N = 93312
9 Traps N = 230400

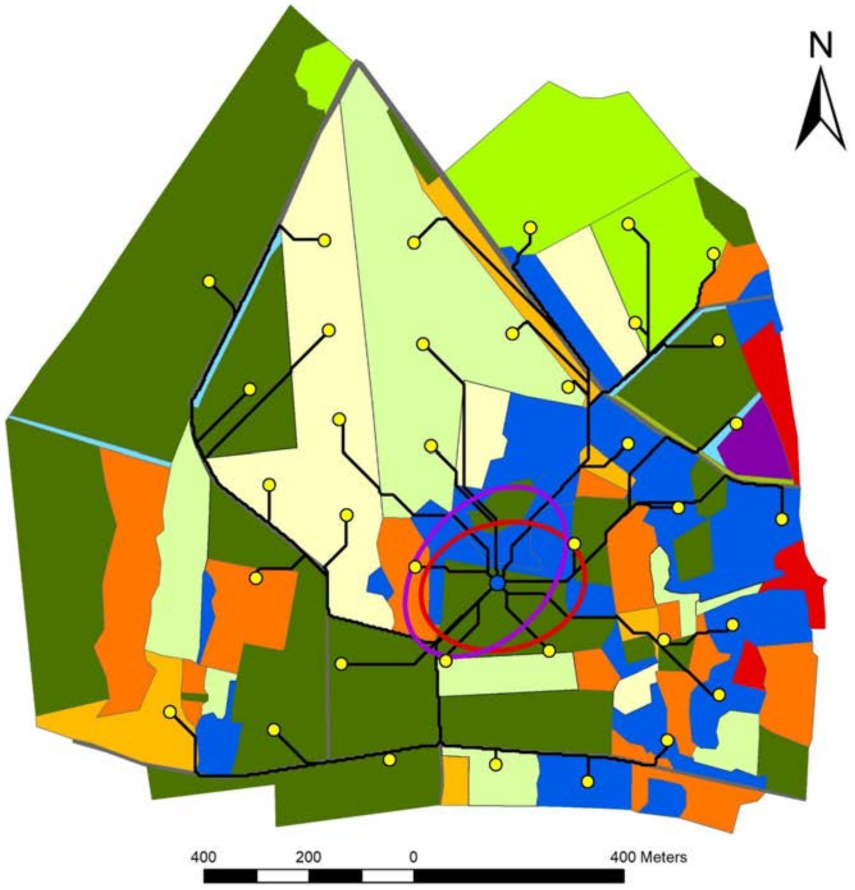


Conclusions

Landscape composition and configuration affect the dispersal of the beetle and PWN:

- Clear cuts did not greatly disturb its flight path
- Non-habitat areas with broadleaves were avoided

Development of an innovative method to pinpoint the origin of an outbreak in the landscape

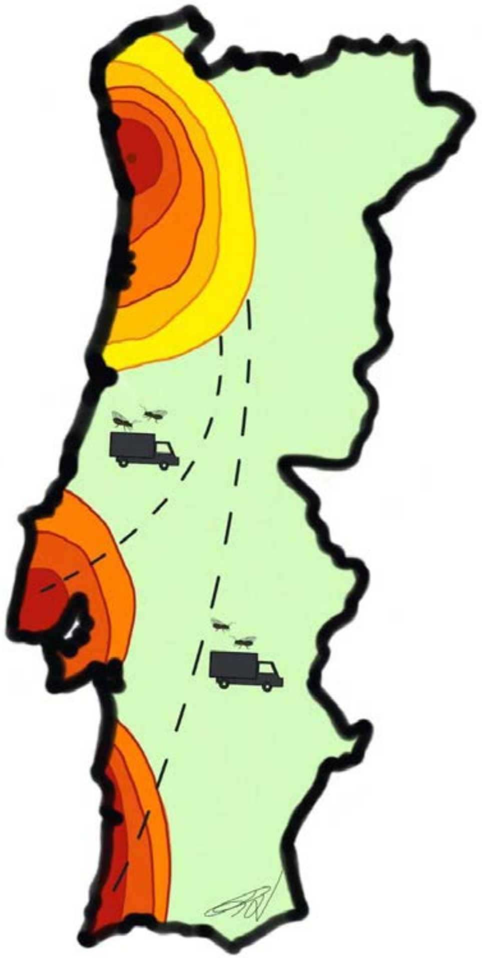


Chapter 3

Modelling the invasion dynamics of the African citrus psyllid: The role of human-mediated dispersal and urban and peri-urban citrus trees

Published in *NeoBiota*, *84*, 369-396

Pedro Nunes (ISA)
Manuela Branco (ISA)
José Carlos Franco (ISA)
Christelle Robinet (INRAE)

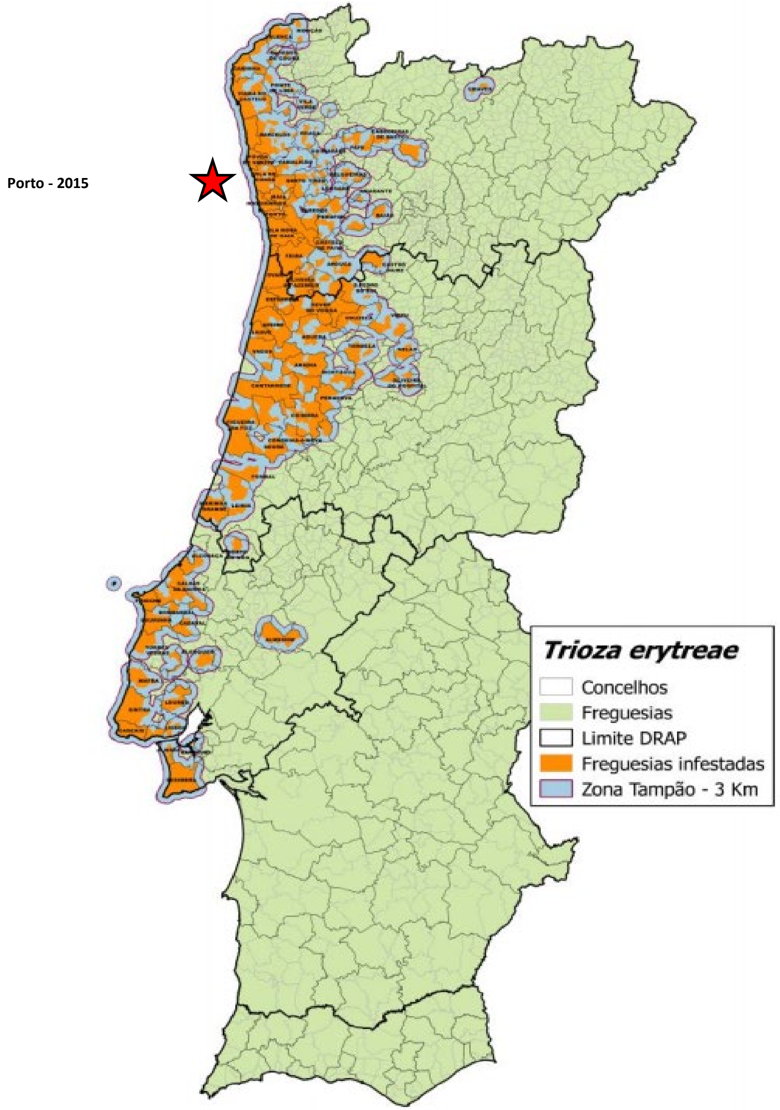


Objectives

Verify if the hybrid stratified dispersal modelling is suitable for the spread of *T. erytreae*

Understand the role of human-mediated spread in the current invasion of the psyllid in Portugal

Highlight the importance of isolated host trees in the current invasion of the psyllid in Portugal



Methods

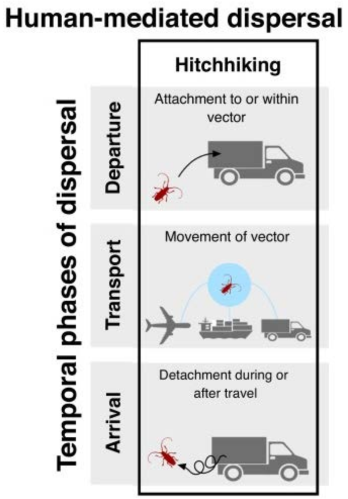
Hybrid Stratified dispersal Model (Robinet et al. 2016)

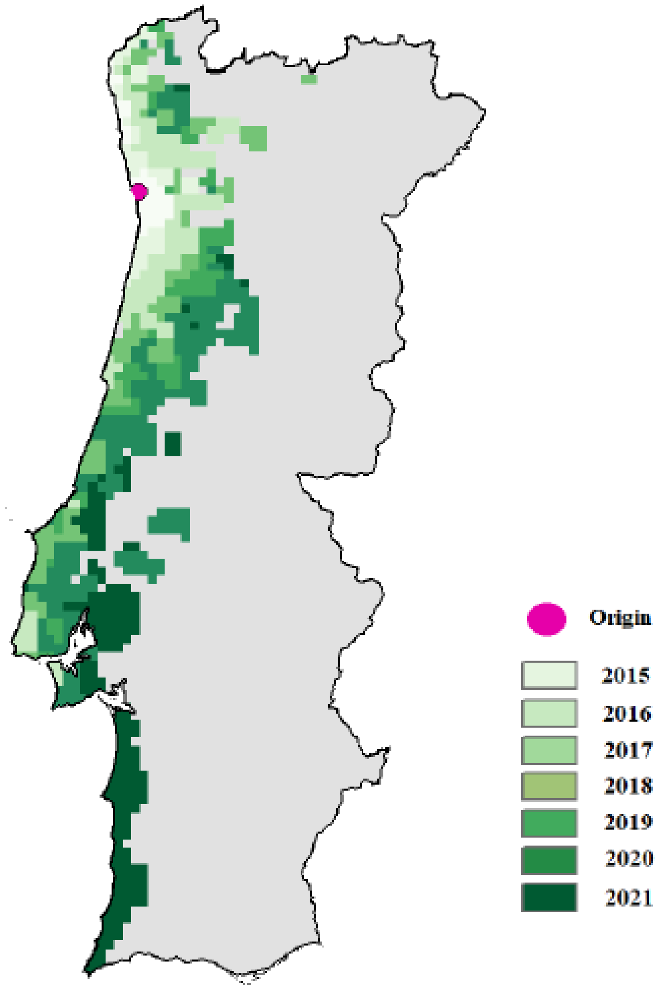
- Reaction-diffusion model

$$\frac{\partial N}{\partial t} = D\left(\frac{\partial^2 N}{\partial x^2} + \frac{\partial^2 N}{\partial y^2}\right) + rN\left(1 - \frac{N}{K}\right)$$

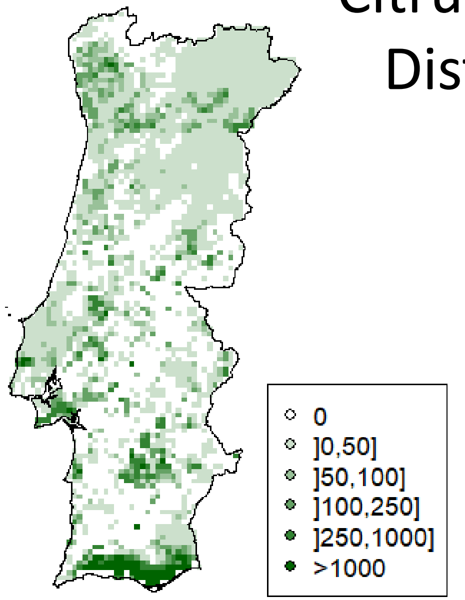
- Stochastic long-distance dispersal model

NB = 1 + e; e – Poisson distribution

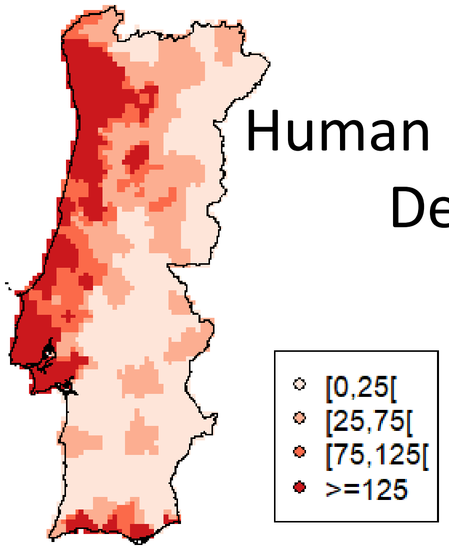




Citrus Orchards Distribution



Human Population Density



Methods

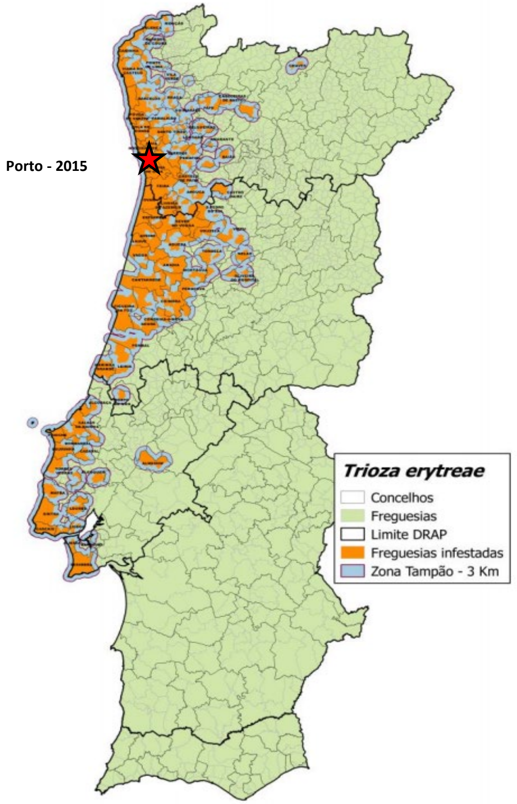
Model Validation using DGAV report data

32 model simulations – 300 replicates each

$$\text{F1-Score} = \frac{2 \times (precision \times recall)}{precision + recall} = \left(\frac{TP}{TP + \frac{1}{2}(FP + FN)}\right)$$

Table 3.1 – Parameters and scenarios tested in the modelling.

Model parameters	Scenarios tested	Details
Long-distance dispersal (LDD)	No, Low, Medium, High	No: No LDD Low: $\lambda = 5\ \ln((P/2642) + 1/\ln(2))\ /\ 2$ Medium: $\lambda = 5\ \ln((P/2642) + 1/\ln(2))$ High: $\lambda = 5\ \ln((P/2642) + 1/\ln(2)) \times 2$
Fecundity (Fecund)	Low, High	Low: 327 eggs/female High: 827 eggs/female
Number of introductions of *T. erytreae* (LIS)	True False	True: Two introductions; in Porto in 2014 and in Lisbon 2017 False: One introduction in Porto
Host trees available (Urb)	True False	True: Trees from orchards, plus trees from urban and peri-urban areas False: Trees from orchards only



Methods

Hybrid Stratified dispersal Model (Robinet et al. 2016)

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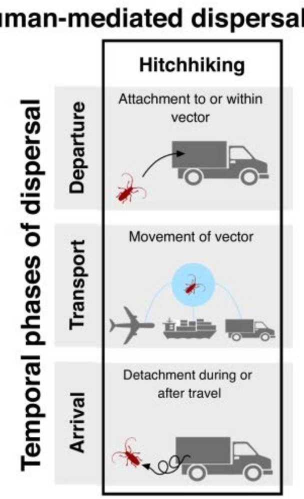
- Stochastic long-distance dispersal model

NB = 1 + e; e – Poisson distribution



Biological traits

Spread rate (C) – 6km/year

Growth (r) (Climatic variables)

Host distribution (K)

Citrus Orchards - Agricultural Census

Urban Trees - Google street view imagery

Methods

Estimating the urban citrus trees

Three urban land-use types:

Vertical urban areas
Horizontal urban areas
Discontinuous urban areas

Urban Areas	Estimated density (trees/ha)	Sampled area (ha)
Vertical	0.37	360.9
Horizontal	3.20	293.4
Discontinuous	5.14	329.1


Methods

Model Validation using DGAV report data

32 model simulations – 300 replicates each

$$\text{F1-Score} = \frac{2\ x\ (precision\ x\ recall)}{precision + recall} = \left(\frac{TP}{TP + \frac{1}{2}(FP + FN)}\right)$$

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Long-distance dispersal (LDD)	No, Low, Medium, High	No: No LDD Low: λ = 5 ln((*P*/2642) + 1/ln(2)) / 2 Medium: λ = 5 ln((*P*/2642) +1/ln(2)) High: λ = 5 ln((*P*/2642) + 1/ln(2)) x 2
Fecundity (Fecund)	Low, High	Low: 327 eggs/female High: 827 eggs/female
Number of introductions of *T. erytreae* (LIS)	True False	True: Two introductions; in Porto in 2014 and in Lisbon 2017 False: One introduction in Porto
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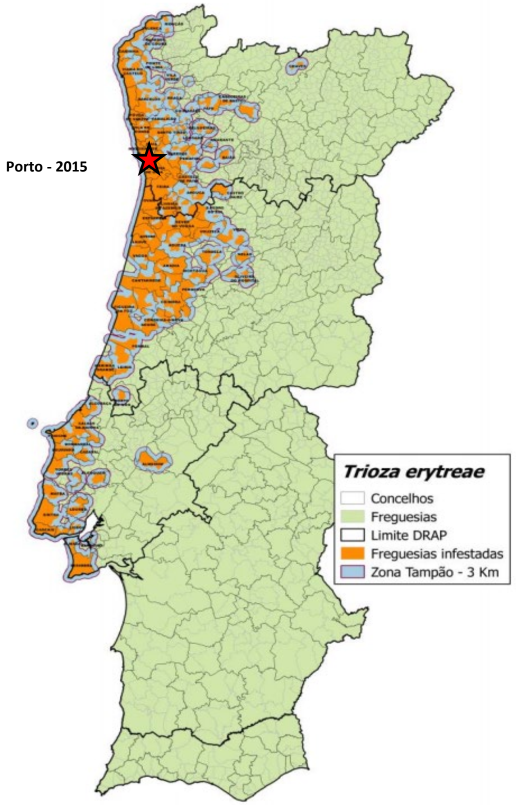


Results

The Stratified dispersal model accurately simulated the invasion dynamics of *T. erytreae*

Model performance: F1-Score = 0.803

Human-mediated spread was involved the invasion of *T. erytreae*

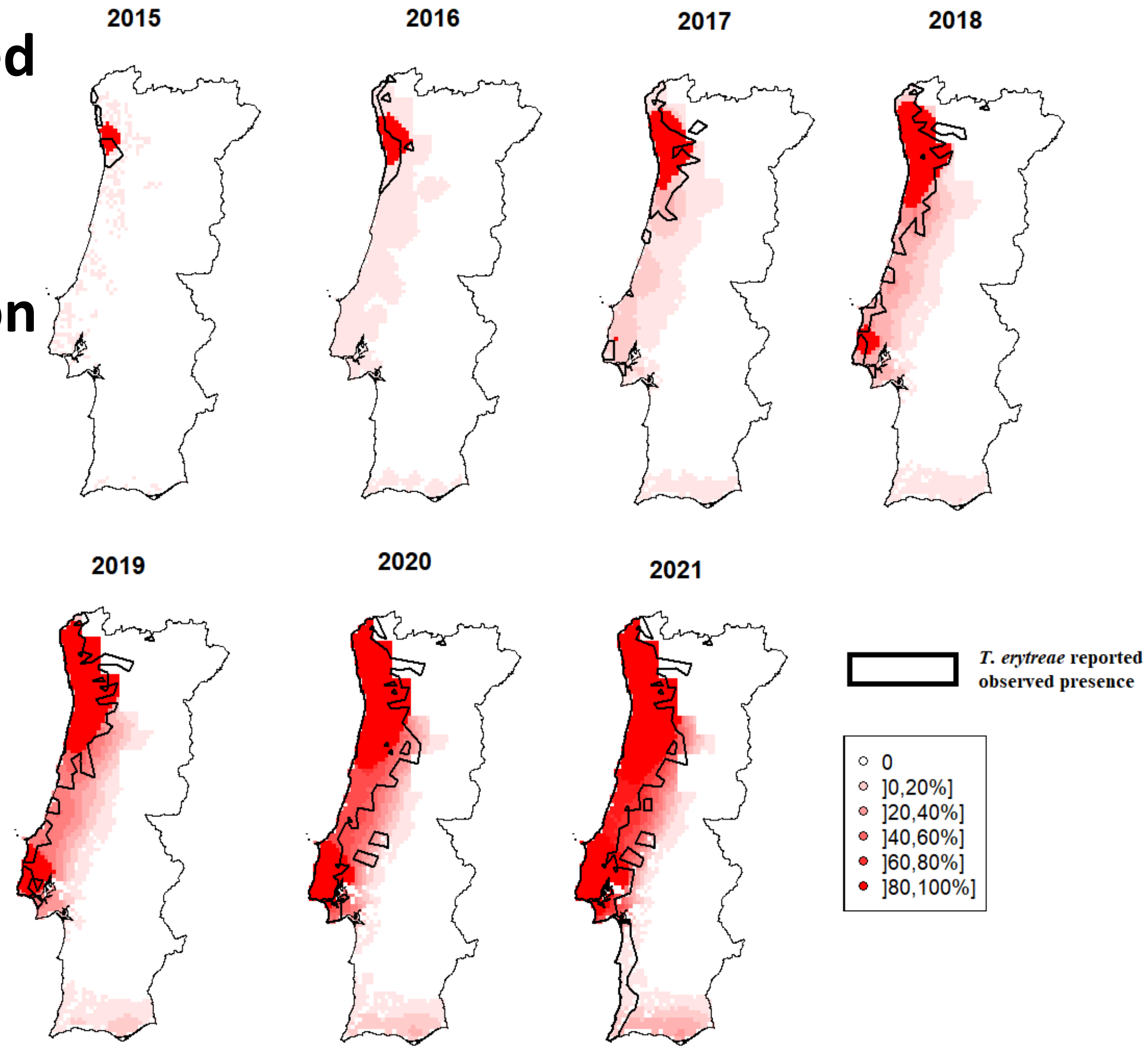
Inclusion of LDD

Model performance: F1-Score = 0.803 vs 0.583

Citrus trees from urban and peri-urban environments played an important role in the spread of *T. erytreae*

Inclusion of 7427 Urban Trees (**0.06%**)

Model Performance: F1-Score = 0.801 vs 0.686

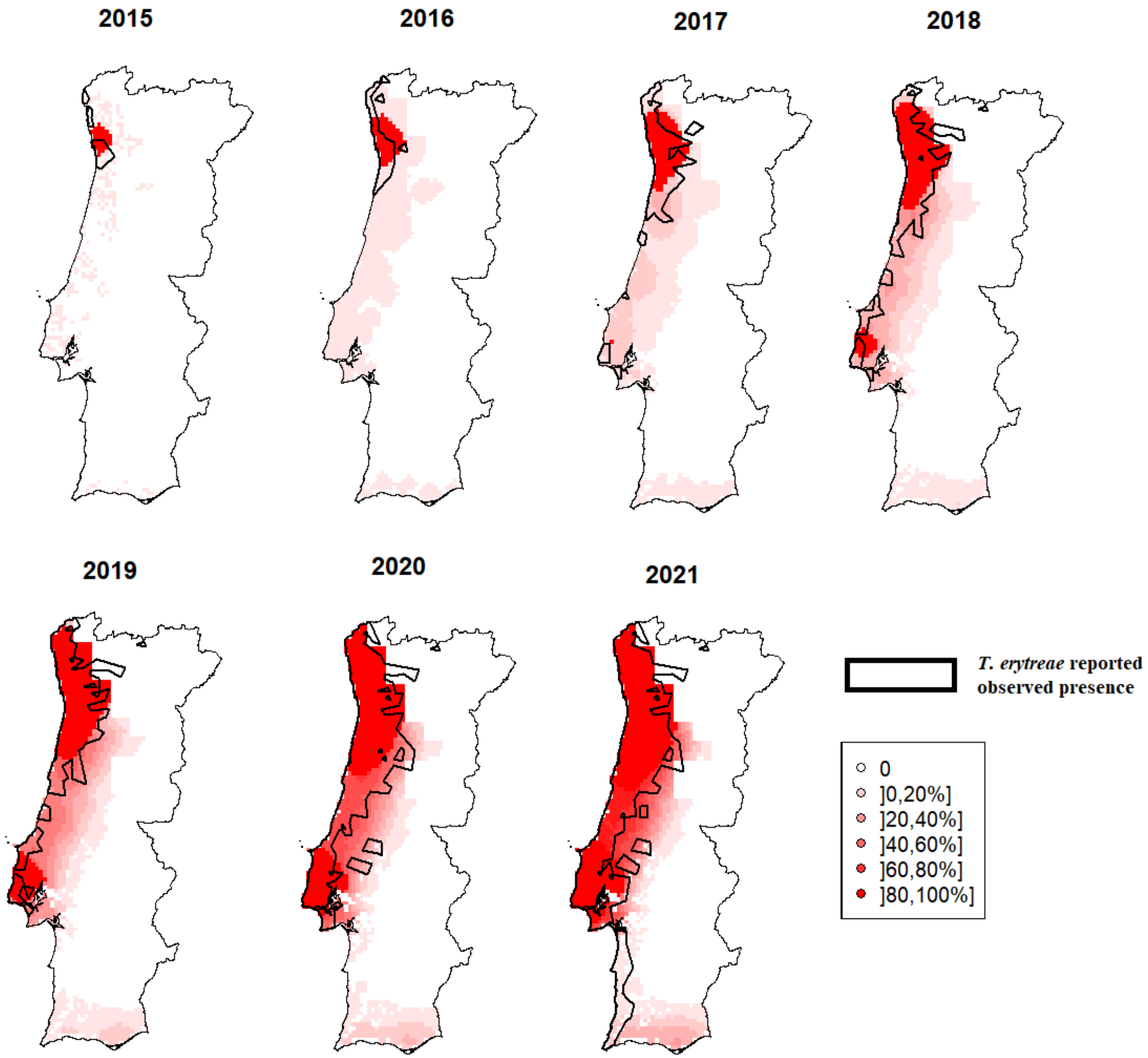


Conclusions

The stratified dispersal model was a good tool for simulating the invasion dynamics of *T. erytreae:*

- Human-mediated spread was a key-factor in the fast invasion of *T. erytreae* in Portuguese territory
- Citrus trees from urban and peri-urban environments played an important role in the spread of *T. erytreae* in Portugal

Highlighted the potential of Google street view imagery for surveying urban tree density.



Chapter 4

Patterns of invasibility in agricultural landscapes: are spatio-temporal epidemiology approaches helpful?

To be submitted to Agriculture, Ecosystems & Environment

Pedro Nunes (ISA)
Manuela Branco (ISA)
José Carlos Franco (ISA)
Mário Santos (UTAD)

Objectives

Test the suitability of this epidemiological approach to model the dispersal of a pest species in a heterogenous landscape

Study the importance of the landscape structure towards the invasion success

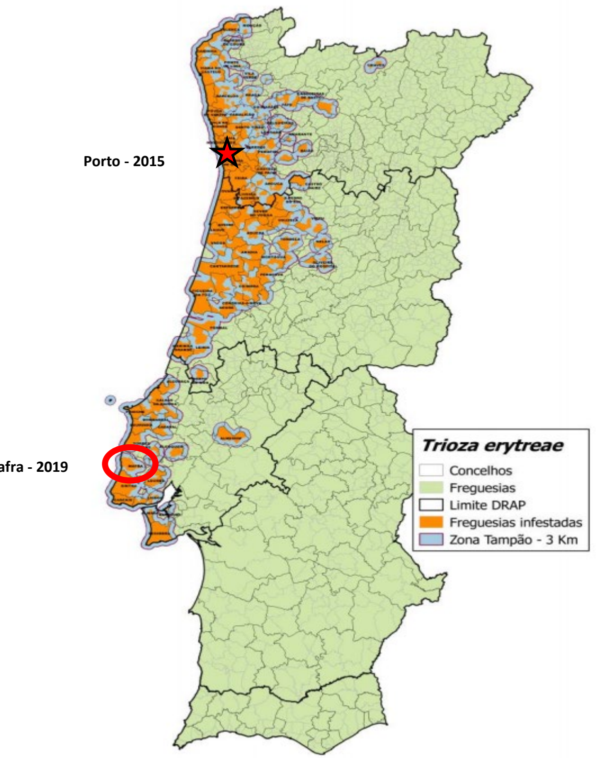
Support relevant management actions to halt or reduce the species spread

Methods

Field Data

3 Monitoring field trips in May, July and October of 2019

20 lemon trees in 30 lemon tree orchards in the Oeste region

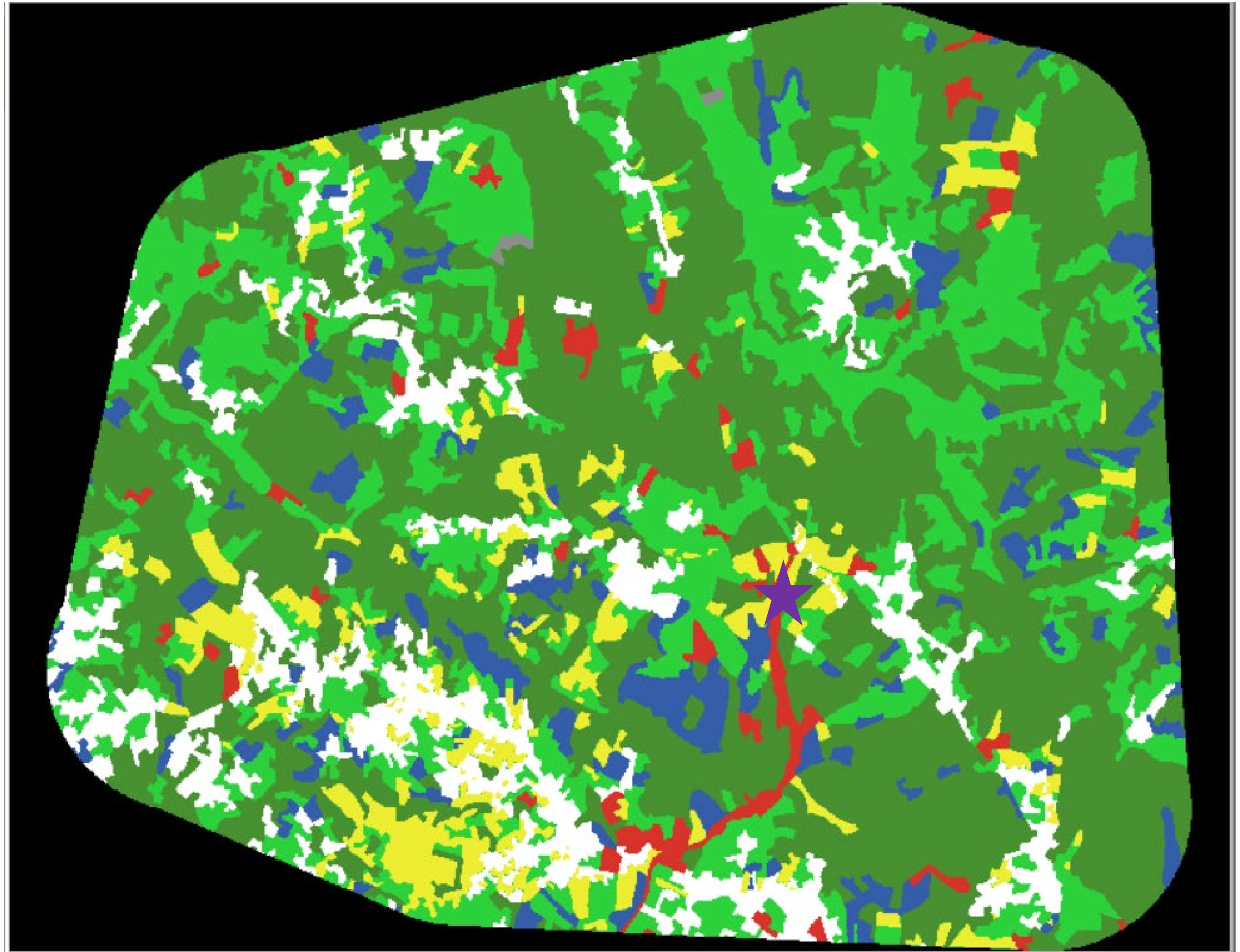


Methods

Virtual Landscape

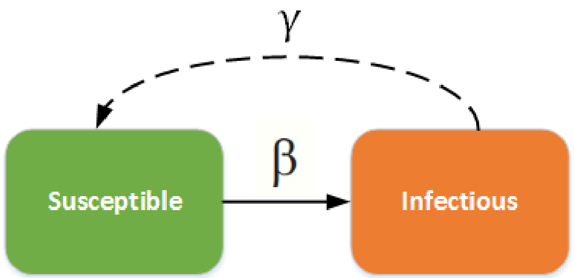
- Residential Urban
- Lemon Orchards
- Non-Residential Urban
- Agriculture
- Forest
- Other

★ Start of Invasion



Methods

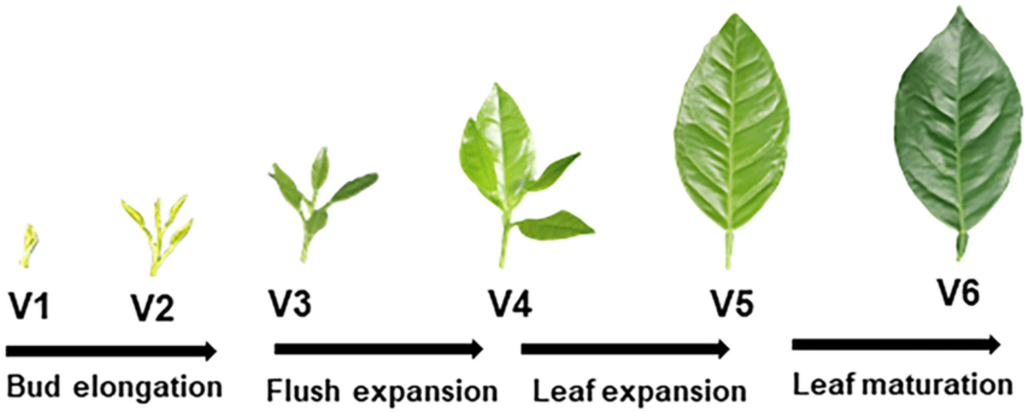
Epidemiological Spatio-temporal Celular based model



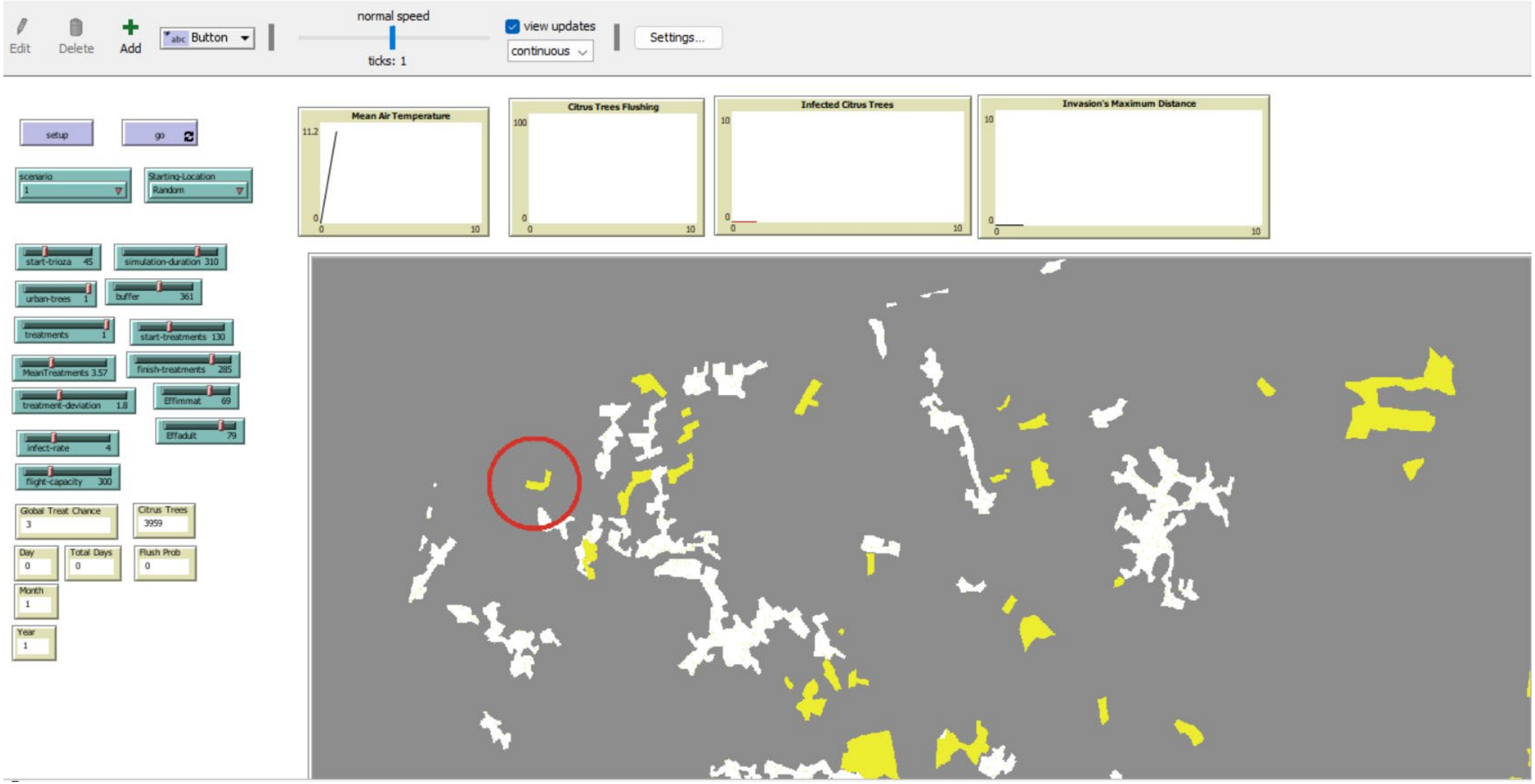
SIS Model

Cell size = 5mx5m
Time scale = daily

Leaf flushing as a key factor



Methods



Edit
Delete
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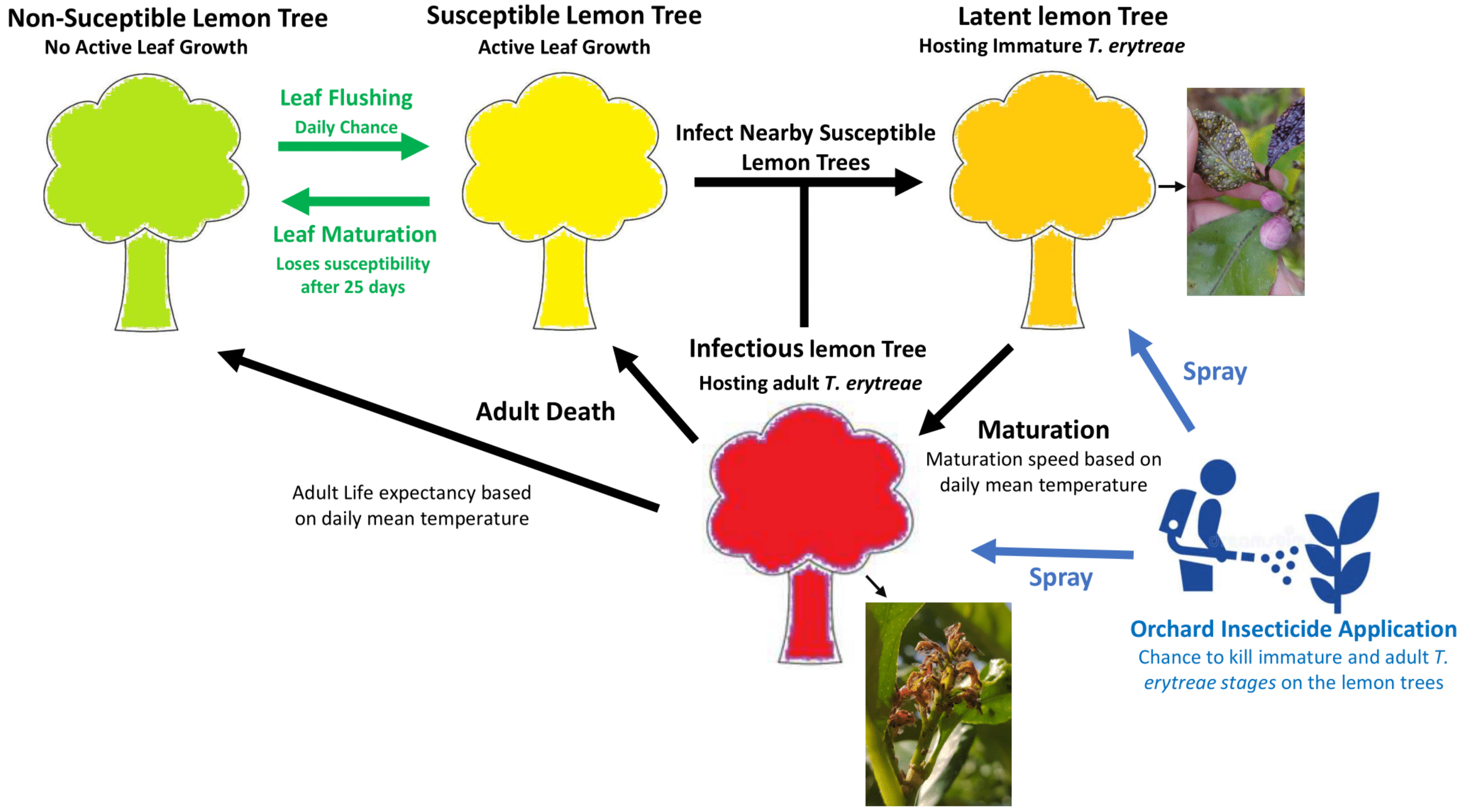
1
Starting-Location
Random
start-trioza 45
simulation-duration 310
urban-trees 1
buffer 361
treatments 1
start-treatments 130
MeanTreatments 3.57
finish-treatments 285
treatment-deviation 1.8
Effimmat 69
Effadult 79
infect-rate 4
flight-capacity 300
Global Treat Chance
3
Citrus Trees
3959
Day
0
Total Days
0
Flush Prob
0
Month
1
Year
1
Mean Air Temperature
Citrus Trees Flushing
Infected Citrus Trees
Invasion's Maximum Distance

Methods



Mean Temperature

One simulation of *tmed* from the model is presented in the figure below.

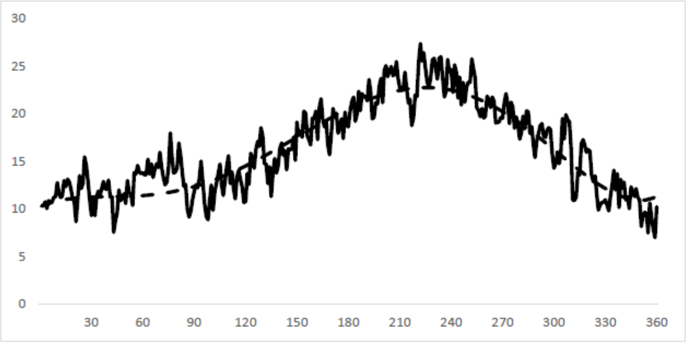
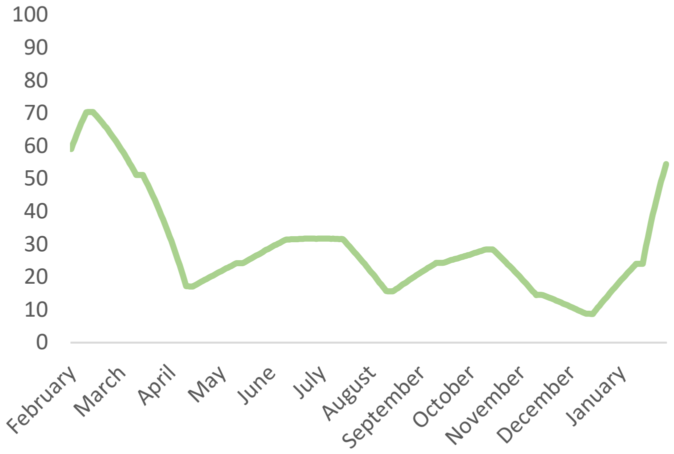


Fig. S4.6.2 *tmed* simulated from the model for one year (360 days) and the estimated seasonal pattern.

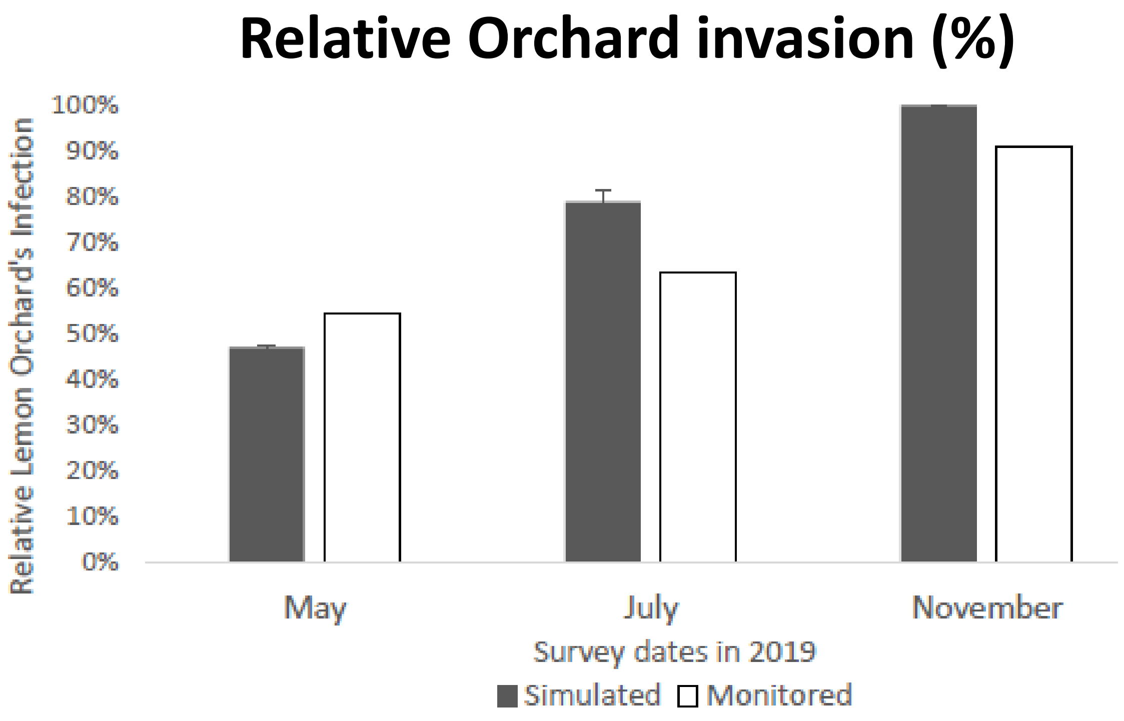
Leaf Flushing

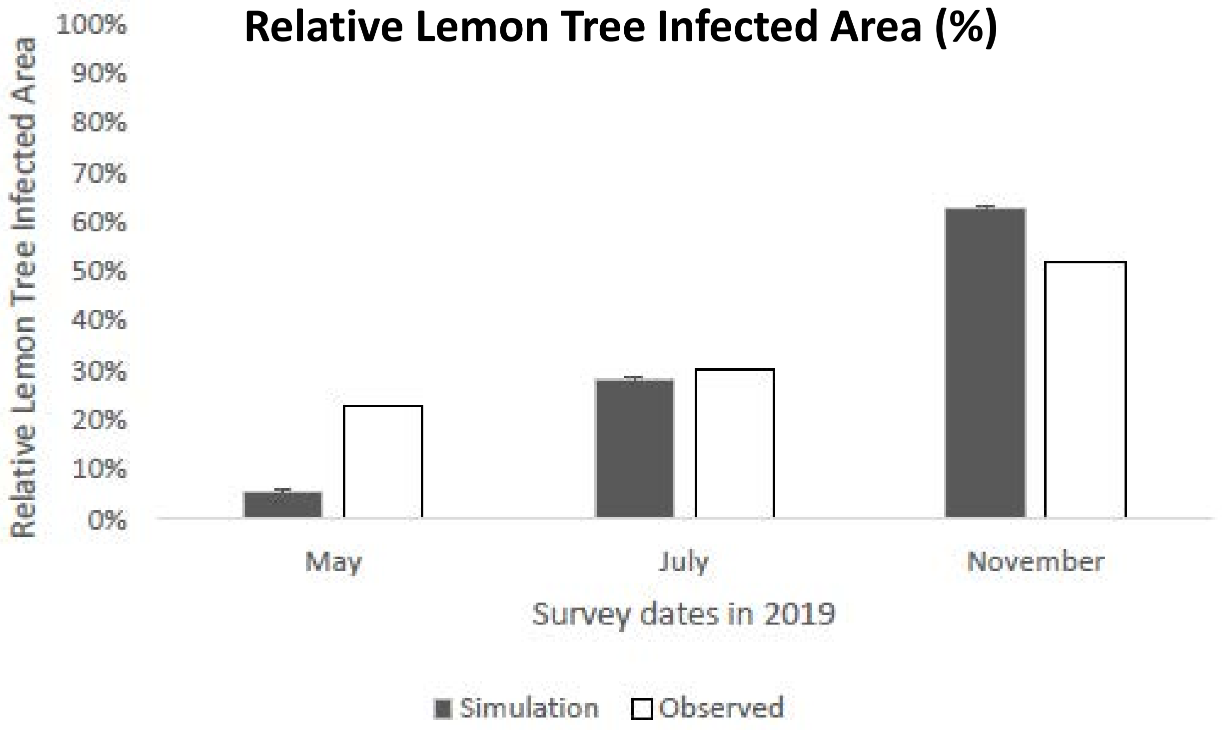


Results

1. Model Performance Evaluation

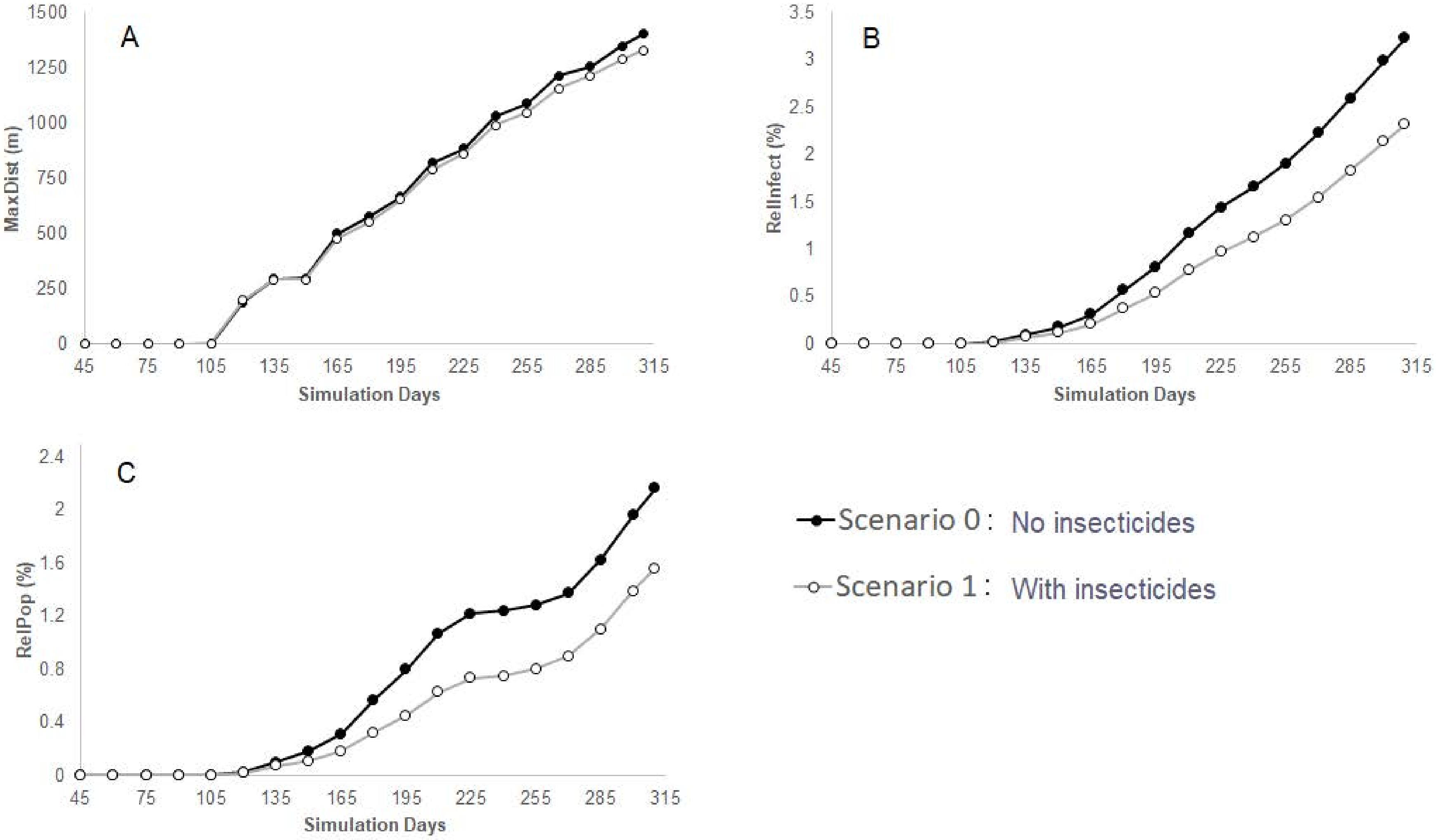
Field work compared with 30 simulations





Results

2. Insecticide application effectiveness



Results

3. Landscape's role in the invasion patterns

Isolated host trees from urban areas promoted the species invasive success

Isolated trees likely countered the negative effect of orchard fragmentation

Host tree density did not affect the invasive species dispersal ability

Multivariate regression model

Unstandardized coefficients

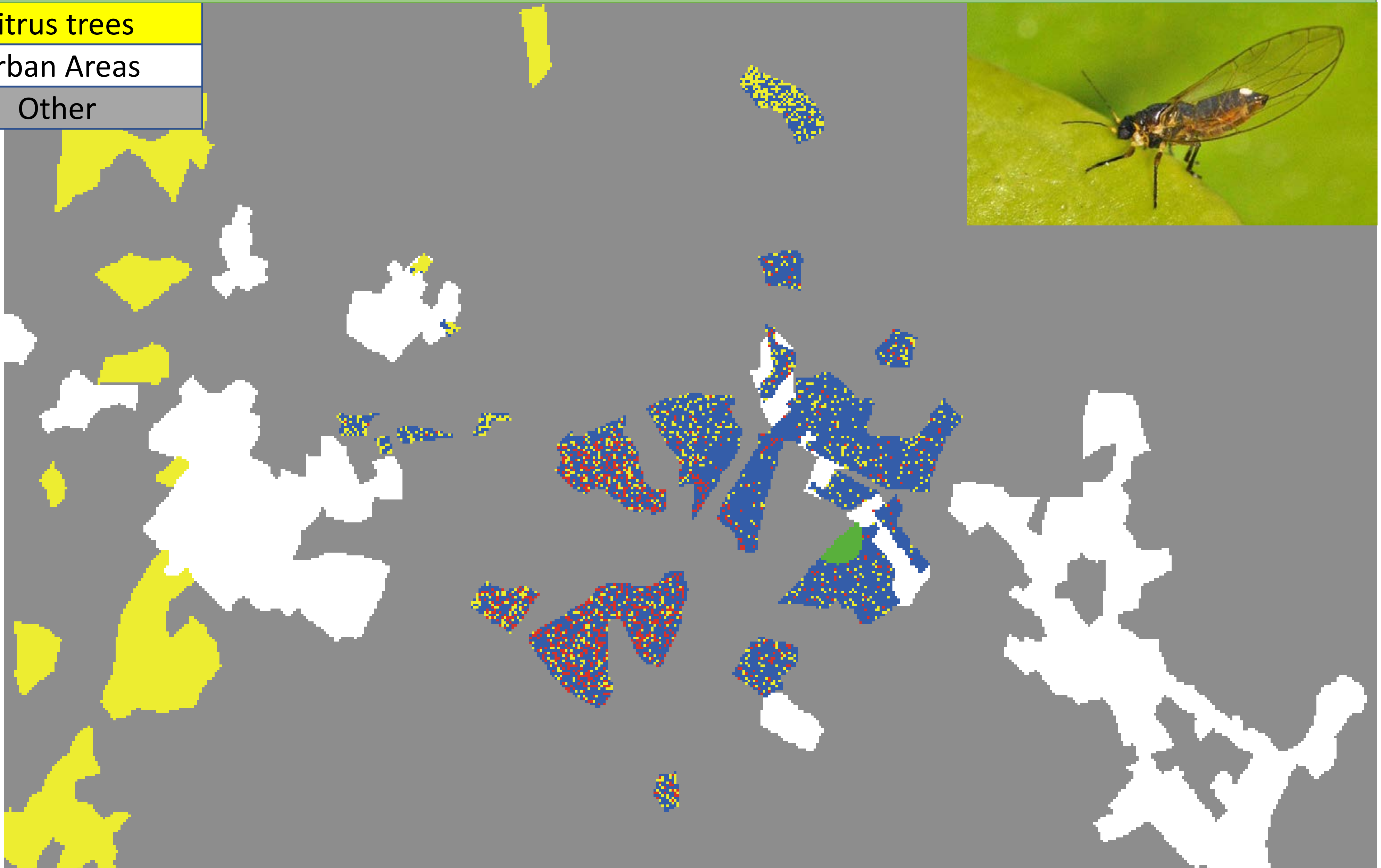
Model Dependent variable:	Maximum Distance	Relative Infected Area	Relative Infected Trees
Relative urban area	1007.397	0.118	0.082
	$p < 0.001$	$p < 0.001$	$p < 0.001$
Lemon tree density	129.895	0.186	0.138
	$p = 0.518$	$p < 0.001$	$p < 0.001$
Orchard frag.	46.153	-0.035	-0.009
	$P = 0.687$	$p < 0.001$	$p < 0.001$

Results

Previously infested	Citrus trees
Active Psyllid	Urban Areas
Infestation Origin	Other

Model Example

No Urban Trees

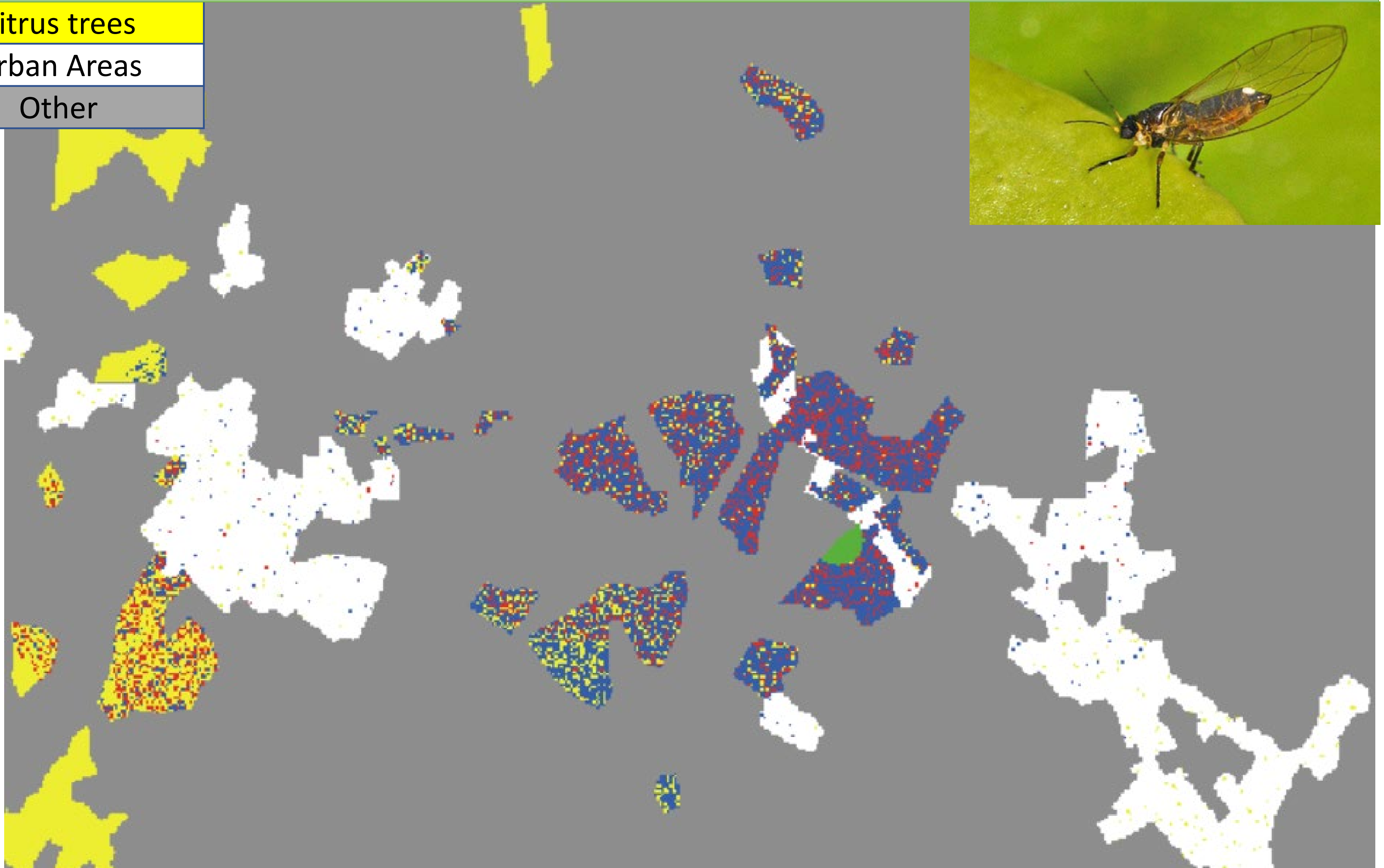


Results

Previously infested	Citrus trees
Active Psyllid	Urban Areas
Infestation Origin	Other

Model Example

With Urban Trees

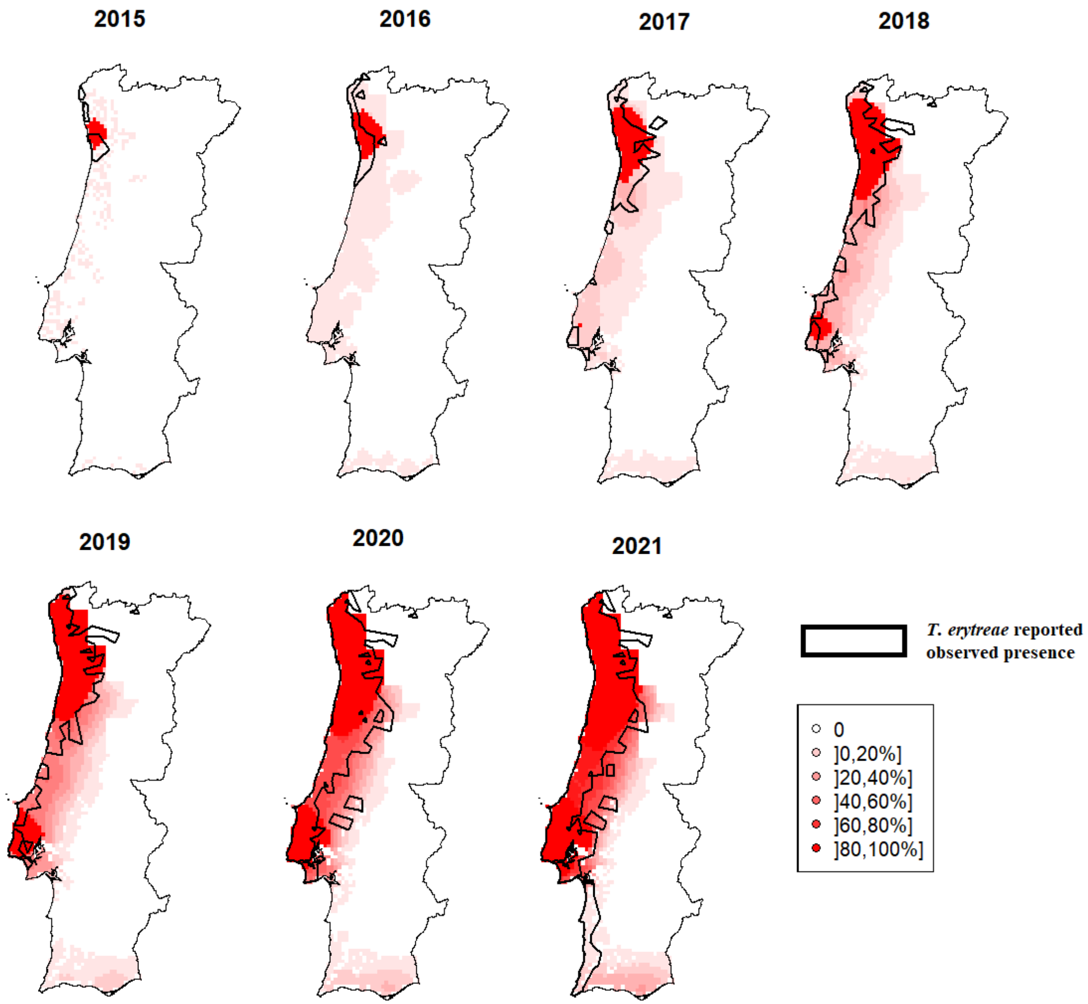


Conclusions

Urban host trees play a significant role in the spread of *T. erytreae* at a local scale.

Using only chemical control seems to be not be effective in slowing this type of species spread

Development of a simple and flexible new epidemiological modelling approach for invasion biology



Post-Doc

Beyond Project

INRAE

PHIM Plant Health Institute Montpellier

“Distribution modeling and surveillance of a plant disease at large scales: the case study of the Huanglongbing in Citrus farming”

Supervision:

Christine Meynard (INRAE – CBGP)

Virginie Ravigne (CIRAD – PHIM)

Nicolas Sauvion (INRAE – PHIM)

Post-Doc

Beyond Project

INRAE

PHIM Plant Health Institute Montpellier

Studying the potential distribution and spread potential of Huanglongbing and its vectors

Expected Outcomes:

Risk analysis and mapping

Surveillance

Pest Management

Tools:

Species distribution models

Species dispersal models