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How might spatially explicit landscape scale models be improved?

Nik Cunniffe, Department of Plant Sciences

How might spatially explicit landscape scale models be improved?

1. Spatially explicit, landscape scale models
    1. Retrospective analysis: sudden oak death
    2. Using models in real-time: HLB (citrus greening) in the EU

2. Are any important features not represented (at least in my models…)
    1. Stakeholder behaviour
    2. Pathogen genetics

3. How can we use models to design better management strategies?
    1. Optimal control theory
    2. Reinforcement learning

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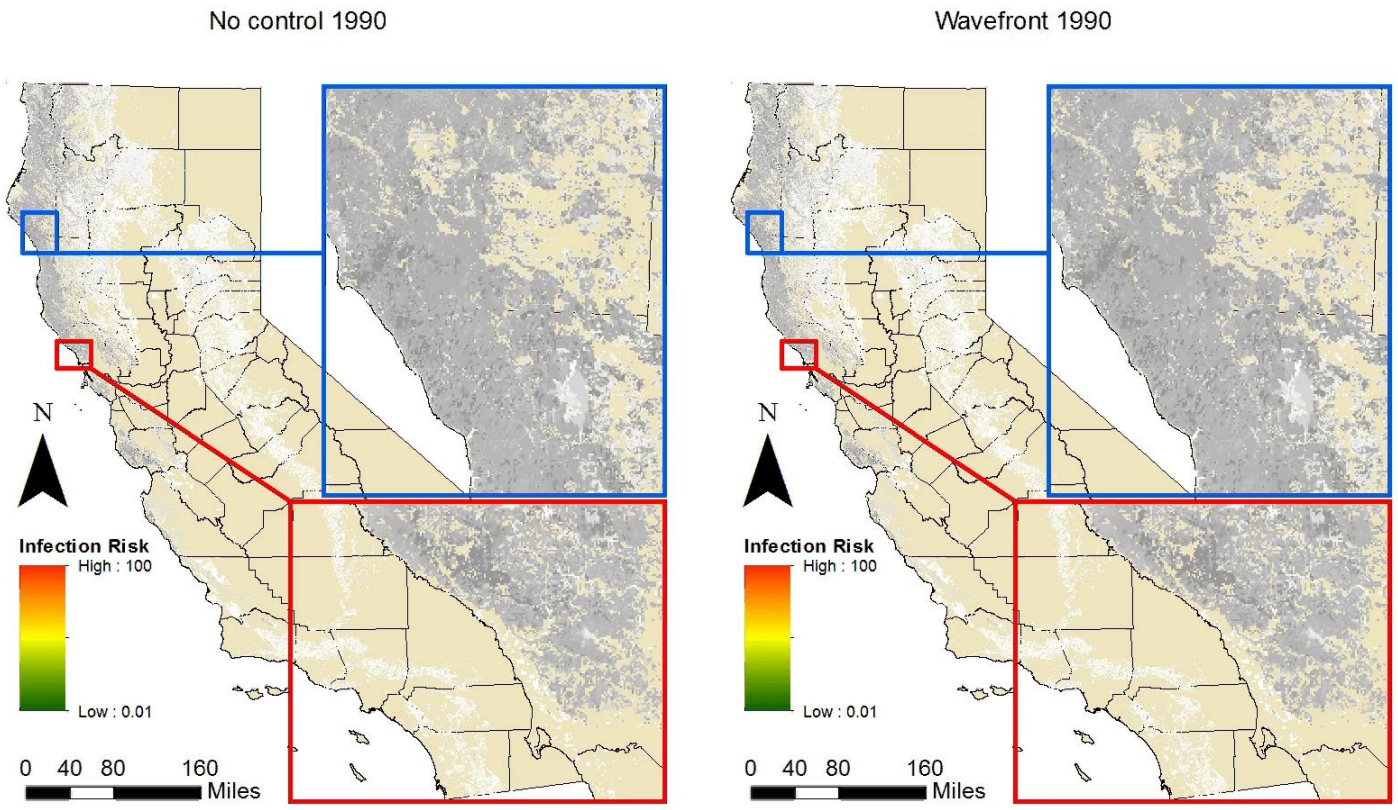
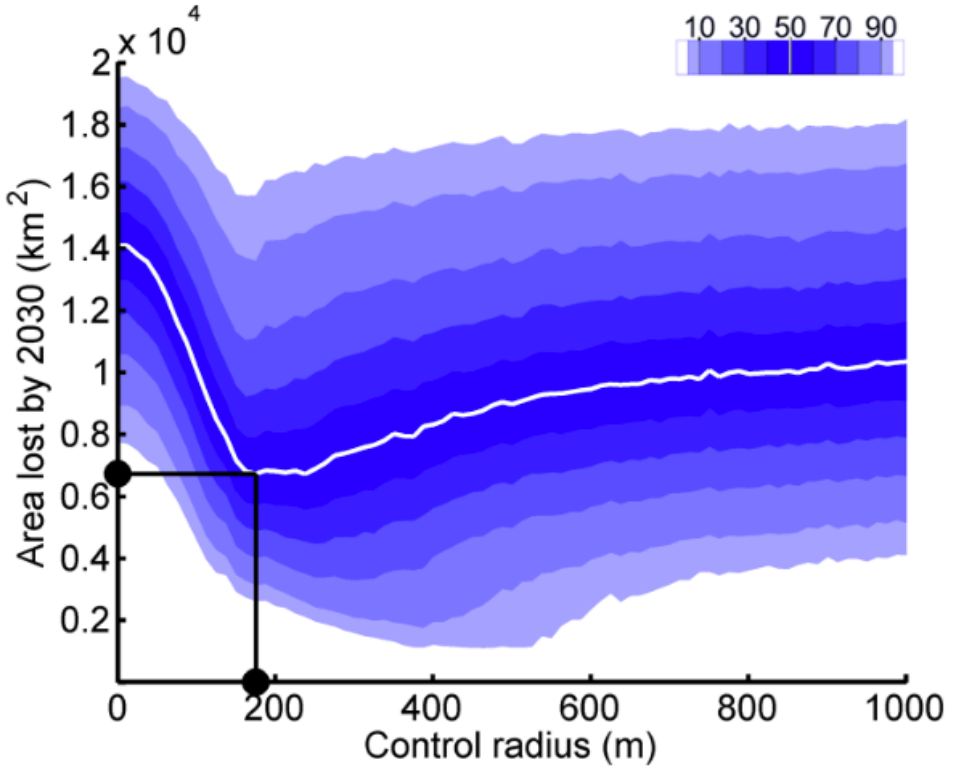
Retrospective analysis: *P. ramorum* in California

No control

With control





Optimum radius balances control *versus* unnecessary removals

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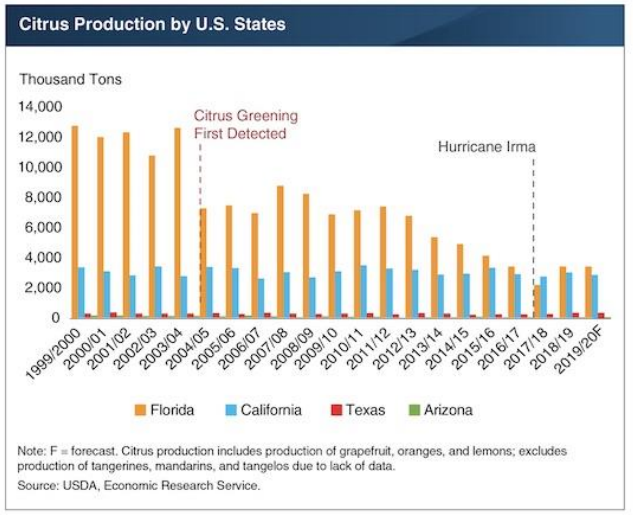
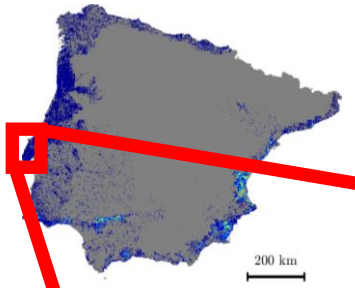
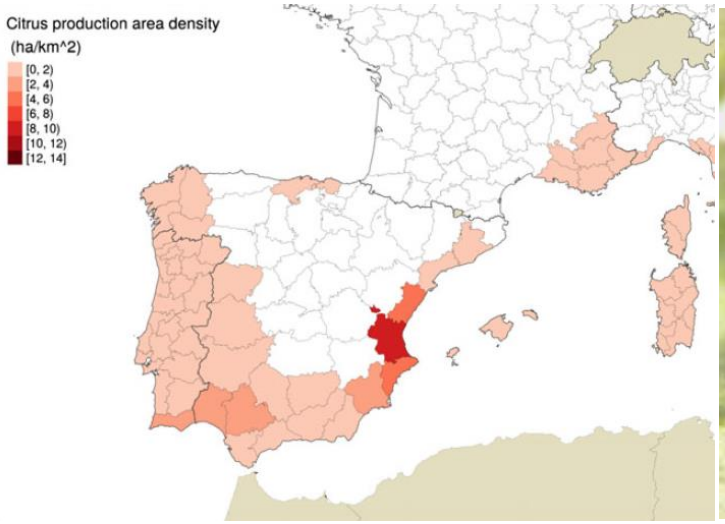
Cunniffe *et al.* (2016) *PNAS* 113:5640-5645

Use in real-time: HLB (citrus greening) in the EU

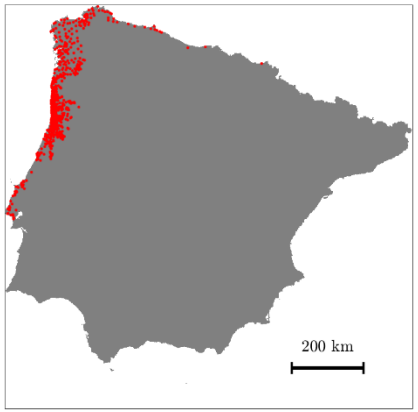




John Ellis



Trioza erytreae
African citrus psyllid



Spread of *T. erytreae* away from 2023 locations vectoring a (hypothetical) introduction of HLB on citrus plants

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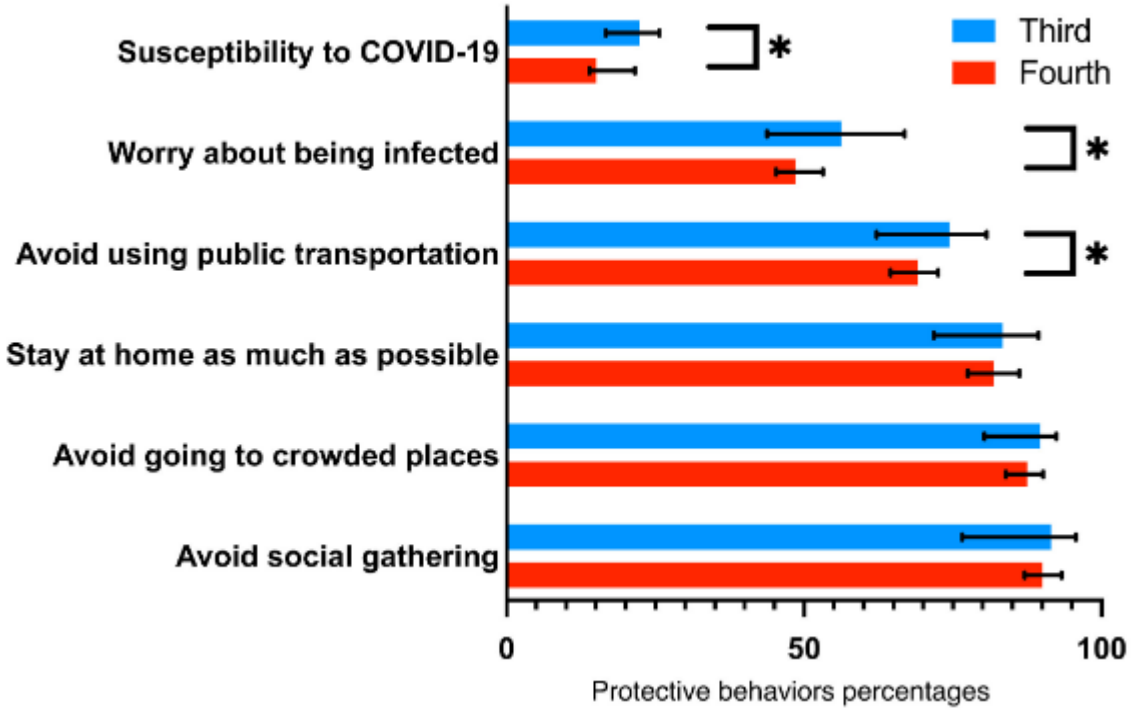
What's missing? Stakeholder behaviour



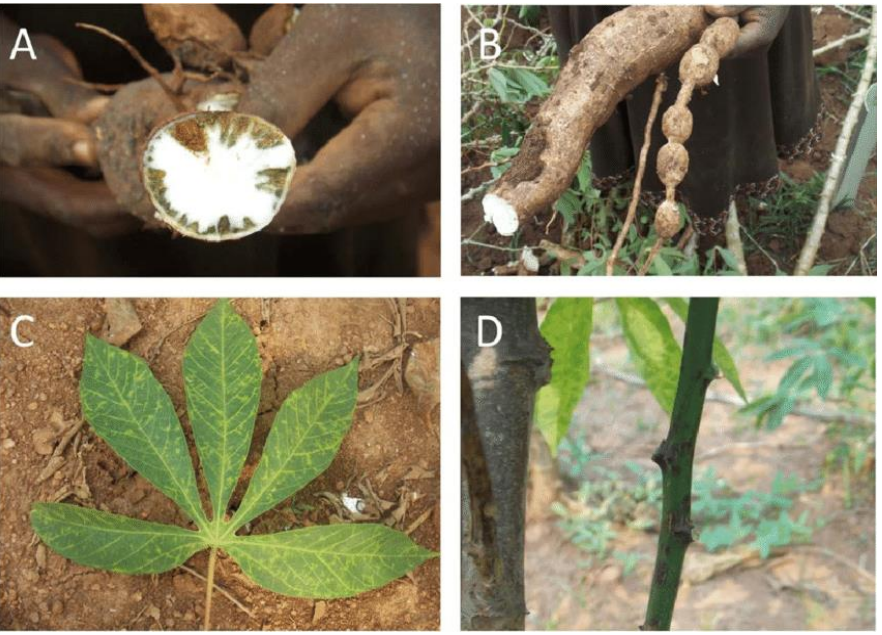
Du *et al.* (2022) *PNAS*

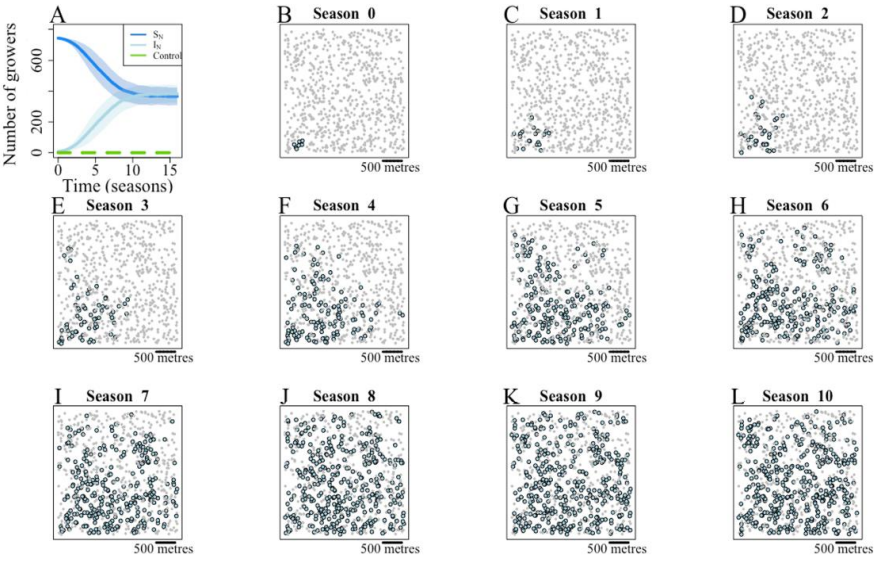
Qu. How to include behaviour & uptake of control in landscape scale models?

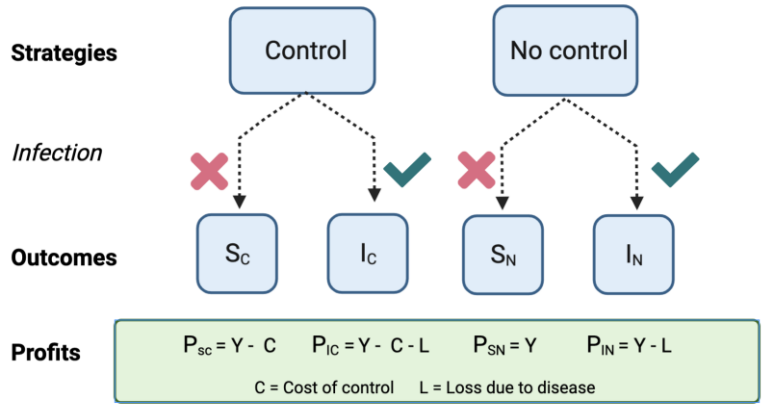
What's missing? Stakeholder behaviour

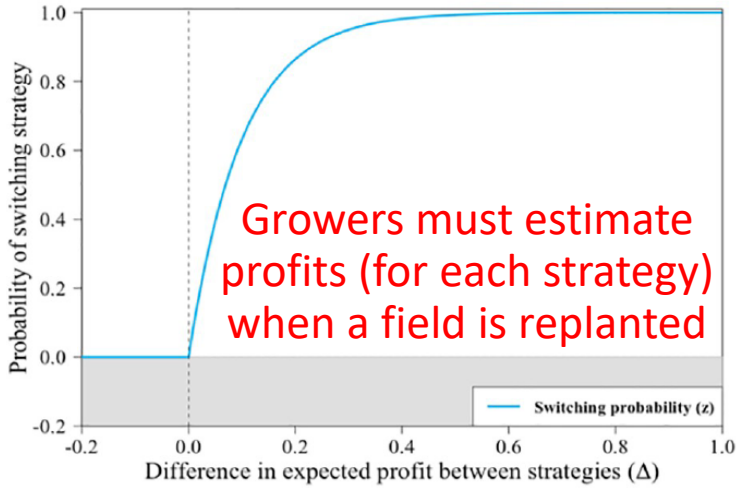
Frédéric Hamelin (Uni. Rennes)

Rachel Murray Watson

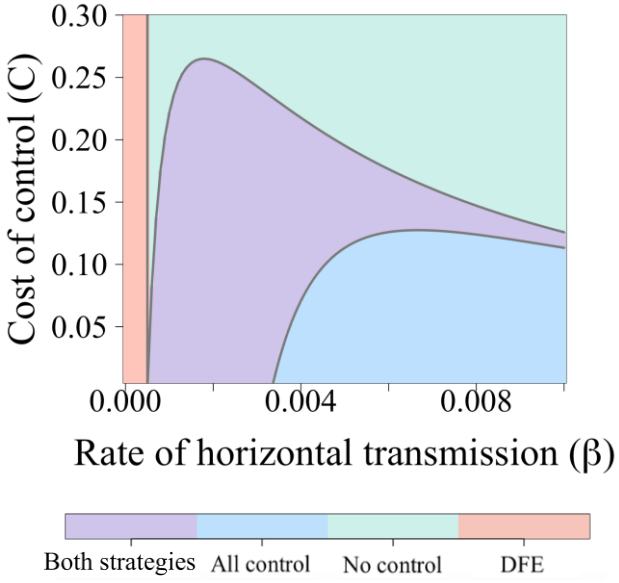








Growers must estimate profits (for each strategy) when a field is replanted

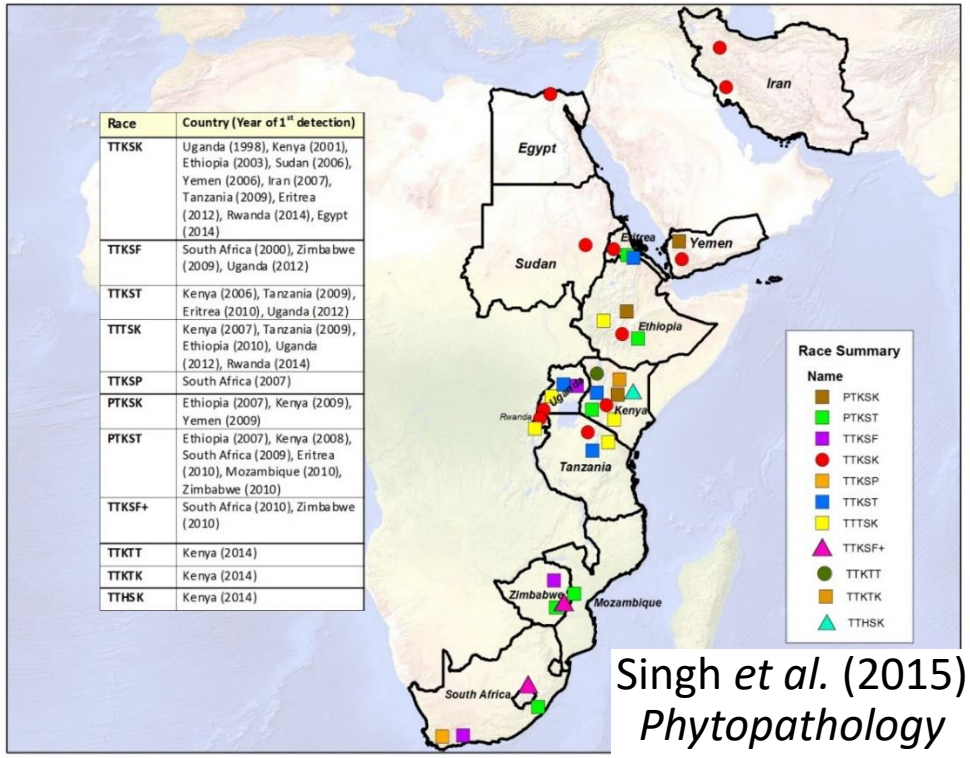


Uptake of control depends on (perceived) benefits *versus* costs

Murray Watson *et al.* (2022) *PLOS Comp. Biol.* 18:e1010309

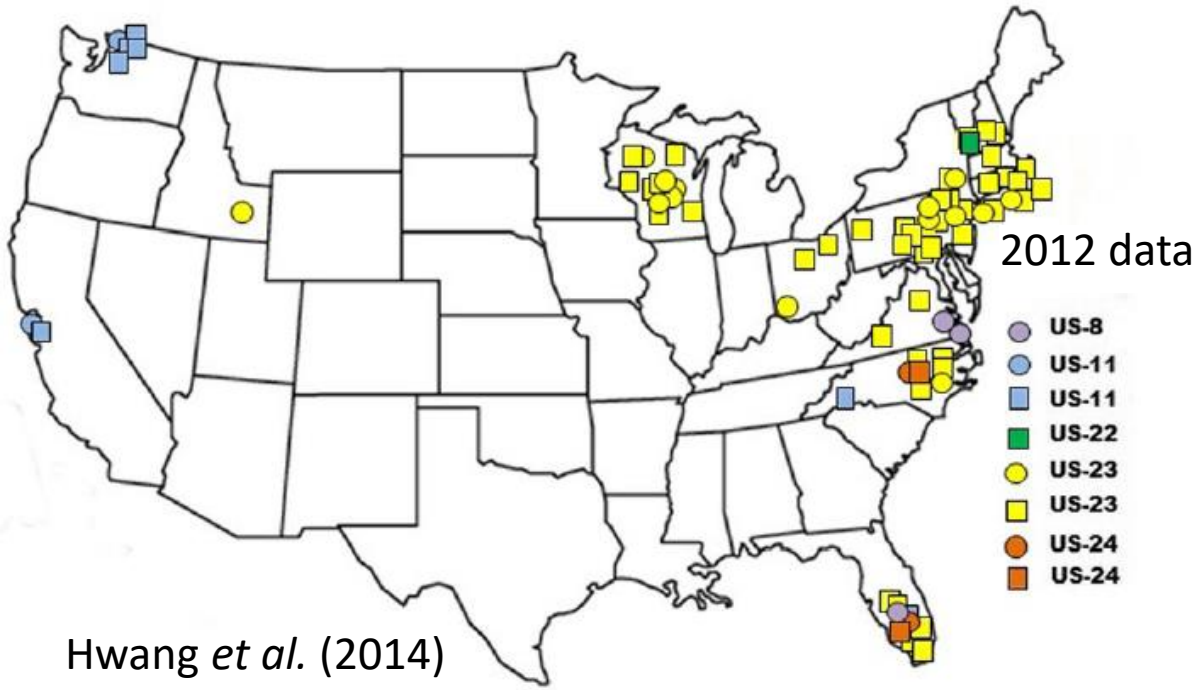
Murray Watson & Cunniffe (2022) *JRS Interface* 19:20220517

What's missing? Pathogen genetics



Race	Country (Year of 1st detection)
TTKSK	Uganda (1998), Kenya (2001), Ethiopia (2003), Sudan (2006), Yemen (2006), Iran (2007), Tanzania (2009), Eritrea (2012), Rwanda (2014), Egypt (2014)
TTKSF	South Africa (2000), Zimbabwe (2009), Uganda (2012)
TTKST	Kenya (2006), Tanzania (2009), Eritrea (2010), Uganda (2012)
TTTSK	Kenya (2007), Tanzania (2009), Ethiopia (2010), Uganda (2012), Rwanda (2014)
TTKSP	South Africa (2007)
PTKSK	Ethiopia (2007), Kenya (2009), Yemen (2009)
PTKST	Ethiopia (2007), Kenya (2008), South Africa (2009), Eritrea (2010), Mozambique (2010), Zimbabwe (2010)
TTKSF+	South Africa (2010), Zimbabwe (2010)
TTKTT	Kenya (2014)
TTKTK	Kenya (2014)
TTHSK	Kenya (2014)

Singh *et al.* (2015)
Phytopathology

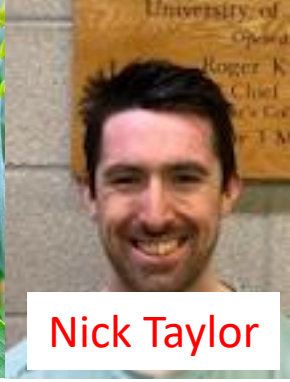


Hwang *et al.* (2014)
Am. J. Potato Res.

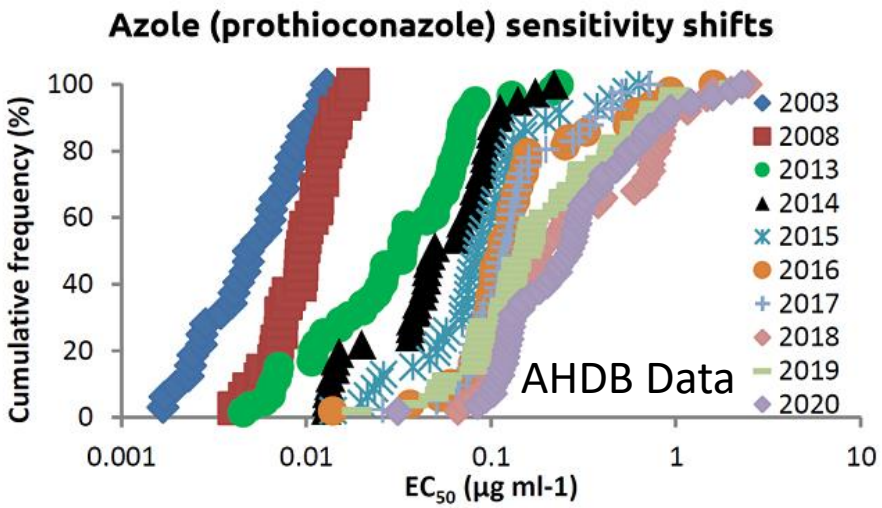
Qu. How to capture pathogen genetics and/or evolution in landscape scale models?

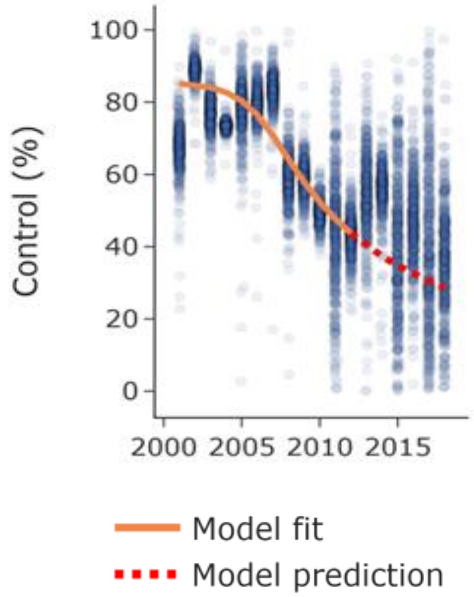
What's missing? Pathogen genetics

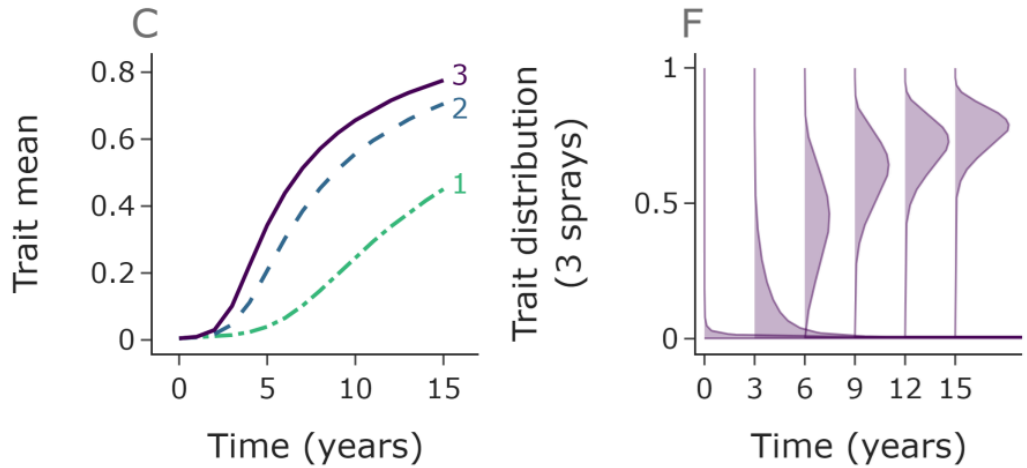

Septoria on winter wheat


Nick Taylor

- Fungicide resistance well studied & characterized in the field
- Models been developed for >40 years
- Models tend to treat resistance as monogenic (but most resistances have a polygenic basis)







Models can track selection & genetic changes

Taylor & Cunniffe (2023) *PLOS Comp. Biol.* 19:e1010969
Taylor & Cunniffe (2023) Phytopathology 113:55-69

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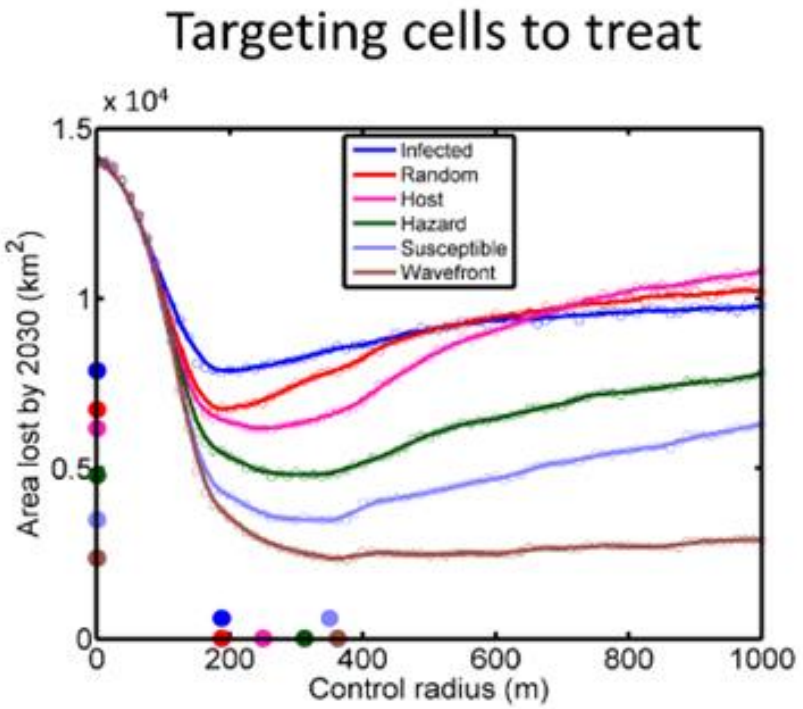
Using models to design better management strategies

Wilkes-3 (26,880 cores)

6.64 PetaFlops/sec



Qu. How to account for the combinatorial explosion in possible “treatments”?

Cunniffe *et al.* (2016) *PNAS* 113:5640-5645

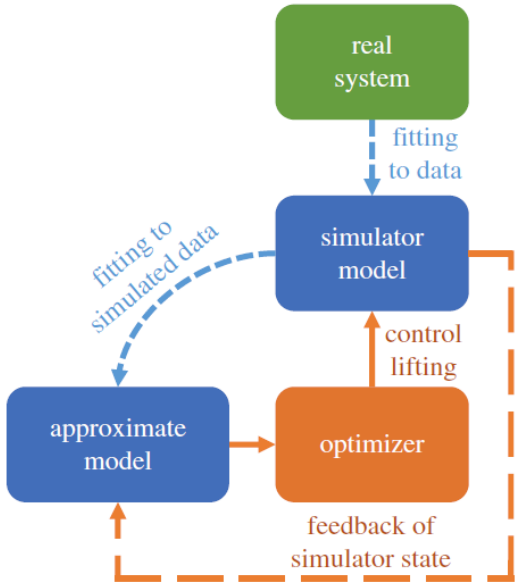
Better management. Optimal control theory

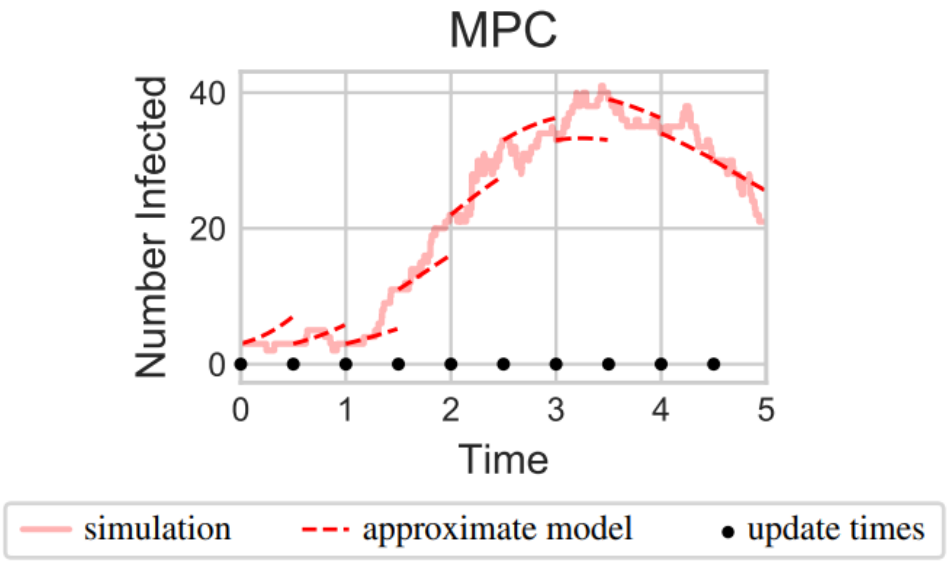
Elliott Bussell

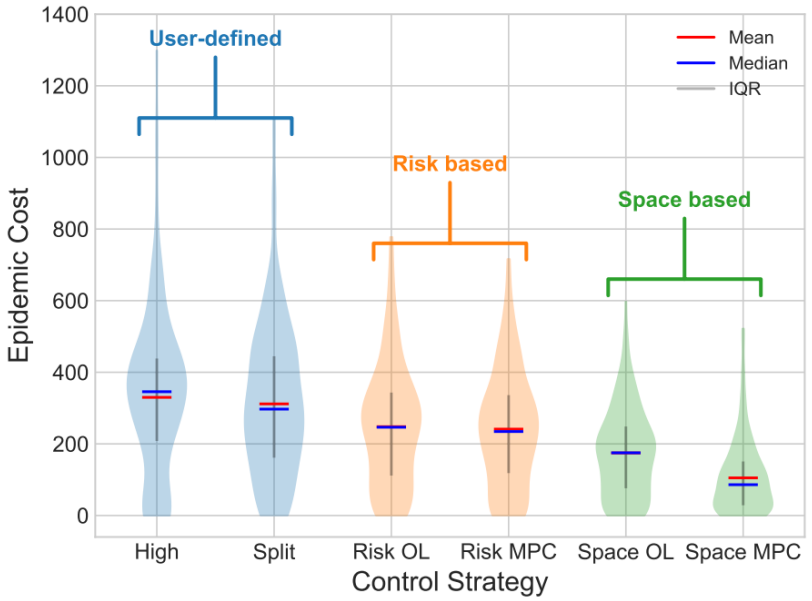
Optimal control theory finds unambiguously "correct" management strategy

But only when the model is simple enough to do (hard!) maths; no good for complex simulations

Qu. Does Model Predictive Control (approximation & repeated recalibration) work? Yes!







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Bussell *et al.* (2019) *Phil. Trans. B.* 374:20180284
Bussell & Cunniffe (2020) *JRS Interface* 17:20190671

Better management. Reinforcement learning

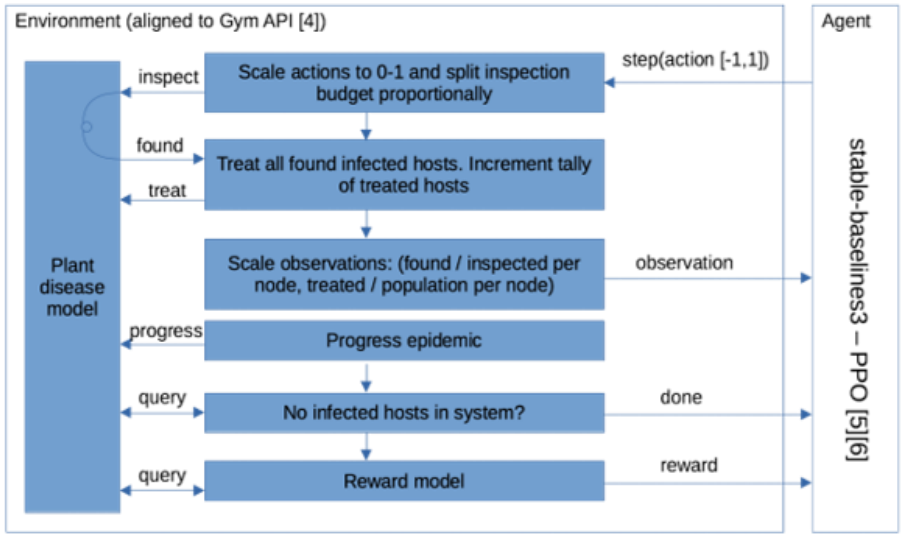
defra
Department for Environment Food and Rural Affairs

Rachel Trimble

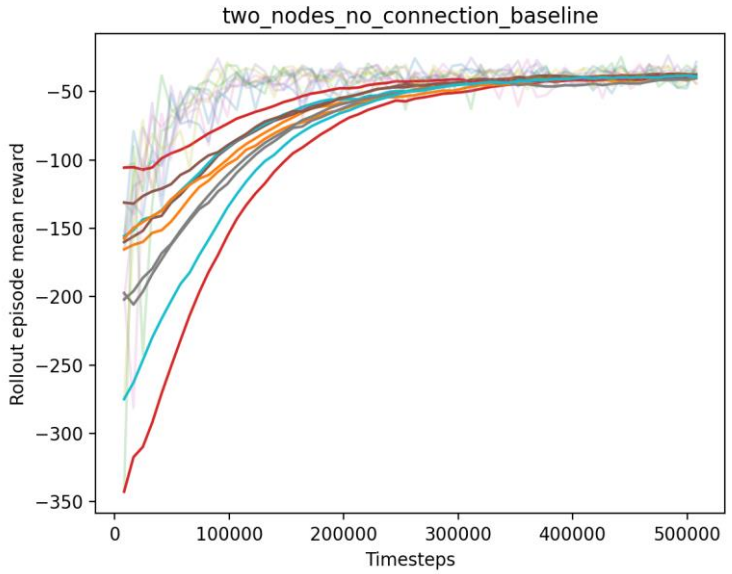
Another way of learning "correct" management strategy is reinforcement learning

Rachel has just started; systematically testing how complex the disease model can be…

Training an agent



Learning curve



Agent performance

Acknowledgements

BBSRC
bioscience for the future

defra
Department for Environment
Food and Rural Affairs

Horizon 2020

British Society for Plant Pathology
BSPP

GIRTON
COLLEGE