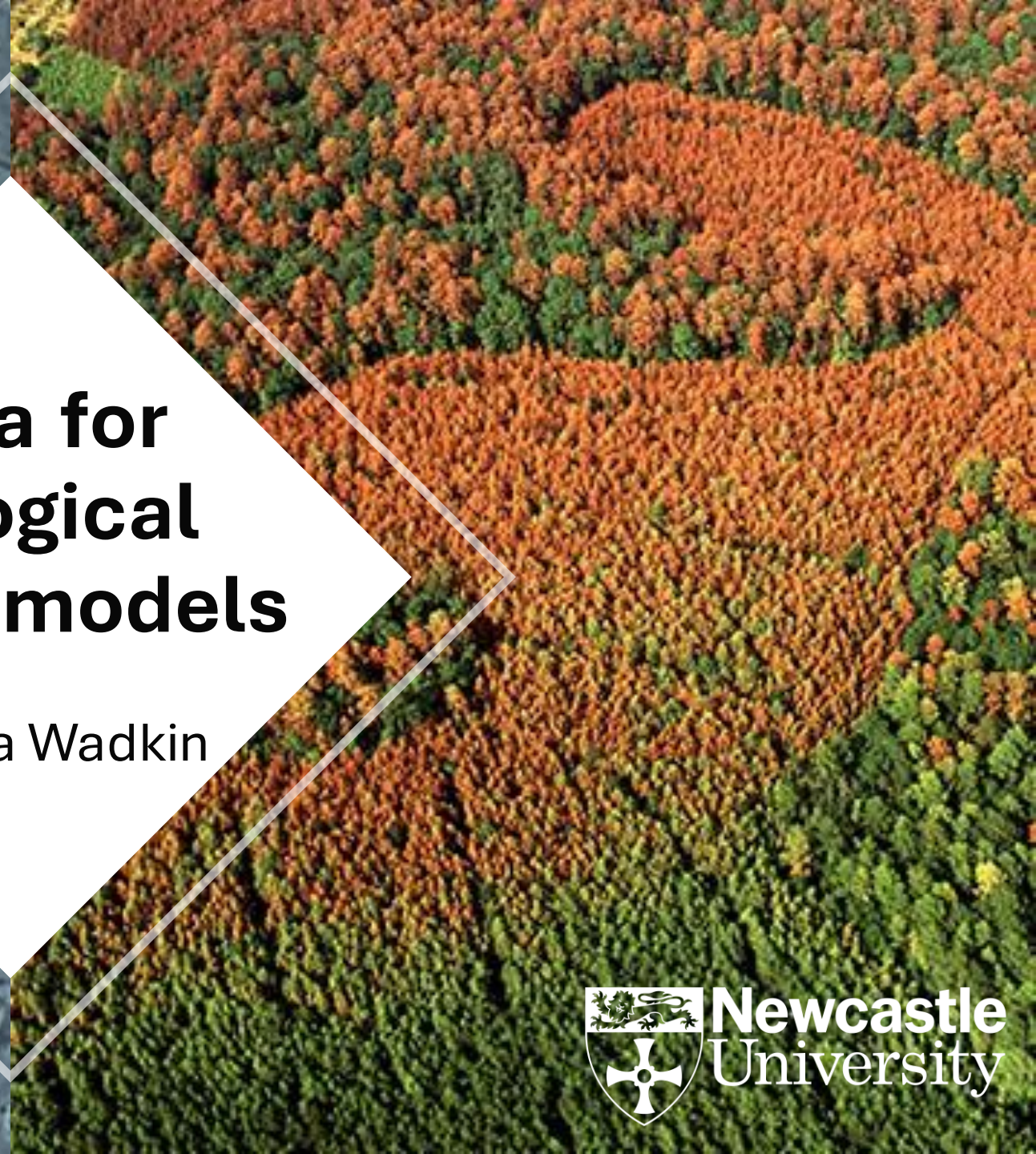
Data for biological maths models

Dr Laura Wadkin



Newcastle University

My background

- Applied mathematics PhD (2016-2020)
- Research associate (2020-present)
- Research areas:
  - Mathematical biology
  - Stochastic modelling
  - Agent-based models

Mathematical biology

Newcastle University

Epidemiology

Cell biology

Ecology

Computational neurology

Biological fluid dynamics

Cancer modelling

Evolutionary biology

Biological geography

Mathematical biology

Newcastle University

Cell biology

Ecology

Cell biology

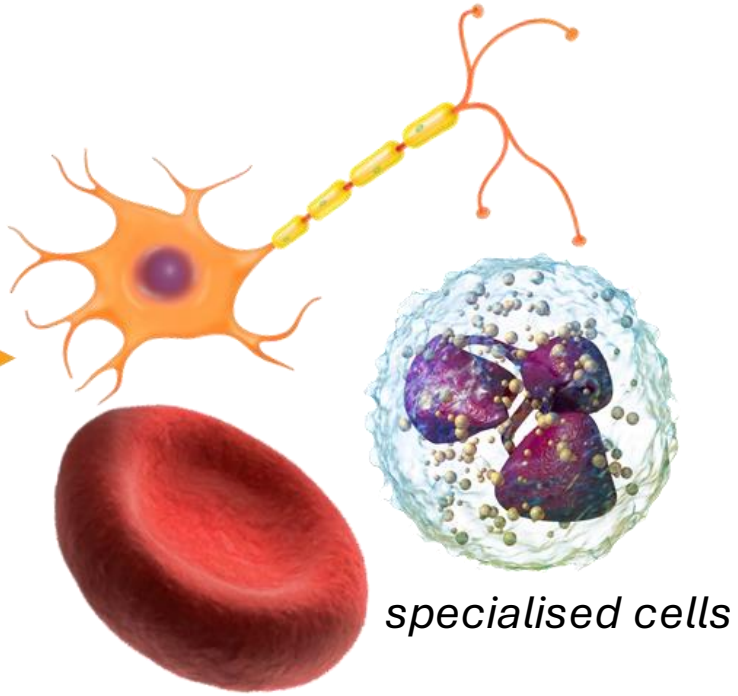
Stem cells (PhD research area)

Newcastle University

Unspecialised cells which *differentiate* (turn into) specialised cells

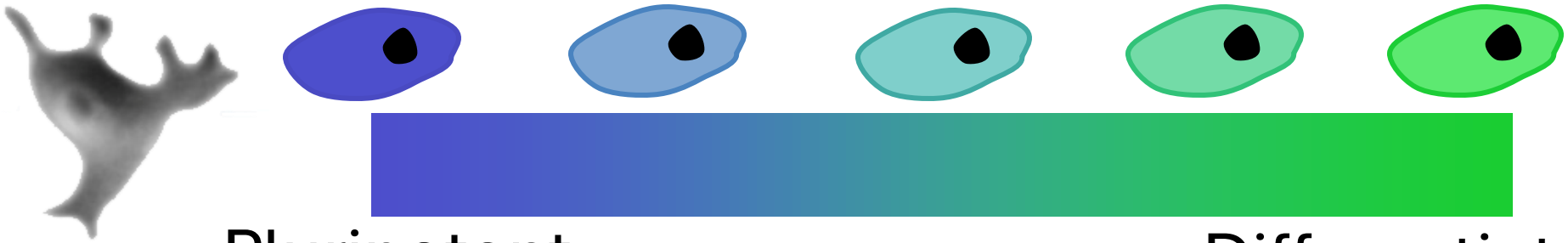
stem cell

differentiation



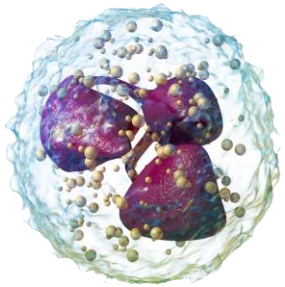
specialised cells

Key property is the **pluripotency**



Pluripotent

Differentiated

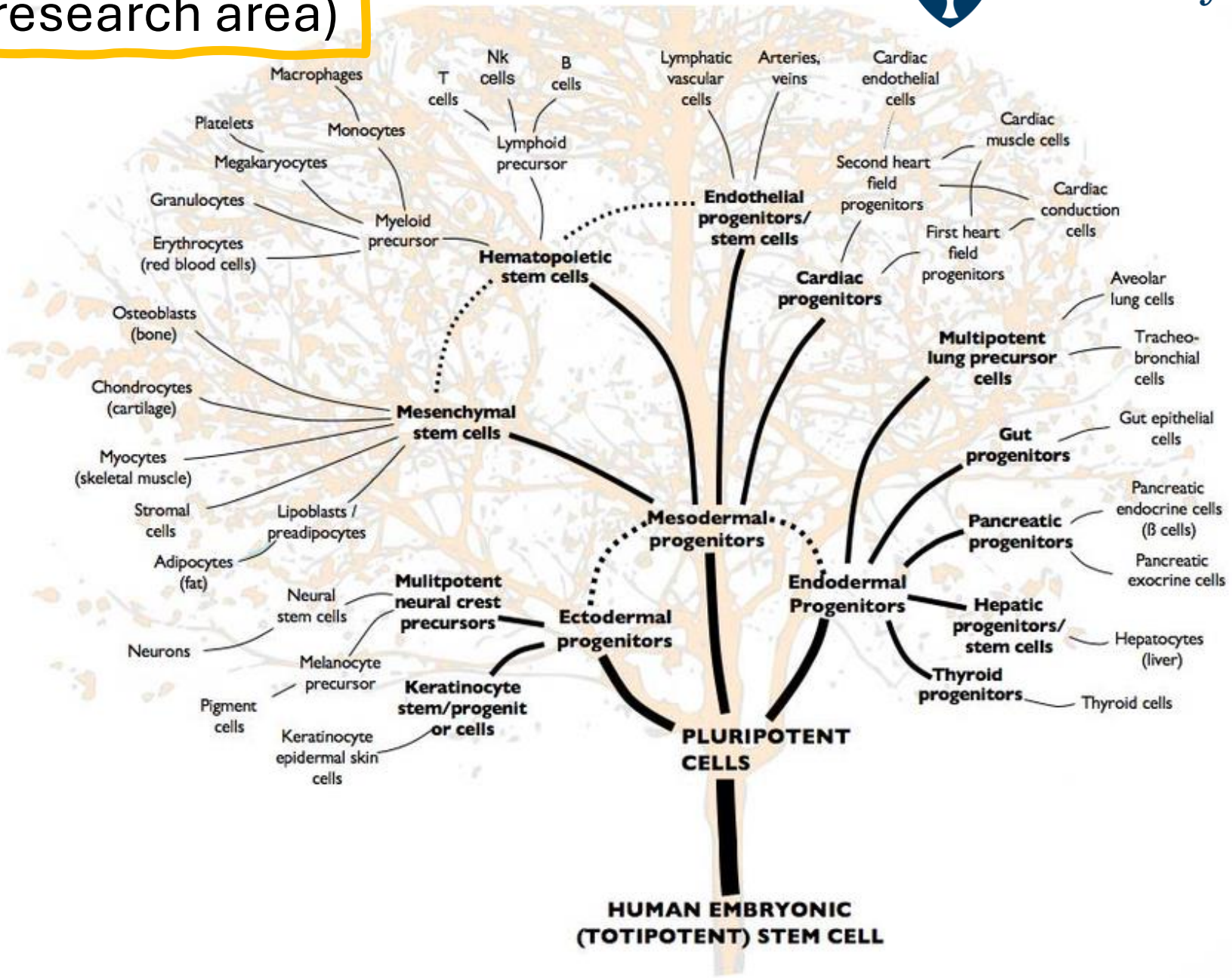


Cell biology

Stem cells (PhD research area)

Problems:

- Cell death
- Controlling differentiation
- Complex mechanisms not fully understood



Cell biology

Stem cells (PhD research area)

Newcastle University

Global goal:

Comprehensive model of behaviours

Improve experiments

PhD goal:

Experimental analysis

Bottom-up approach

Models of isolated individual properties

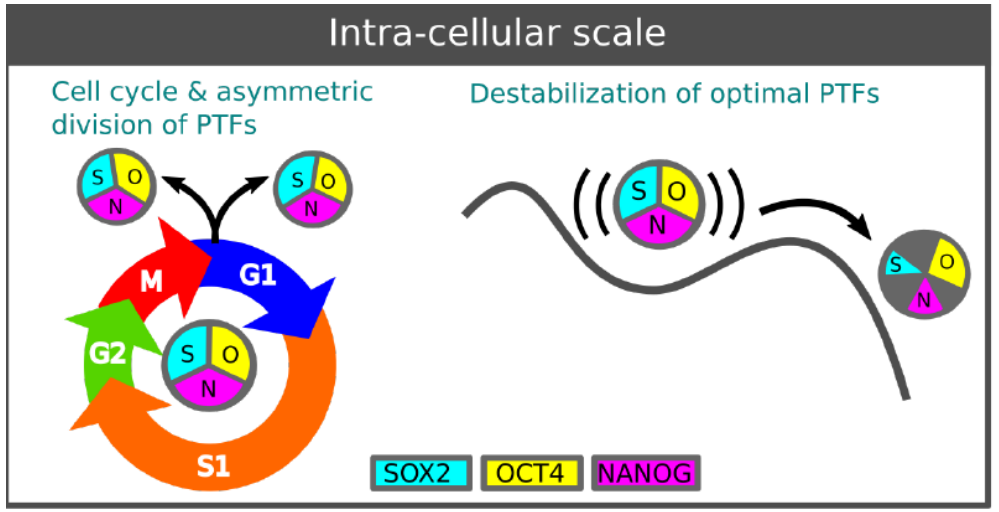
Cell biology

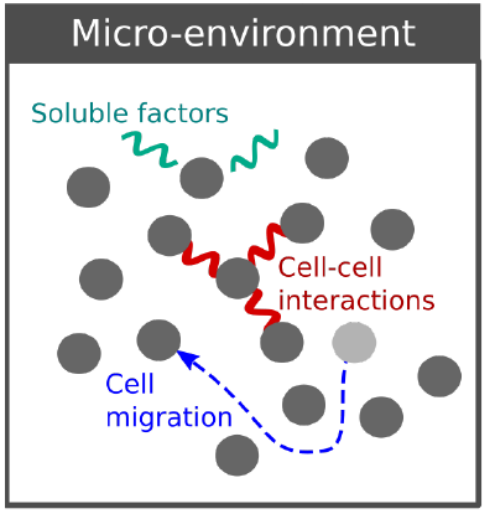
Stem cells (PhD research area)

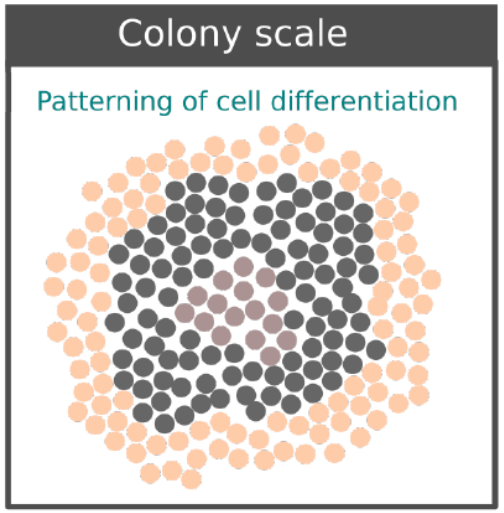
Newcastle University

Want mathematical models for stem cells:

- Stuff going on inside cells
  - Pluripotency
  - Cell cycle and death
  - Chemical interactions
- Stuff going on outside cells
  - Interactions between cells
  - Environmental effects
- Stuff for large groups
  - Colony growth
  - Collective behaviours





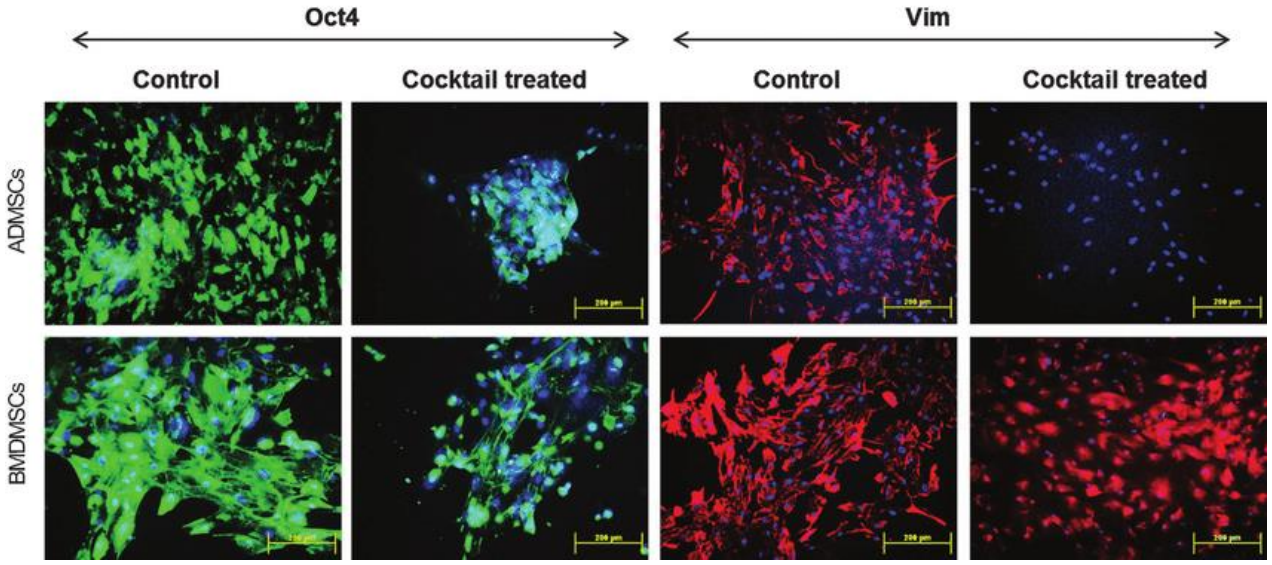


Cell biology

Stem cells (PhD research area)

Get data through experiments:

- Directly (planned with biologists)
- Indirectly (from already conducted experiments)



Tayyeb et. al., 2017

Cell biology

Stem cells (PhD research area)

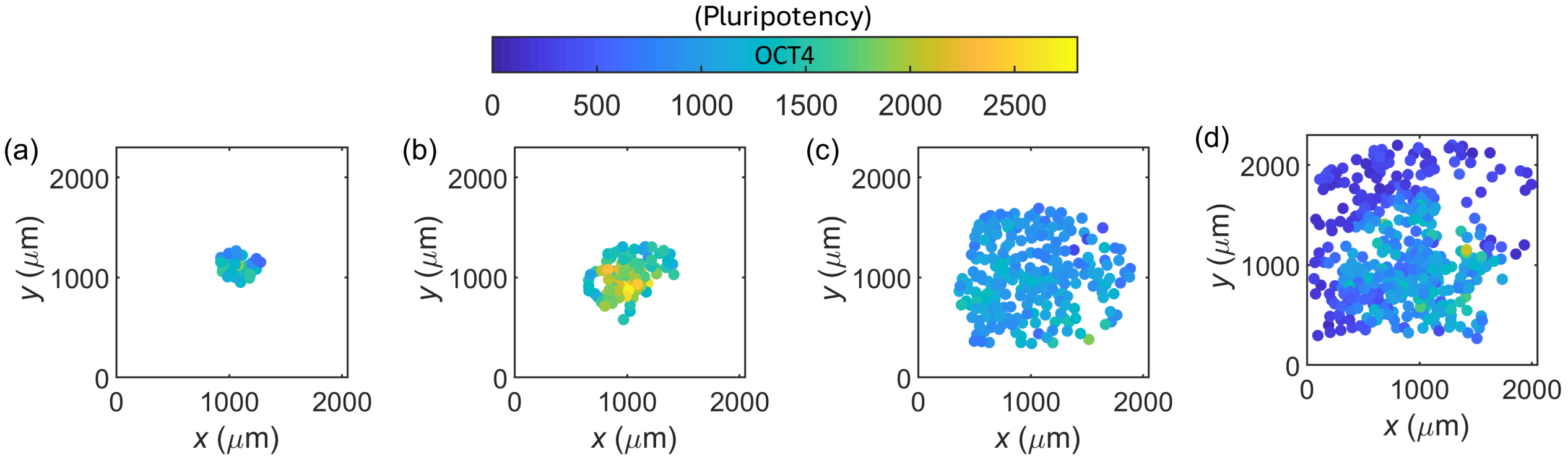
Newcastle University

An example:

Cell biology

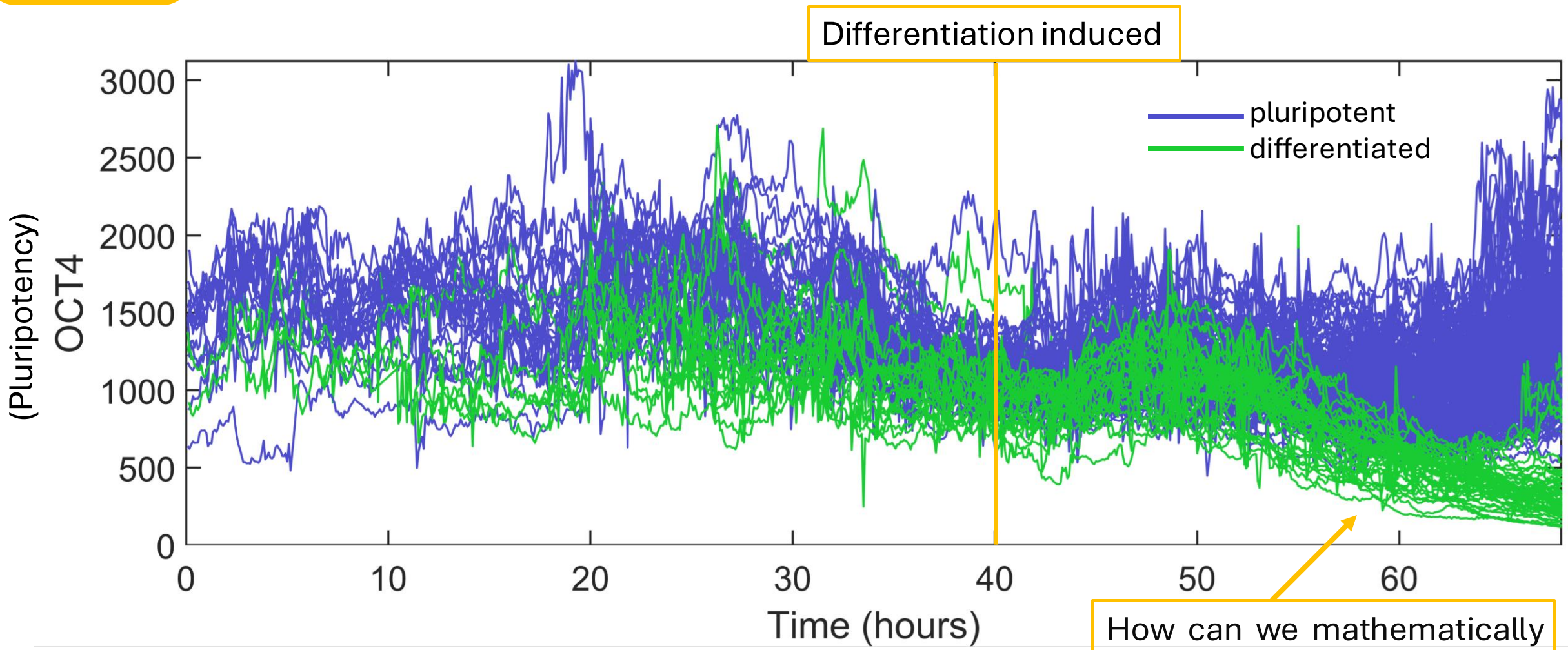
Stem cells: temporal data

- Measured OCT4 (pluripotency measure) in growing colony



Cell biology

Stem cells: temporal data



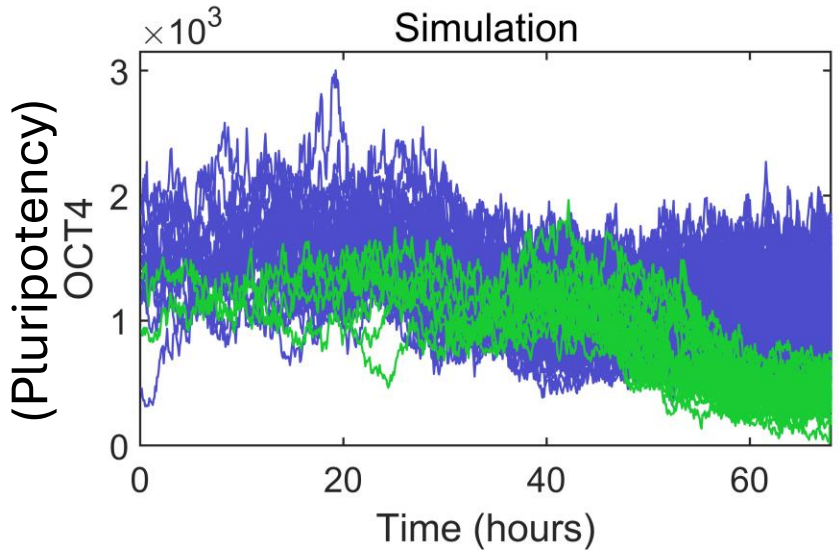
How can we mathematically reproduce this decline in the green cells (but not purple)?

Cell biology

Stem cells: temporal data

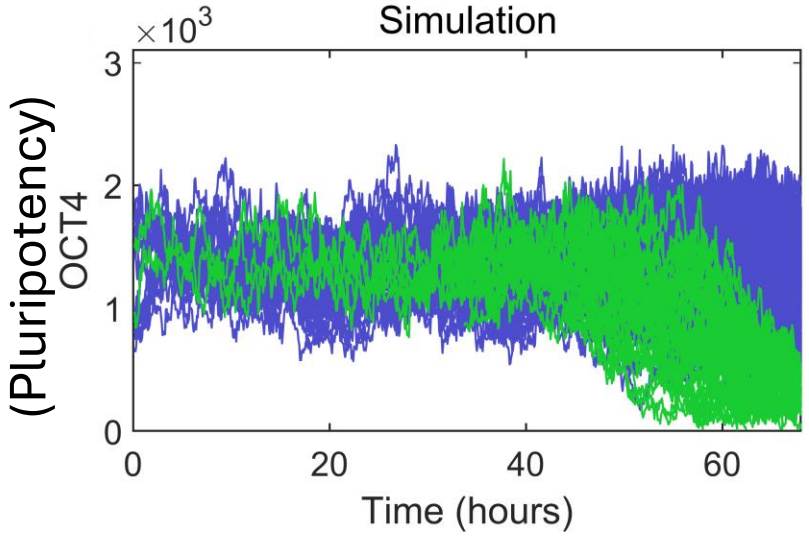
Idea 1: Time dependent carrying capacity?

$$\frac{dO}{dt} = rO\left(1 - \frac{O}{\boldsymbol{K(t)}}\right) + \sigma\xi$$



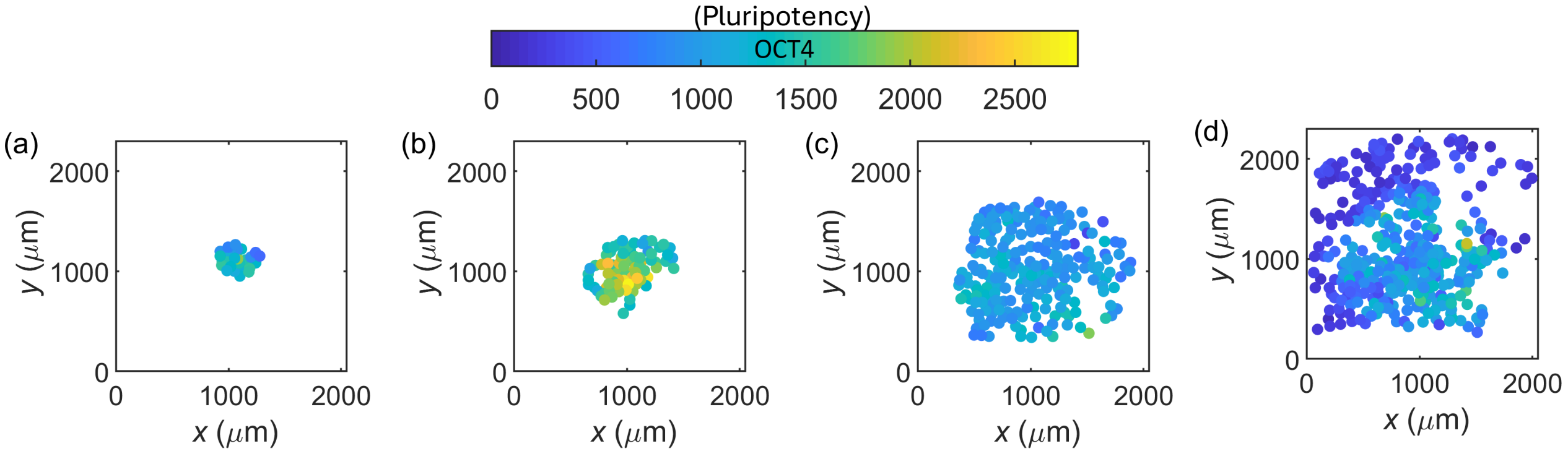
Idea 2: Extra Allee effect term?

$$\frac{dO}{dt} = rO\left(1 - \frac{O}{K}\right)\left(\frac{\boldsymbol{O}}{\boldsymbol{A}} - \mathbf{1}\right) + \sigma\xi$$



Cell biology

Stem cells: spatial data



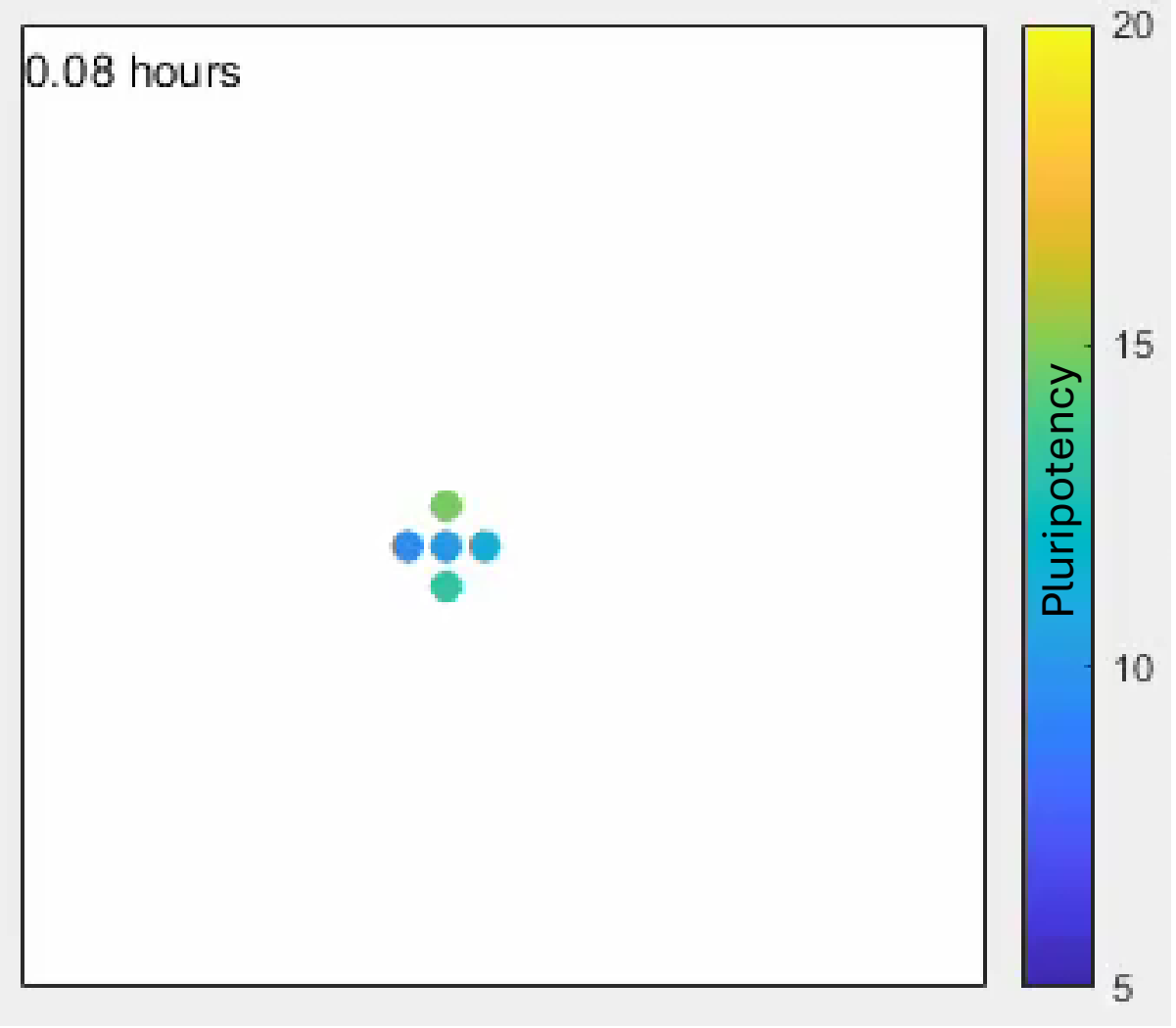
Cell biology

Stem cells: spatial data

Technique: *agent-based modelling*

(aka. individual based modelling)

- Computational model
- Each cell follows probabilistic rules



Pros:

- Often simple (initially)
- Easy to introduce stochasticity
- Can examine collective behaviour

Cons:

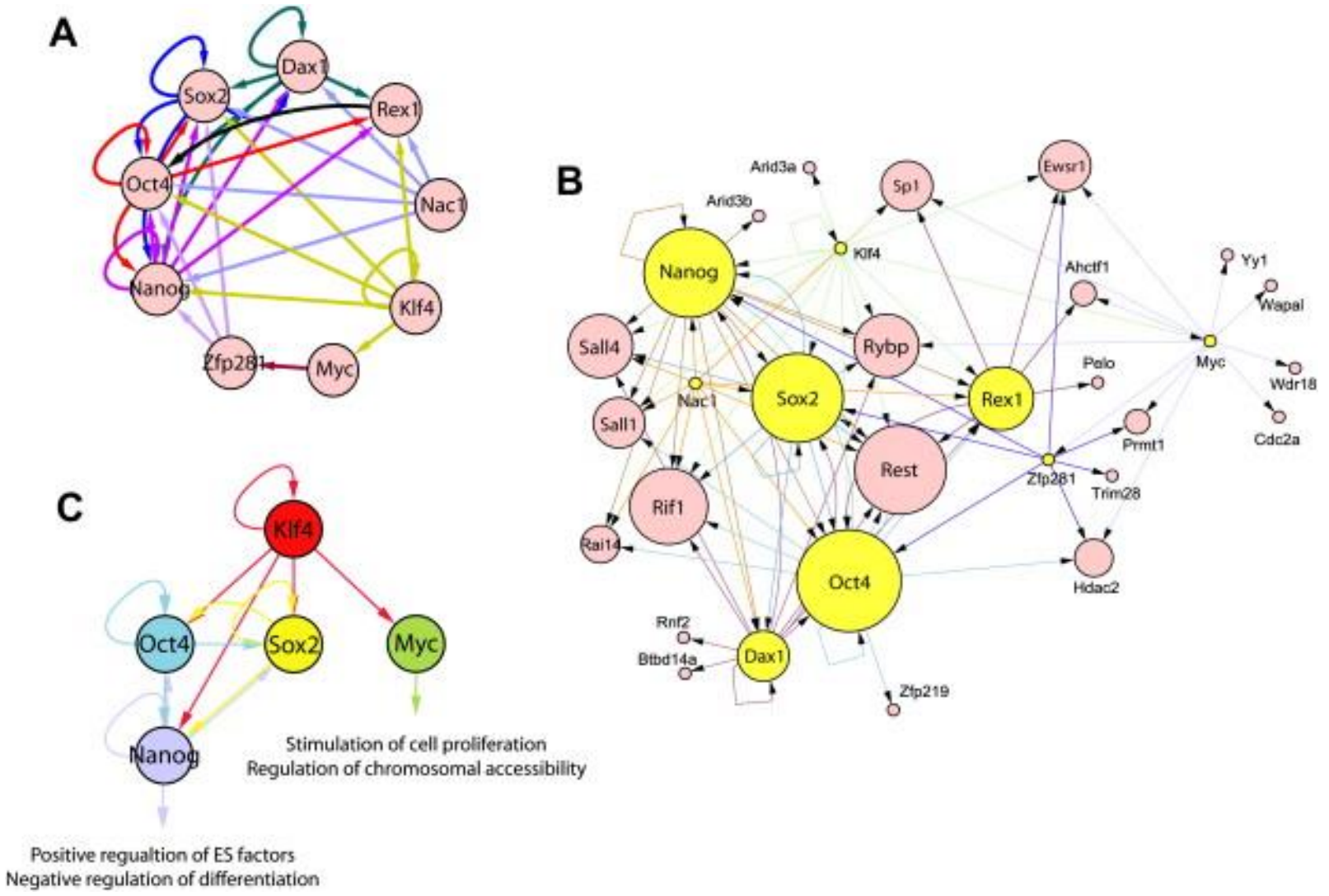
- Computationally expensive
- Can end up with lots of parameters (hard to extract from real data!)

Cell biology

Stem cells (PhD research area)

Challenges:

- Collecting/accessing data
- Interdisciplinary collaborations
- Complex system makes parameter estimation difficult



Kim et. al., 2008

Newcastle University

Epidemiology

Cell biology

Ecology

Computational neurology

Biological fluid dynamics

Cancer modelling

Evolutionary biology

Biological geography

Ecology

Tree diseases and pests (current research area)

Newcastle University

WOODLAND TRUST

Ash dieback

Ash dieback will kill around 80% of ash trees across the UK. At a cost of billions, the effects will be staggering. It will change the landscape forever and threaten many species which rely on ash.

Forest Research

Sweet chestnut blight

C. parasitica infection is usually fatal to European (*Castanea sativa*) and North American (*C. dentata*) sweet chestnut trees. It has almost wiped out North America's sweet chestnut population.

Apple scab, cedar rusts, dothistroma needle blight, emerald ash borer, bronze birch borer, Dutch elm disease, plane wilt, oak wilt, phytophthora root rot, thousand canker disease...

Spread through: beetles, airborne spores, plant roots

Exacerbated by: transport of organic material/live plants

Ecology

Tree diseases and pests (current research area)

Newcastle University

Department for Environment Food & Rural Affairs

www.gov.uk/defra

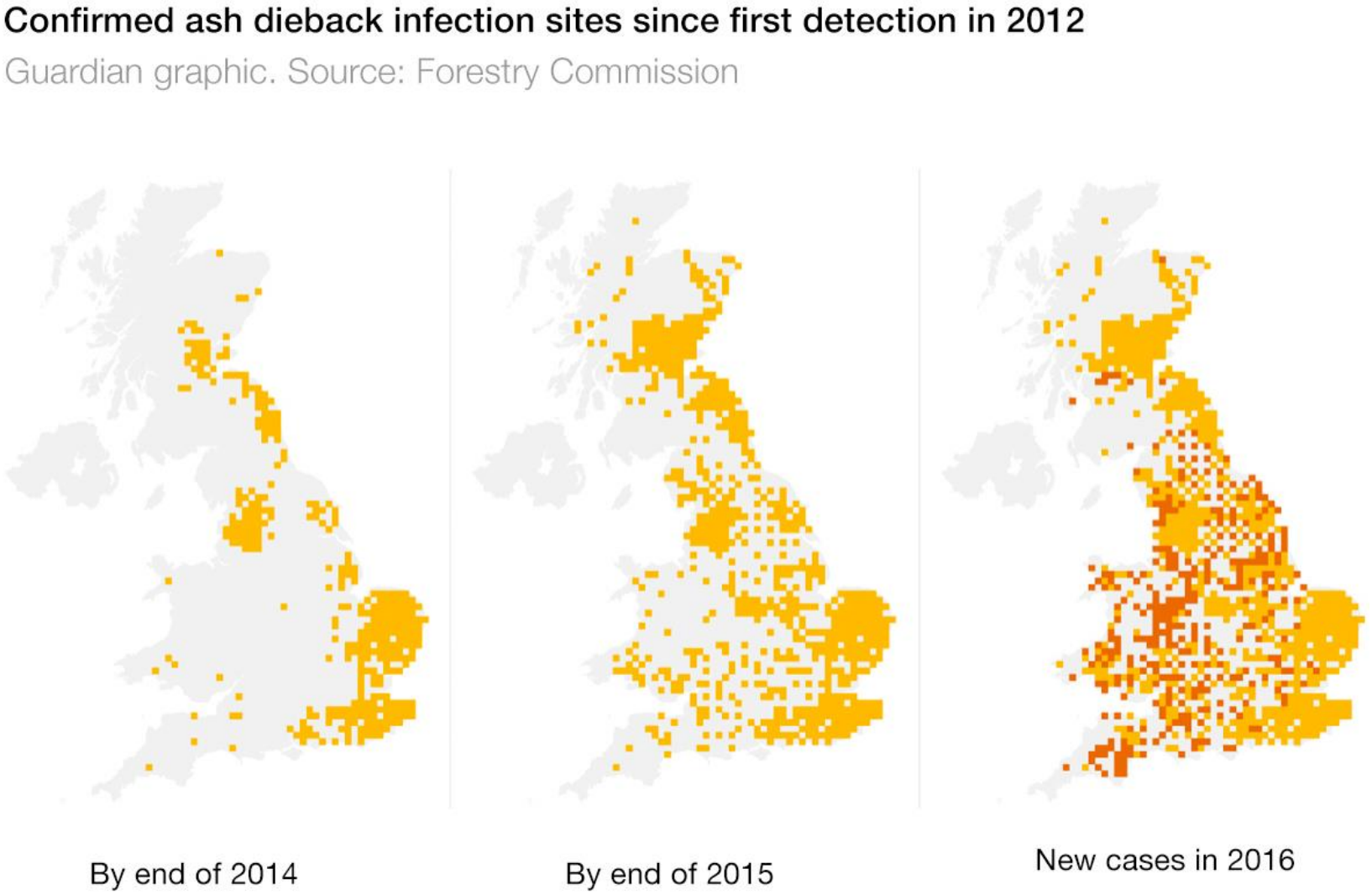
Tree Health Management Plan

- Raise awareness
- Understand spread
- Predict spread
- Stop spread – control pathogen movement

Ecology

Tree diseases and pests (current research area)

- Project aims:
  - Statistical analysis of ecological data
  - Develop mathematical models to describe and predict the spread
  - Use to test the efficacy of different management strategies



Ecology

Tree diseases and pests (current research area)

Newcastle University

An example:

Ecology

Example: Oak Processionary Moth

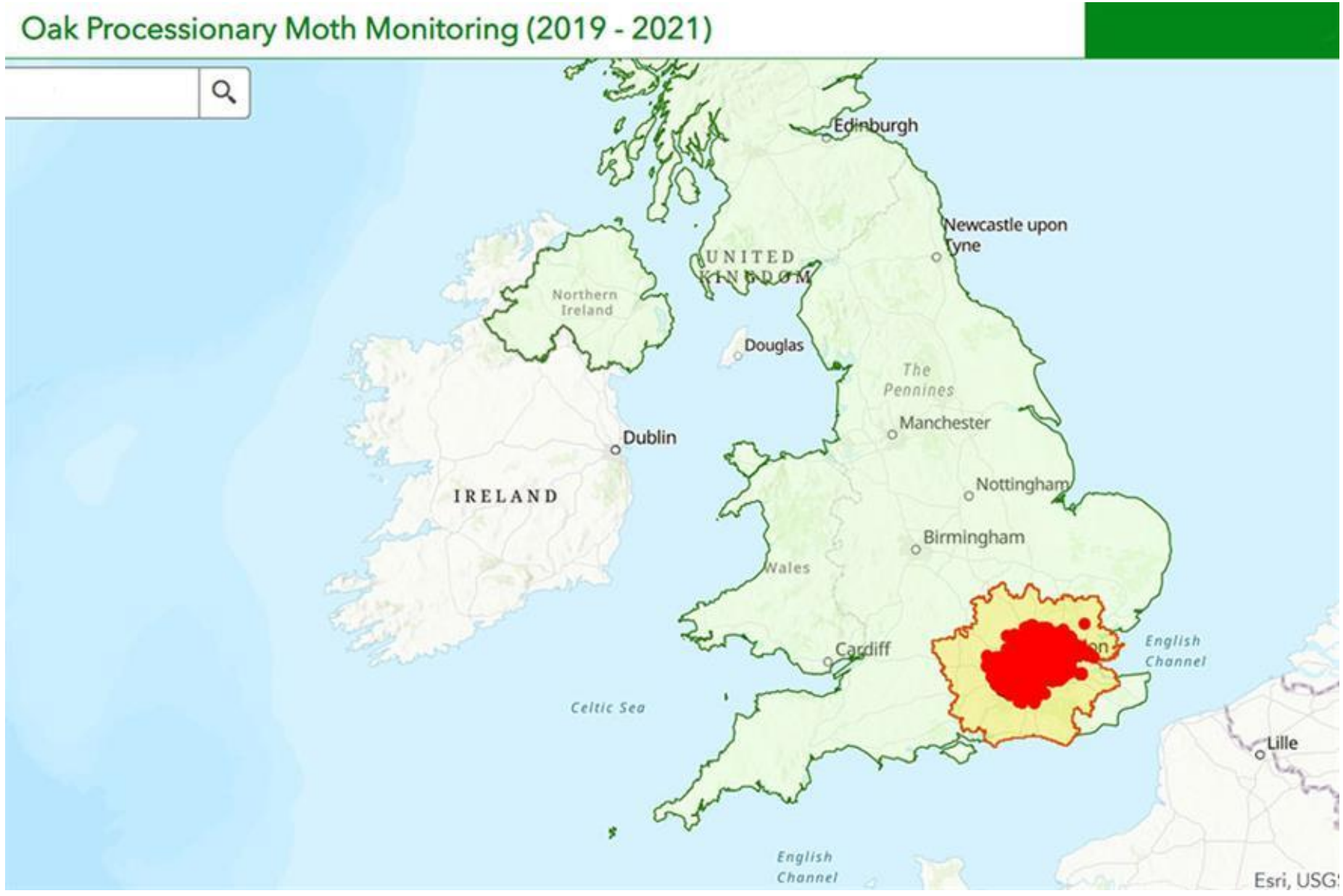
- Established in 2006 (accidental import!)
- Destructive to oak trees
- Poisonous hairs
- In London but spreading
- Monitored by the OPM Control Programme

Department for Environment Food & Rural Affairs

Forestry Commission

Ecology

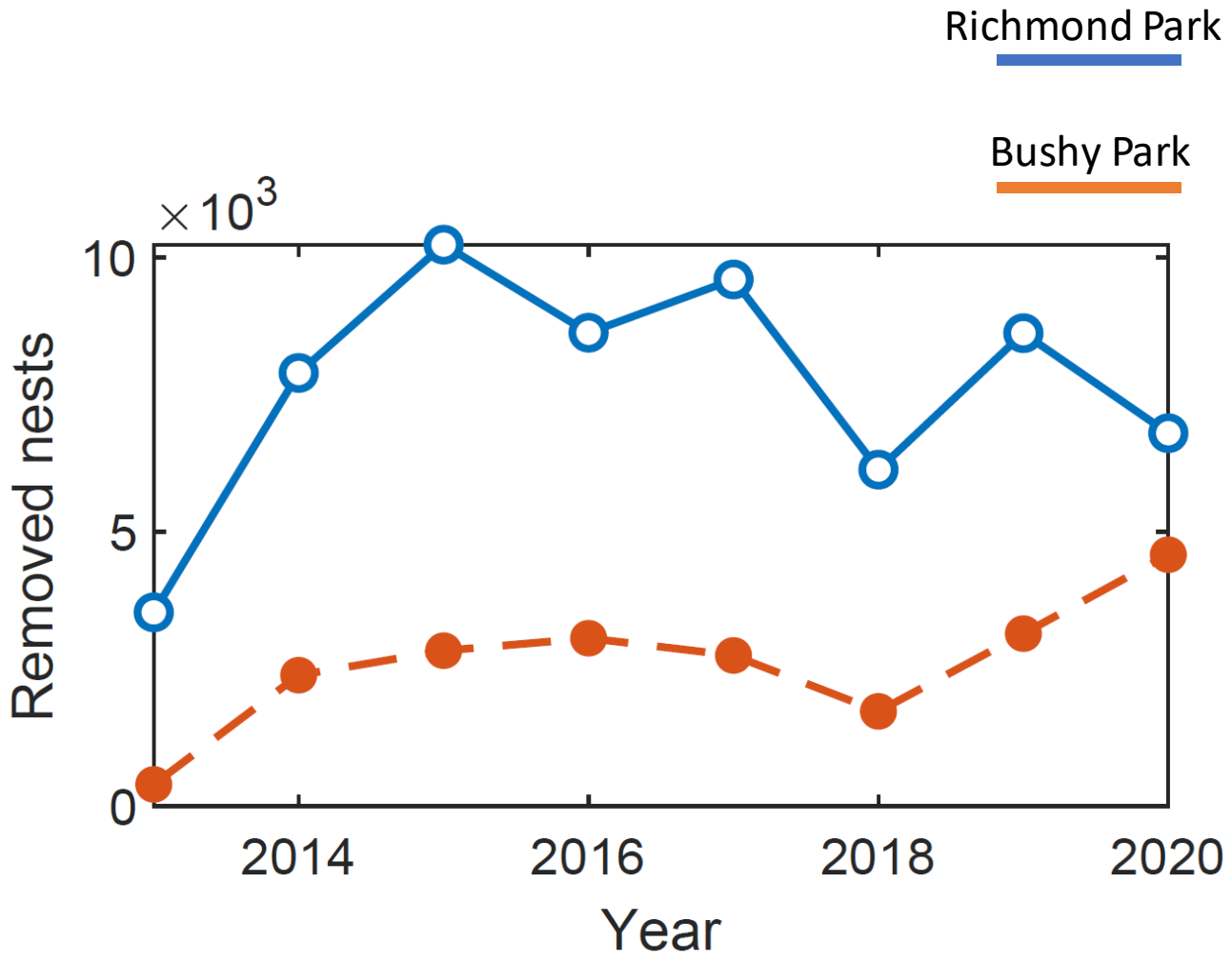
Example: Oak Processionary Moth



Ecology

Example: Oak Processionary Moth

- Example data for two London Parks:
- Temporal analysis, then spatial

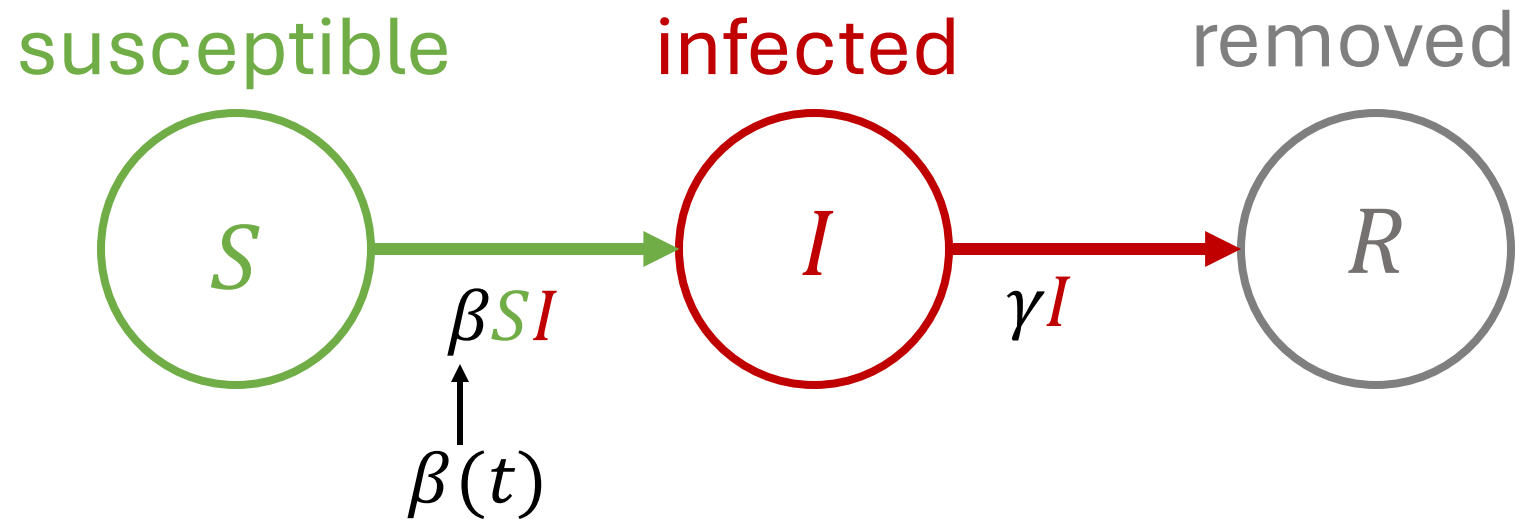


Ecology

Example: Oak Processionary Moth

Newcastle University

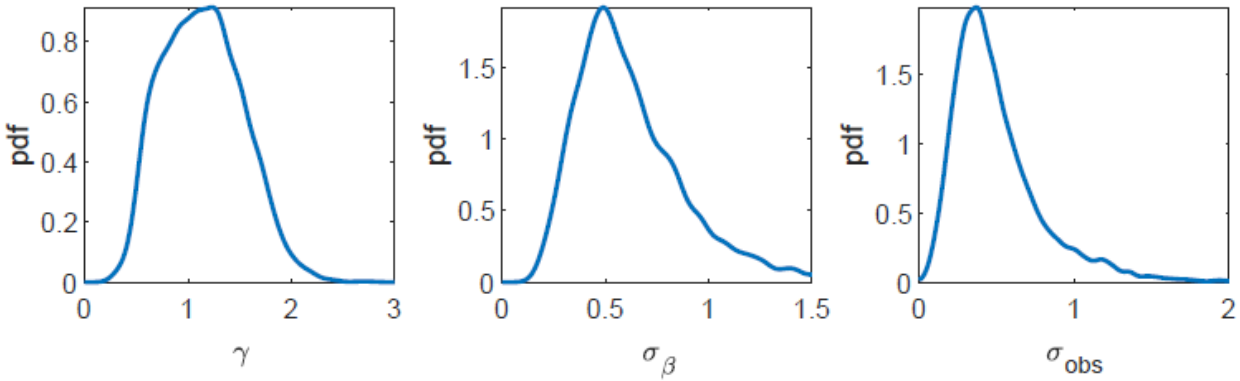
- The mathematical model:



Infection rate variable with time, noise σ

With **lots** of help from
Dr Andy Golightly
(Durham University)

R Inference



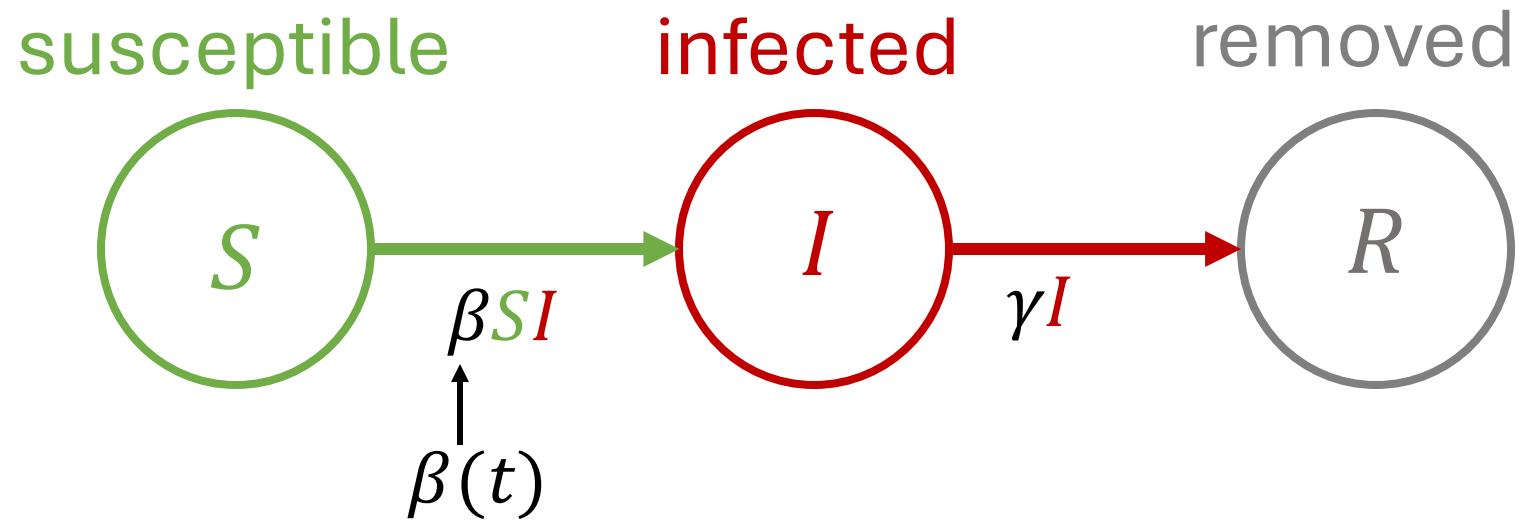
Learn about parameters from the data, e.g., removal rate (γ), noise on the infection rate σ_β and observational noise σ_{obs}

Ecology

Example: Oak Processionary Moth

Newcastle University

- The mathematical model:

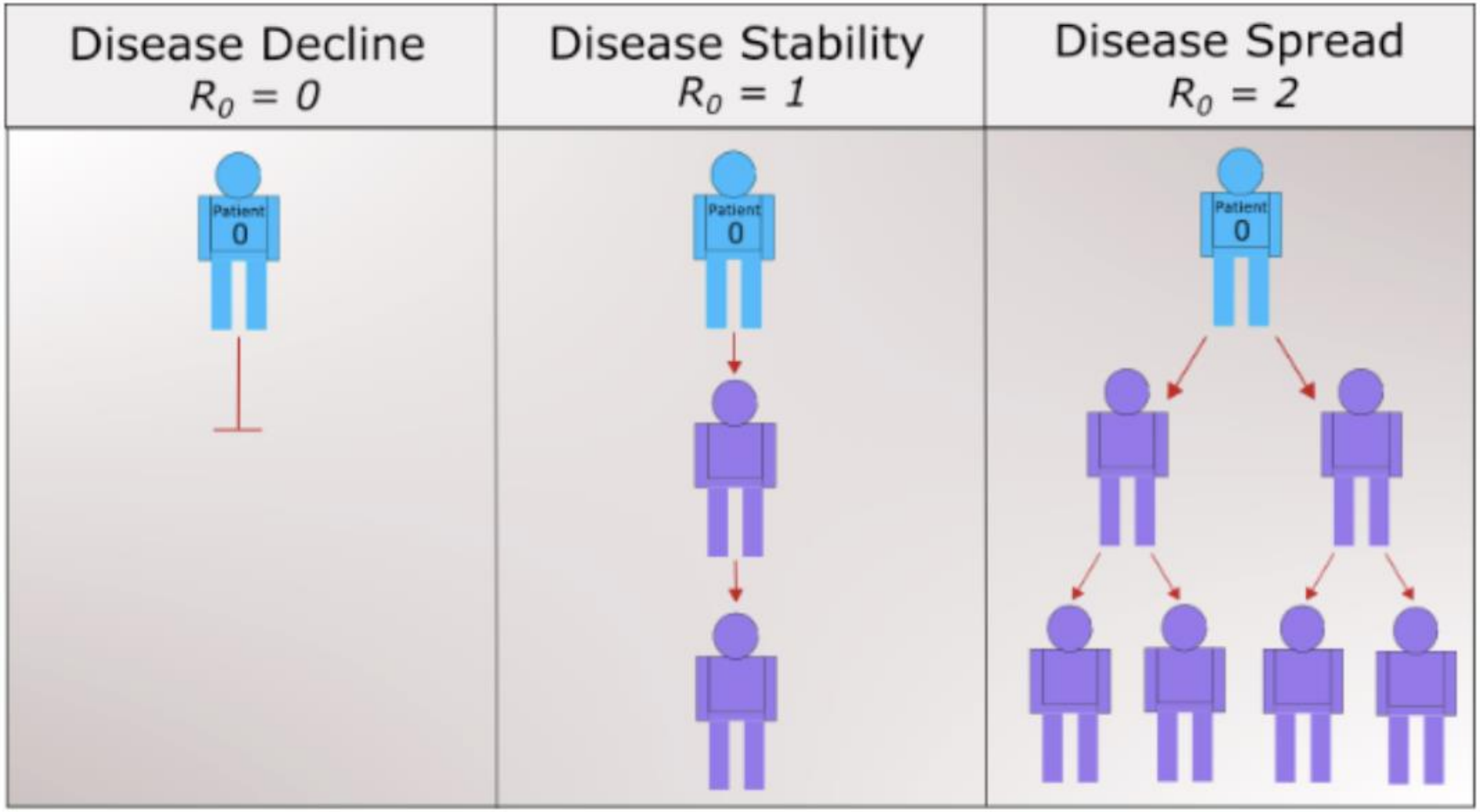


Infection rate variable with time, noise σ

- Pro: allows us to estimate R_0 (reproduction number) from parameters β and γ

Ecology

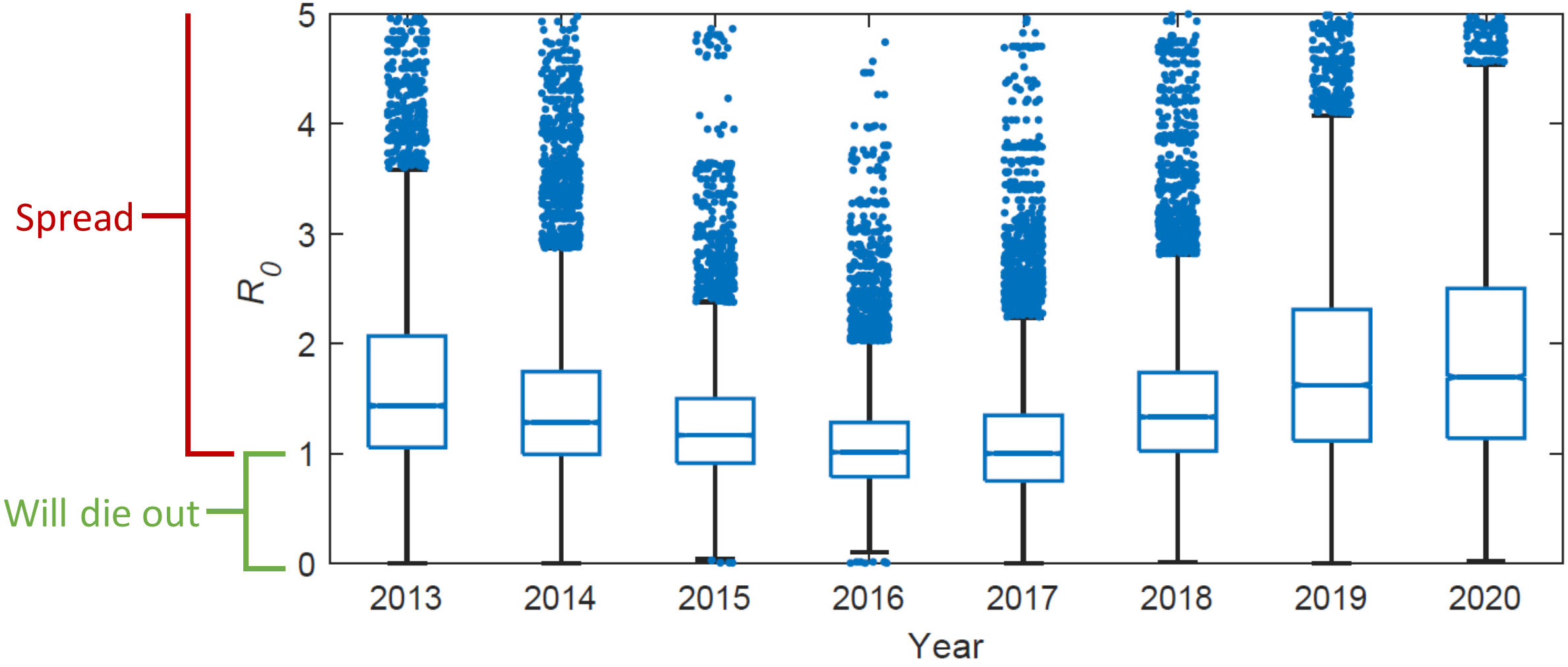
Example: Oak Processionary Moth



Ecology

Example: Oak Processionary Moth

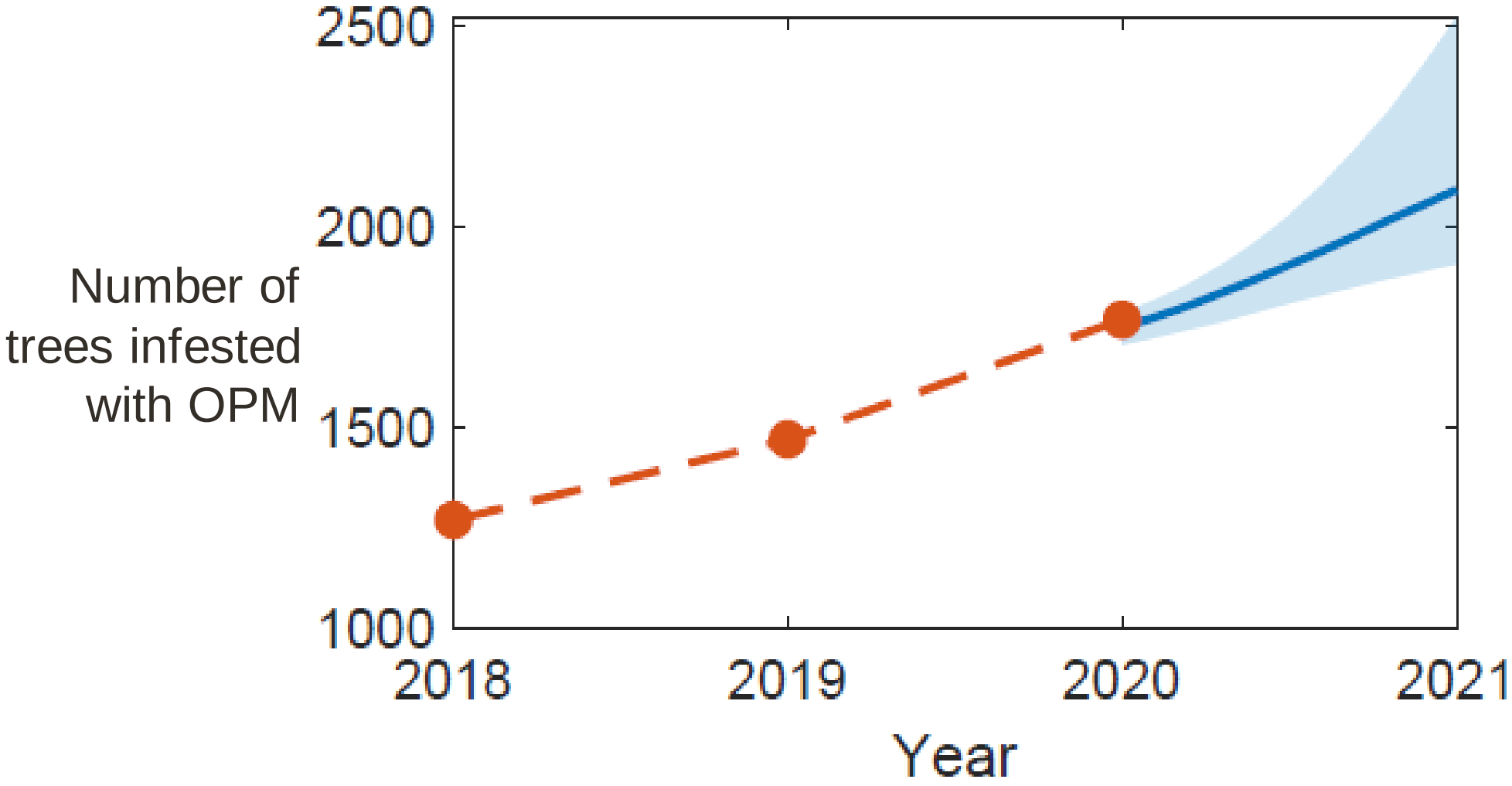
Newcastle University



Ecology

Example: Oak Processionary Moth

Use model for predictions:

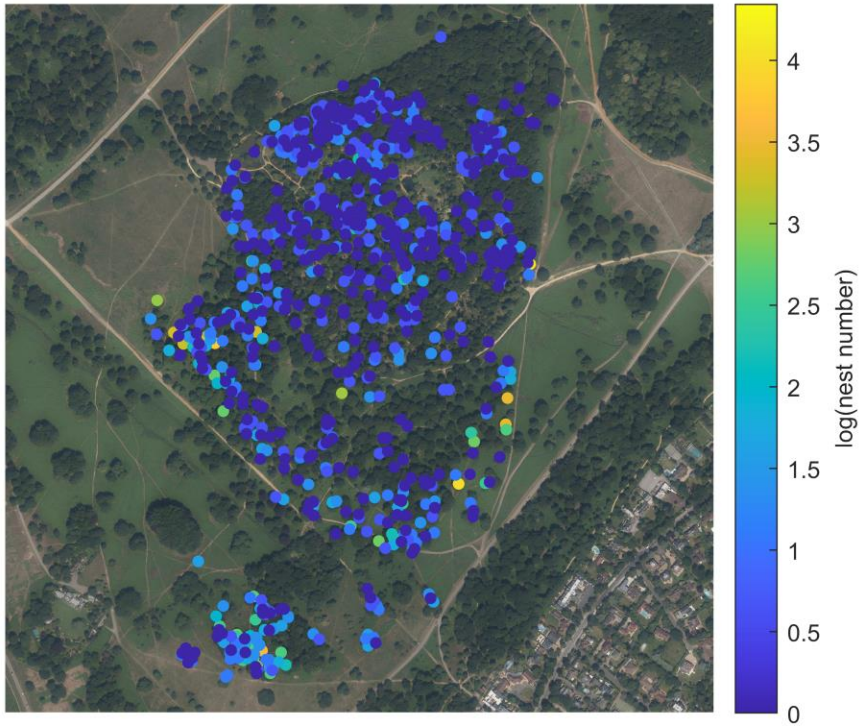


Ecology

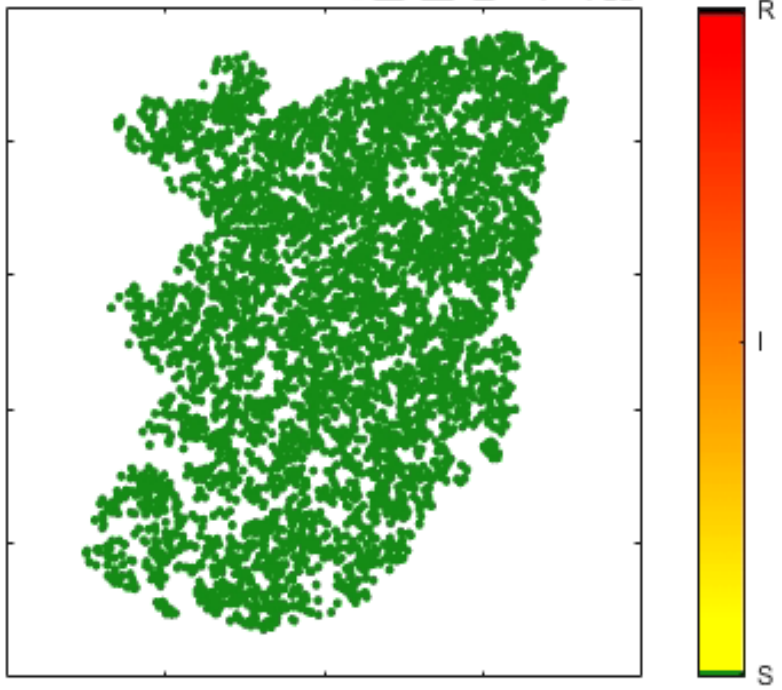
Tree diseases and pests: spatial

Newcastle University

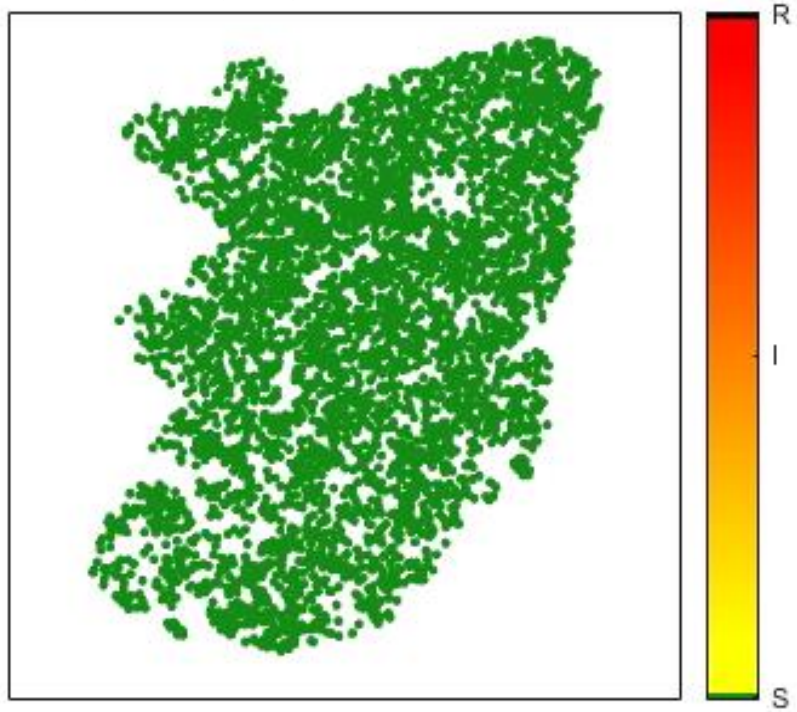
Agent-based models:



Shorter range spread:



Longer range spread:

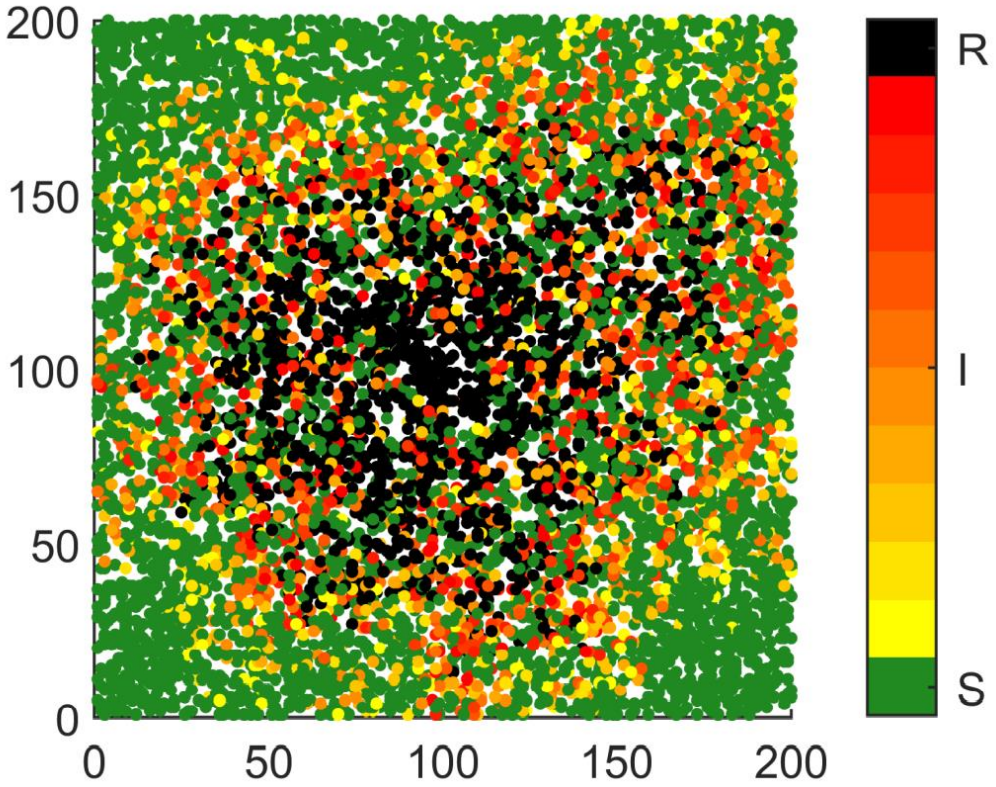


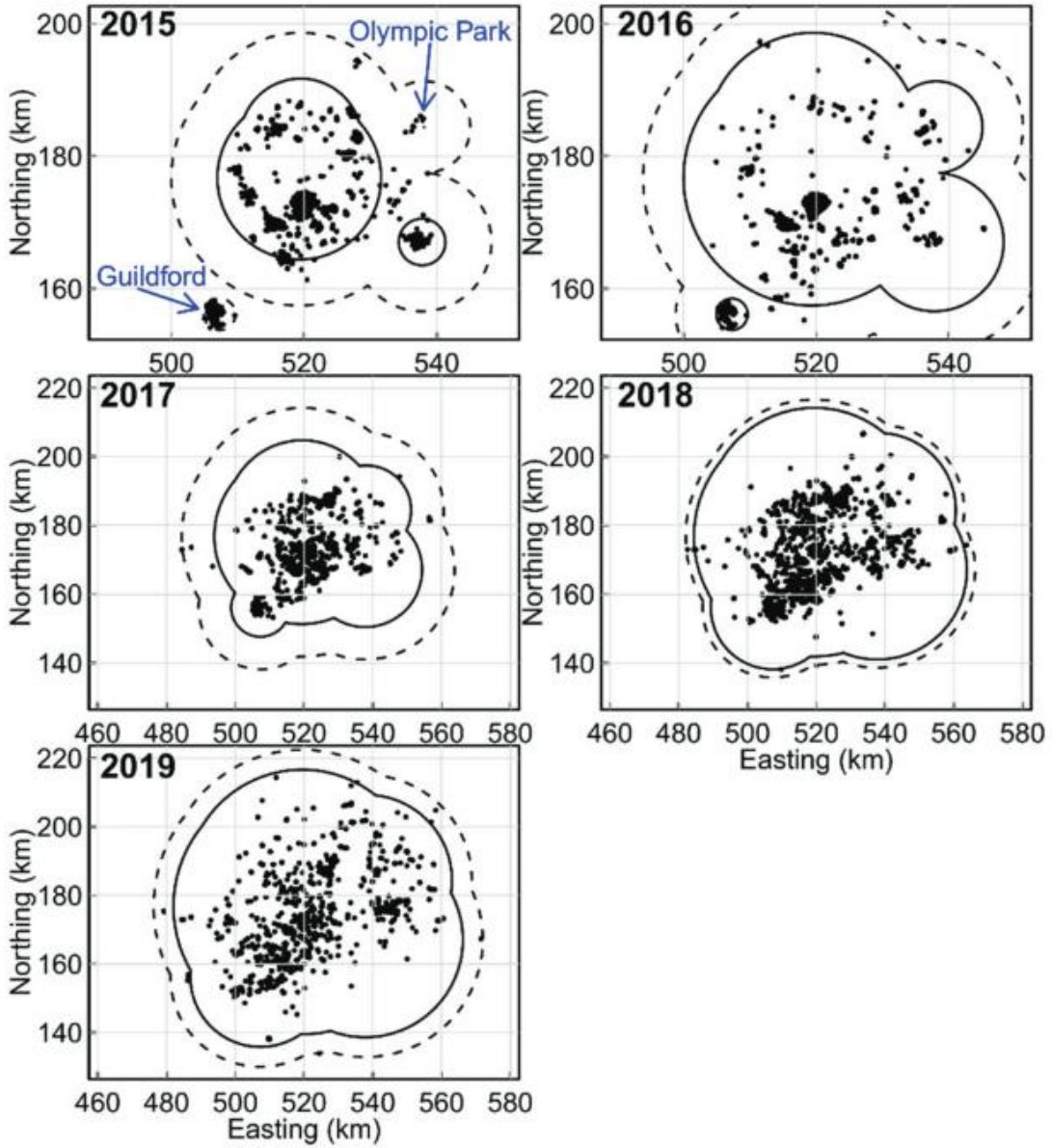
Ecology

Tree diseases and pests: next steps

Newcastle University

Use data from DEFRA to estimate spatial parameters:





Ecology

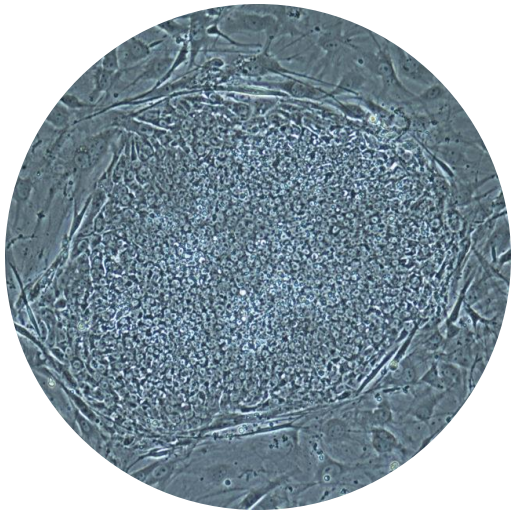
Tree diseases and pests

Challenges:

- Collecting/accessing data
- Ecological collaborations
- Missing data
- Collection biases
- Control methods might be underway

Forestry Commission spraying OPM insecticide

Main ideas




Varied biological applications

but similar mathematical techniques!

Models should be underpinned by real data

(But data collection/access can be challenging)

(and extracting parameter estimates still difficult…)