Bioeconomic modelling of spatial spread and control of forest epidemics: Policy-driven and voluntary strategies

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Plan of the talk

How can models support risk assessment of plant pests and decision making?

- Introduction: Modelling

- Model 1: Prevention vs control on a gradient
- Model 2: Control on a landscape

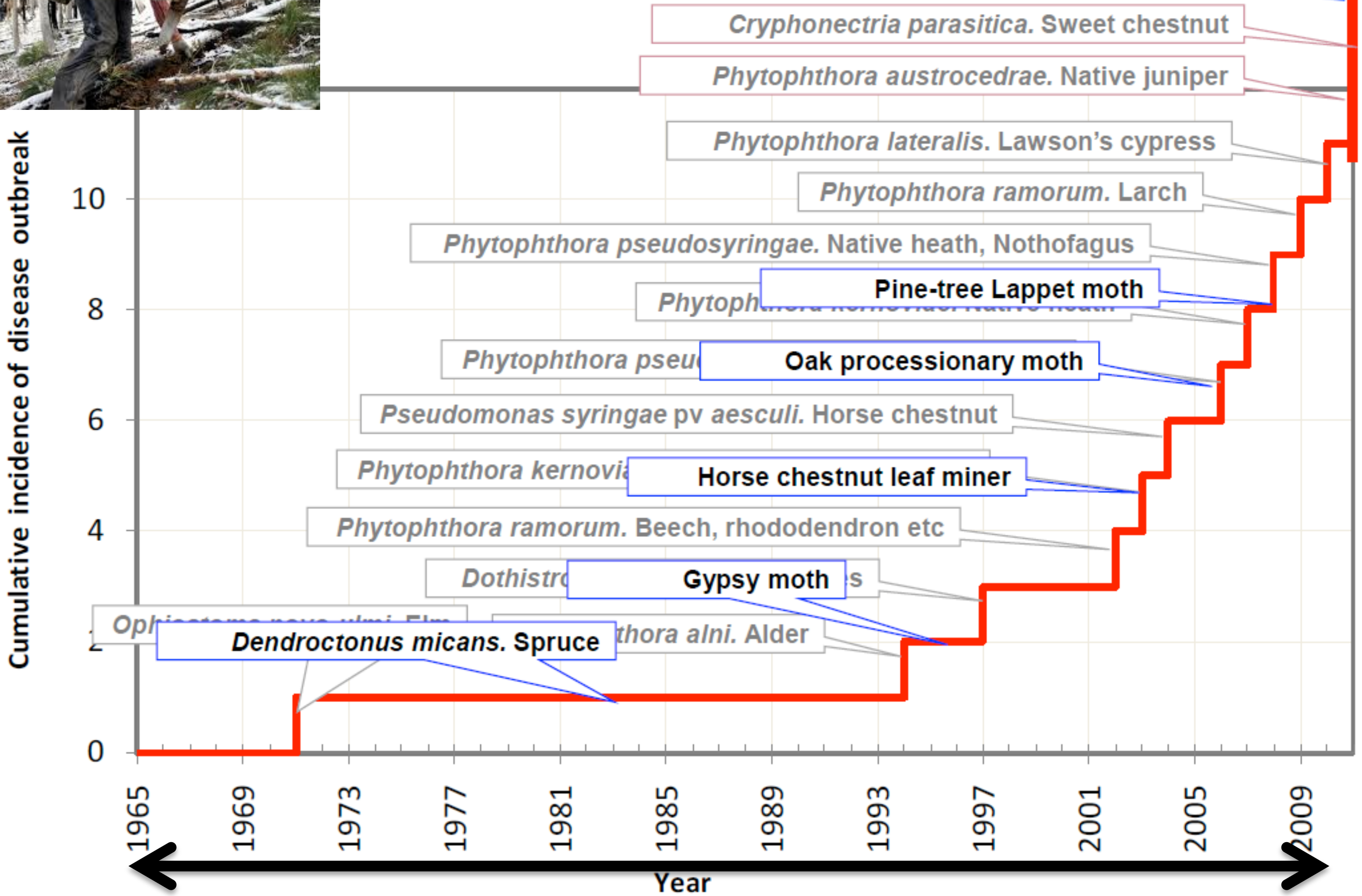
- Conclusions

Conventional disease ecology models treat human behaviors as external to the disease system, whereas bioeconomic analysis treats behavior as an internal component of a jointly determined human-disease ecology system.
Horan et al 2010

[Models] should allow decision makers to determine the point at which to switch between eradication, containment, and learning to live with a problem based on economic, social, environmental, political, technical and legal considerations.
DEFRA TTI call for proposals 2016

Photo courtesy of S Hendry, FR

Background



45 years

Images: Plant Health Task Force

Bio-economic modelling

How can models support risk assessment of plant pests and decision making?

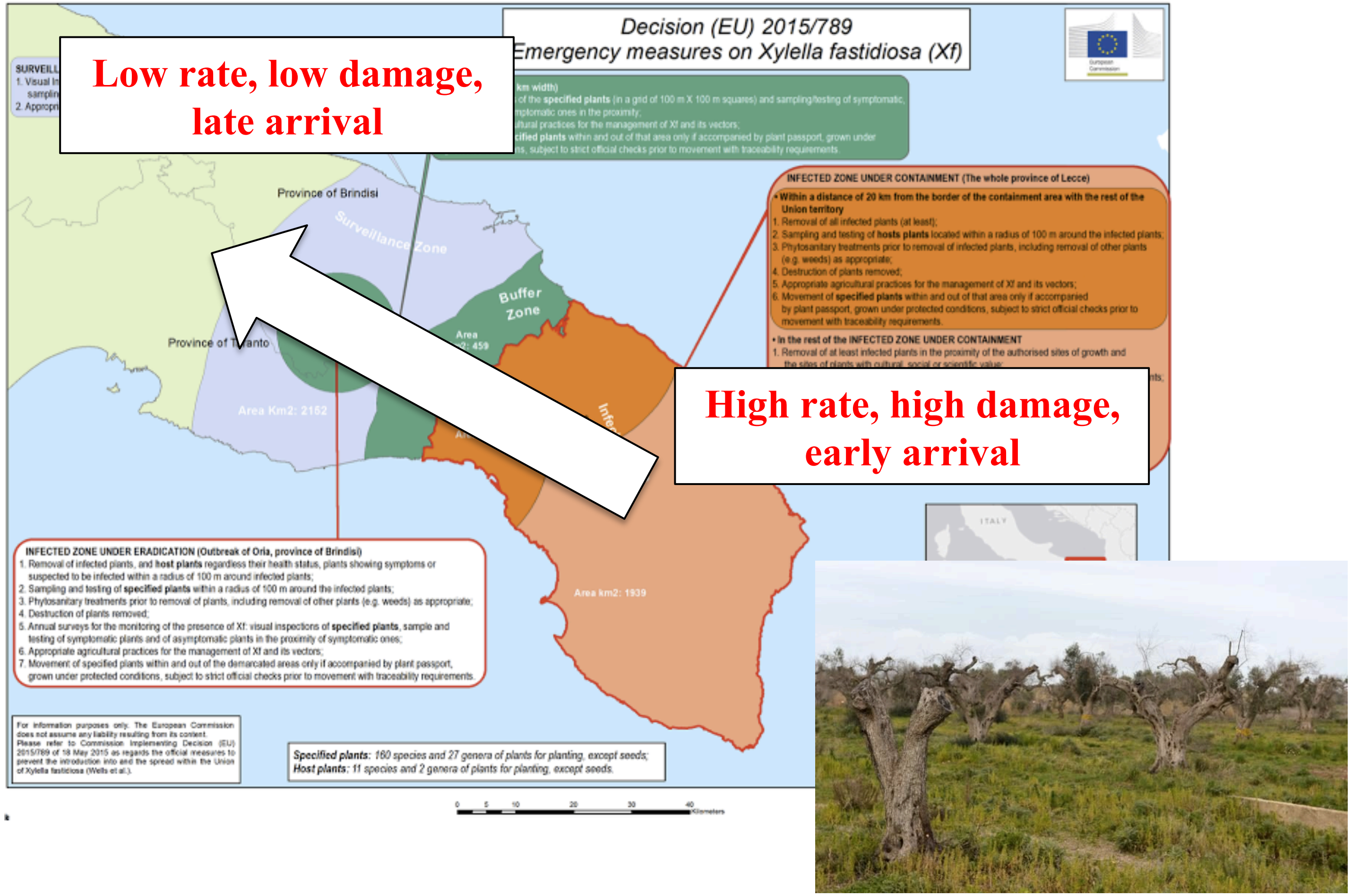
- Forest owner responding to a threat by emerging disease/pest

- Assess the risks:
  - How probable is it that pest/pathogen will invade?
  - When will it invade?
  - How fast will it spread?
  - What is its potential impact?
  - What control strategies are available and how much would they cost?
- How is this information gathered?

- Make decision:
  - What is the balance between costs and benefits of any action?
  - Which strategy to choose or whether to do nothing?
  - How does my decision depend on neighbours?
  - How does my decision impact on neigbours

Model 1: Prevention or treatment

- How does owners perception of disease change the balance between prevention, treatment or 'live with a disease' option?

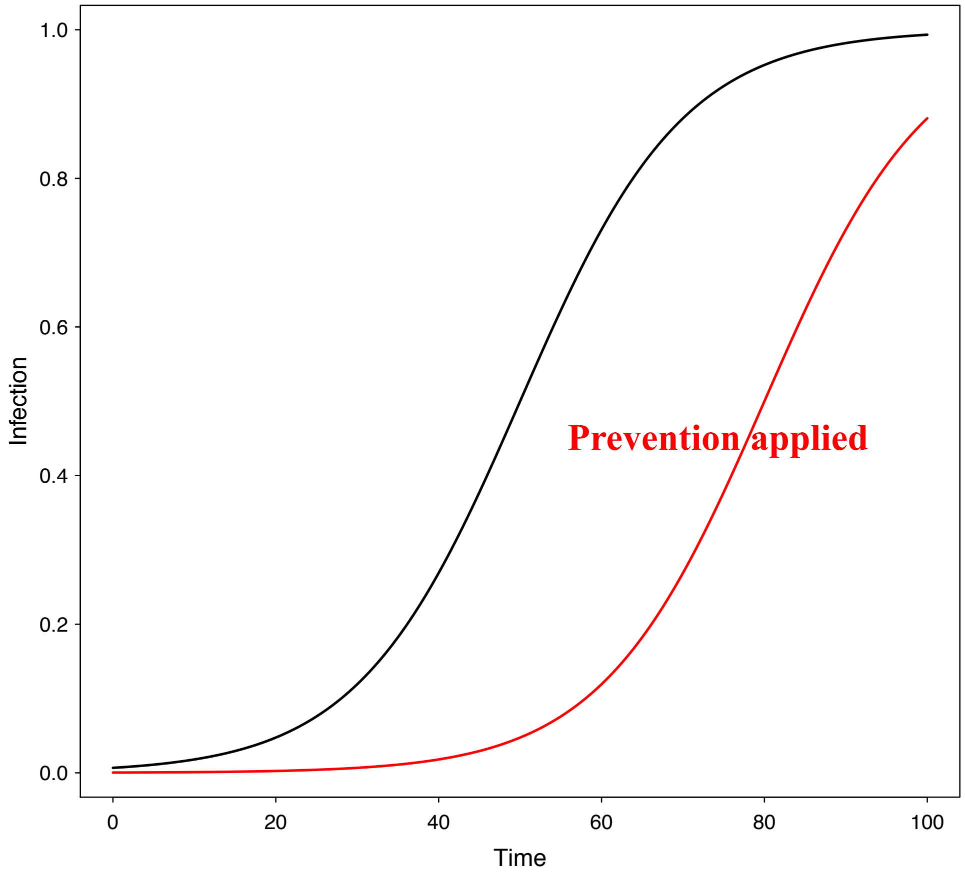


Model 1: Prevention or treatment

- Mature forest with continuous cropping or amenity forest
- Single population on a disease intensity gradient
- SI model with primary infection rate

$$\begin{cases} \dfrac{dS(t)}{dt} = -\beta\left[I(t) + \delta\,\varepsilon\right]S(t) \\ \dfrac{dI(t)}{dt} = \beta\left[I(t) + \delta\,\varepsilon\right]S(t) \end{cases}$$

$$\delta = 1 - \frac{c_P}{B}$$



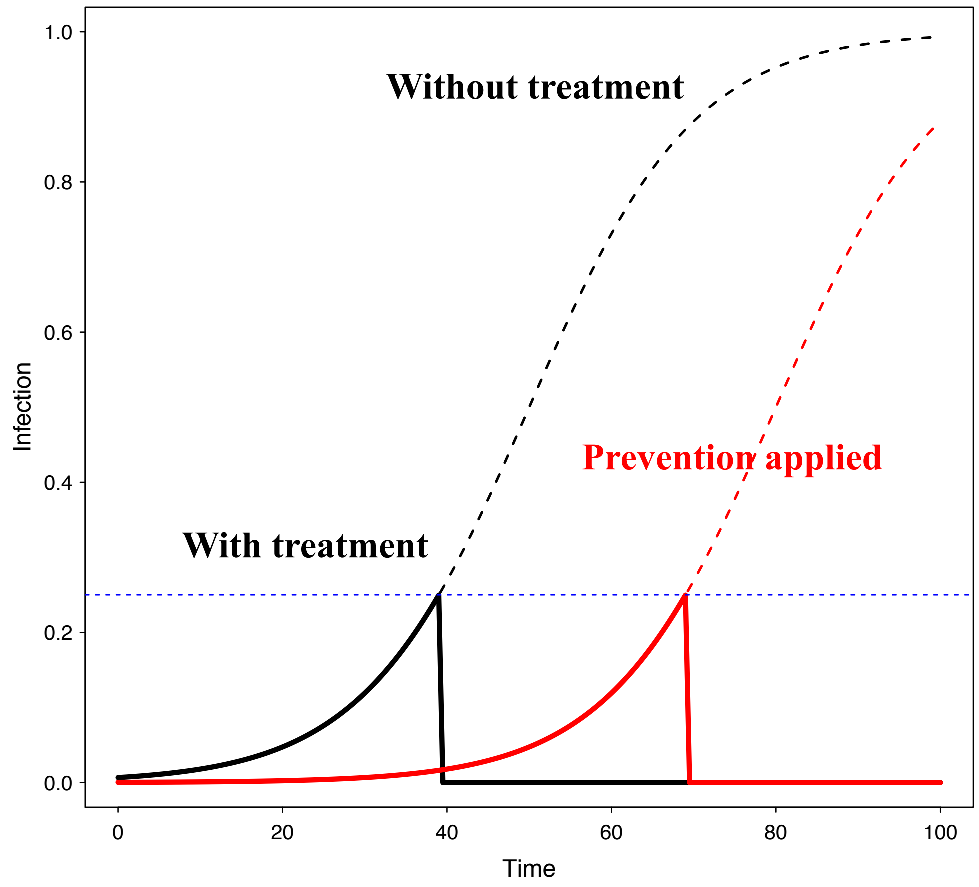
- Prevention delays the arrival
  - voluntary
  - depends on investment level

Model 1: Prevention or treatment

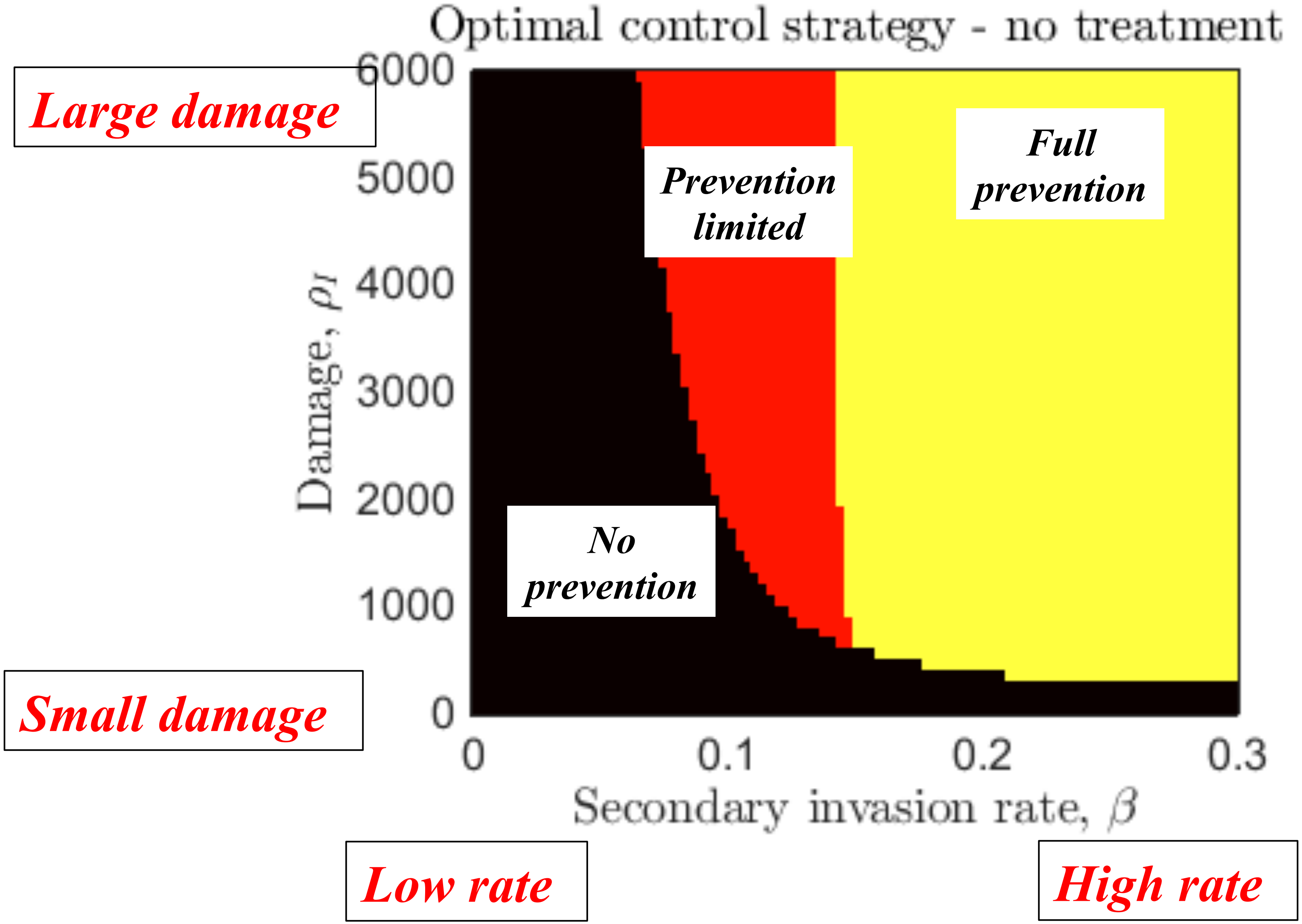
- Treatment eradicates the disease already present
  - compulsory
  - threshold

- Minimise total loss subject to spread of disease:
  - prevention cost (all the time)
  - infection cost (while infection is present)
  - treatment (applied once)

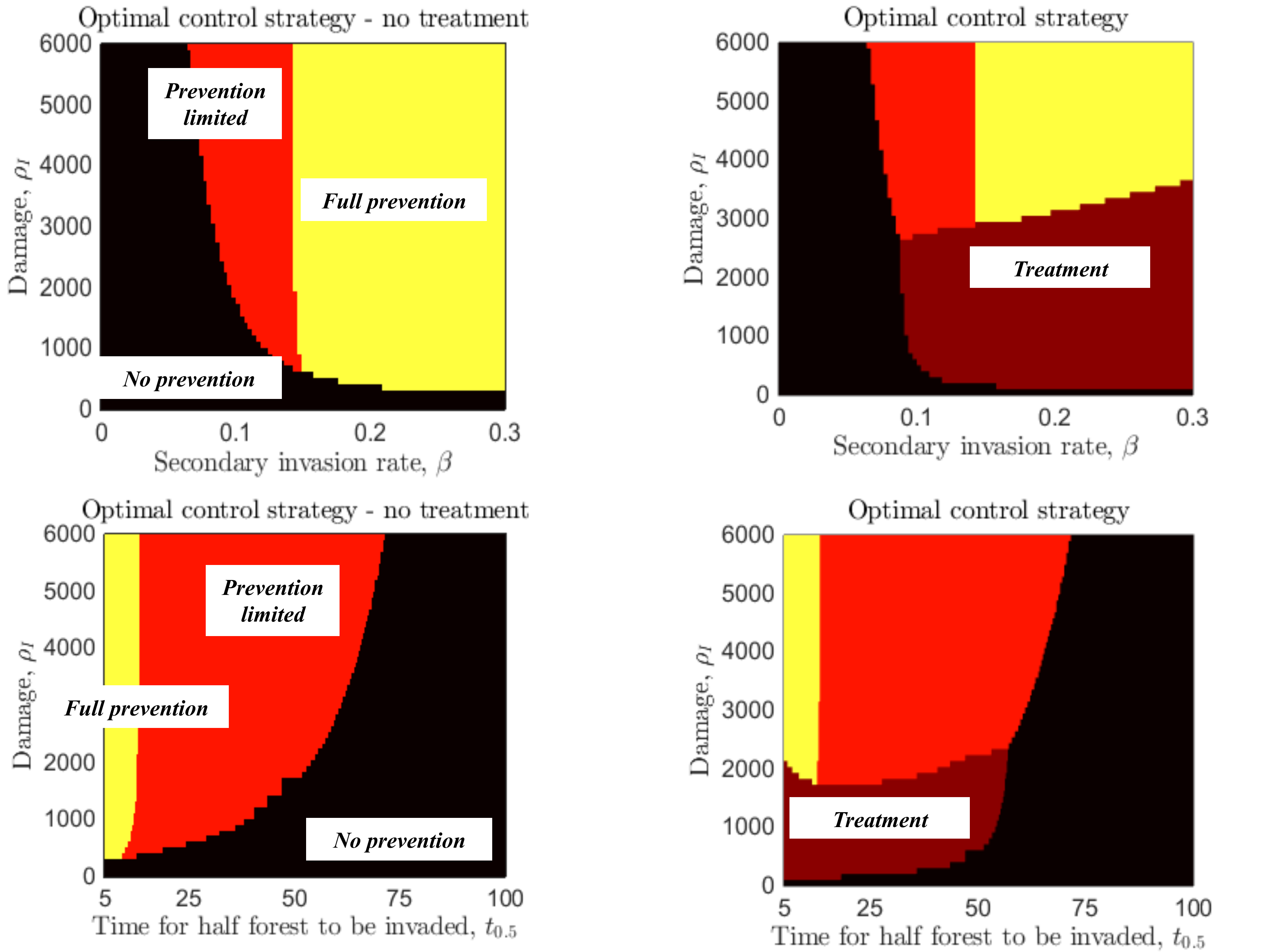
$$\min_{0 \le c_P \le B} J(c_P, T) = \int_0^\infty e^{-dt} c_P L \, dt + \int_0^\tau e^{-dt} c_I I(t) \, dt + e^{-d\tau} c_T L$$



Model 1: Prevention



Model 1: Prevention or treatment



Model 1: Summary

- Zoning emerges from bioeconomic models:

- Close to disease focus:
- if treatment available, forego prevention and treat
- if not, concentrate on prevention and invest all budget

- Far from disease focus:
- if damage low, do nothing or apply treatment if available
- if damage high, apply some level of prevention

Focus of infection

High rate of spread
Early arrival

Low rate of spread
Late arrival

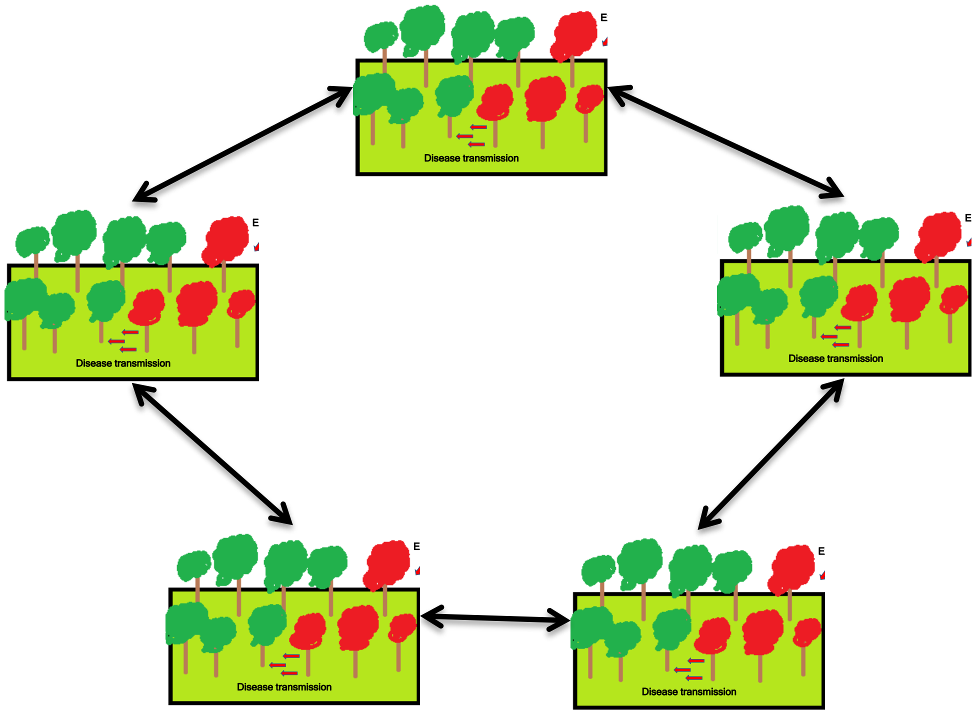
- Extensions:
  - Combination of prevention and treatment is not optimal in this model
  - Extension of the model to optimise with respect to both prevention and treatment

Model 2: Control on landscape

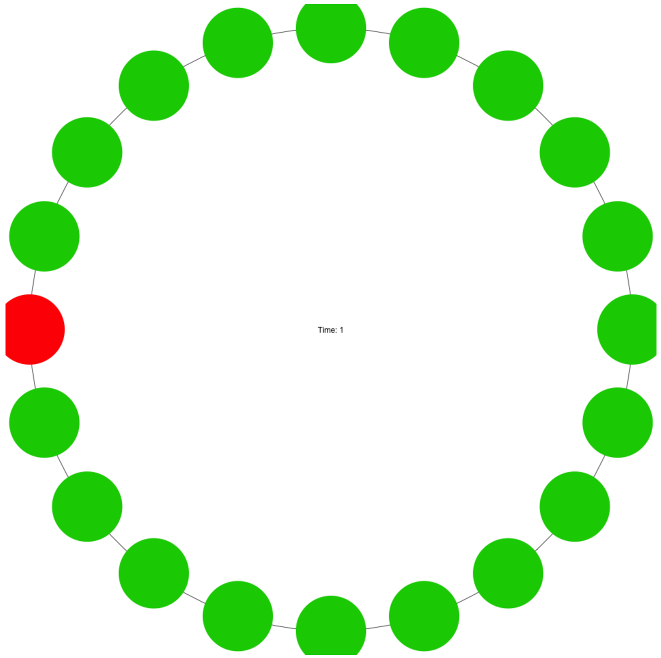
- **How does the efficacy of control depend on decision-making of individual owners?**

- Decisions under limited knowledge
- Decision of one owner impacts on the situation of others

- <u>Single rotation; growing forest</u>



Model 2: Control on landscape



Agent-based model

- Tree growth: $V(t) = \left(1 - e^{-0.0342t}\right)^3$
- Agents located on a 1-dim network
- Decision taken every year:
  - keep forest
  - clear fell
- Disease reduces profit at felling

- Susceptible stays susceptible $\Delta V_{SS} = e^{-d} V(t+1) - V(t)$
- Susceptible becomes infected $\Delta V_{SI} = e^{-d} \rho V(t+1) - V(t)$
- Infected stays infected $\Delta V_{II} = e^{-d} \rho V(t+1) - \rho V(t)$

- Infection spreads with probability *p* to nearest neighbours
- Decision to keep/clear fell based on expected profit

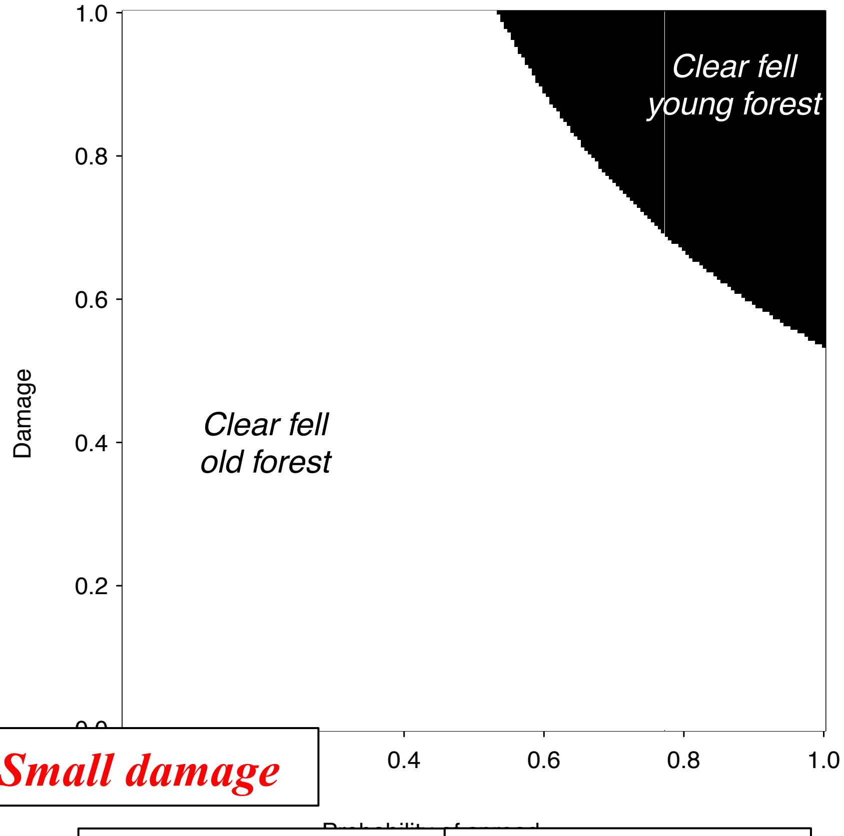
$$\Delta V = (1-p)^{\#\inf} \Delta V_{SS} + \left(1 - (1-p)^{\#\inf}\right) \Delta V_{SI}$$

Model 2: Control on landscape

- N=50
- 51 by 51 parameter sets
- 100 simulations for each set
- Final time t=40

Large damage

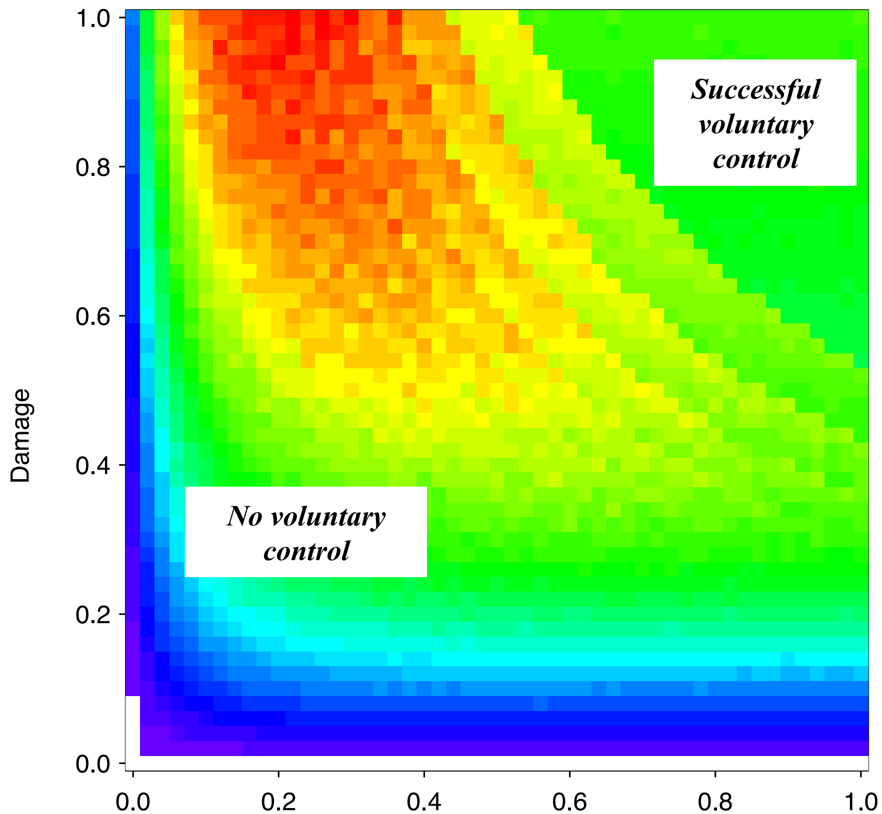
Strategy plot



Small damage

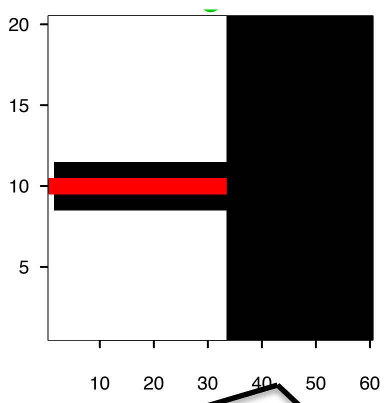
Low rate of spread	**High rate of spread**

Losses

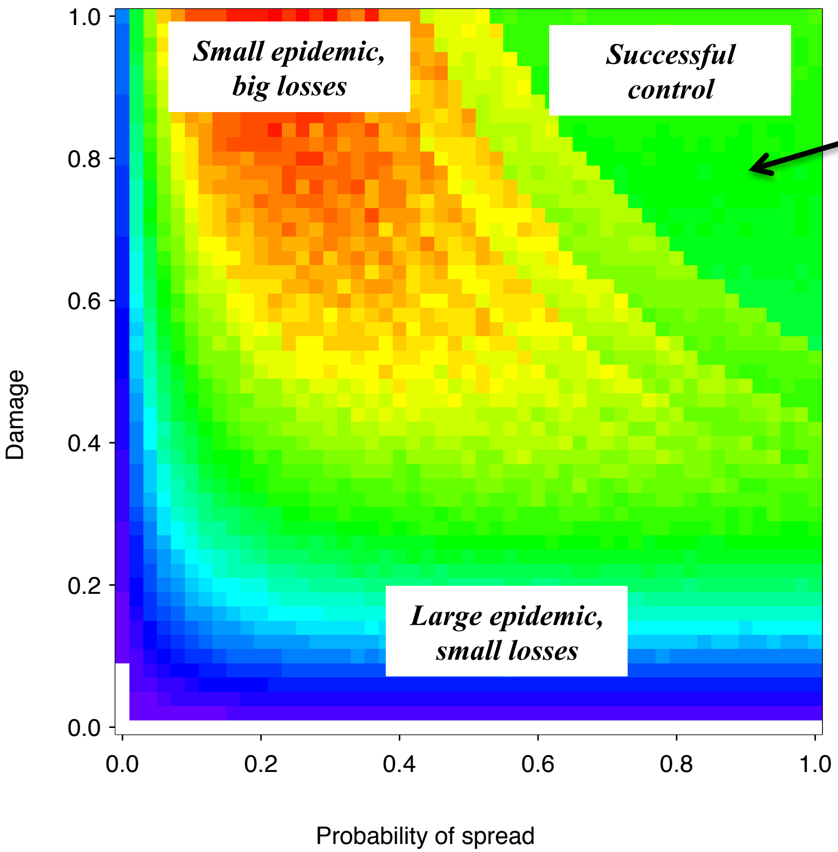


Low rate of spread	**High rate of spread**

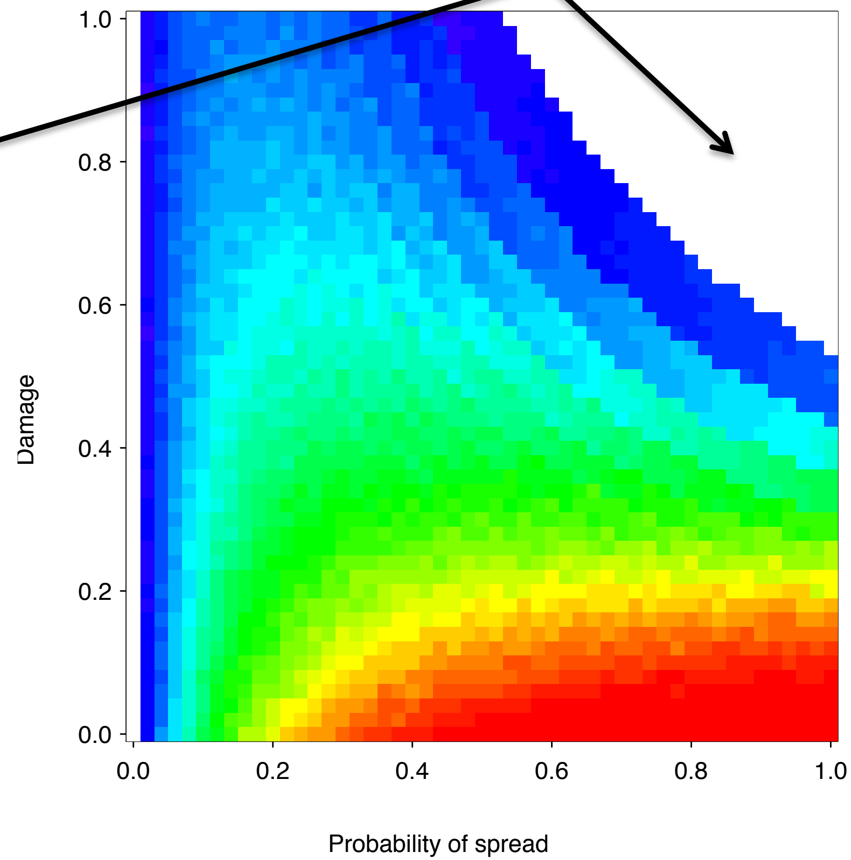
Model 2: Voluntary control



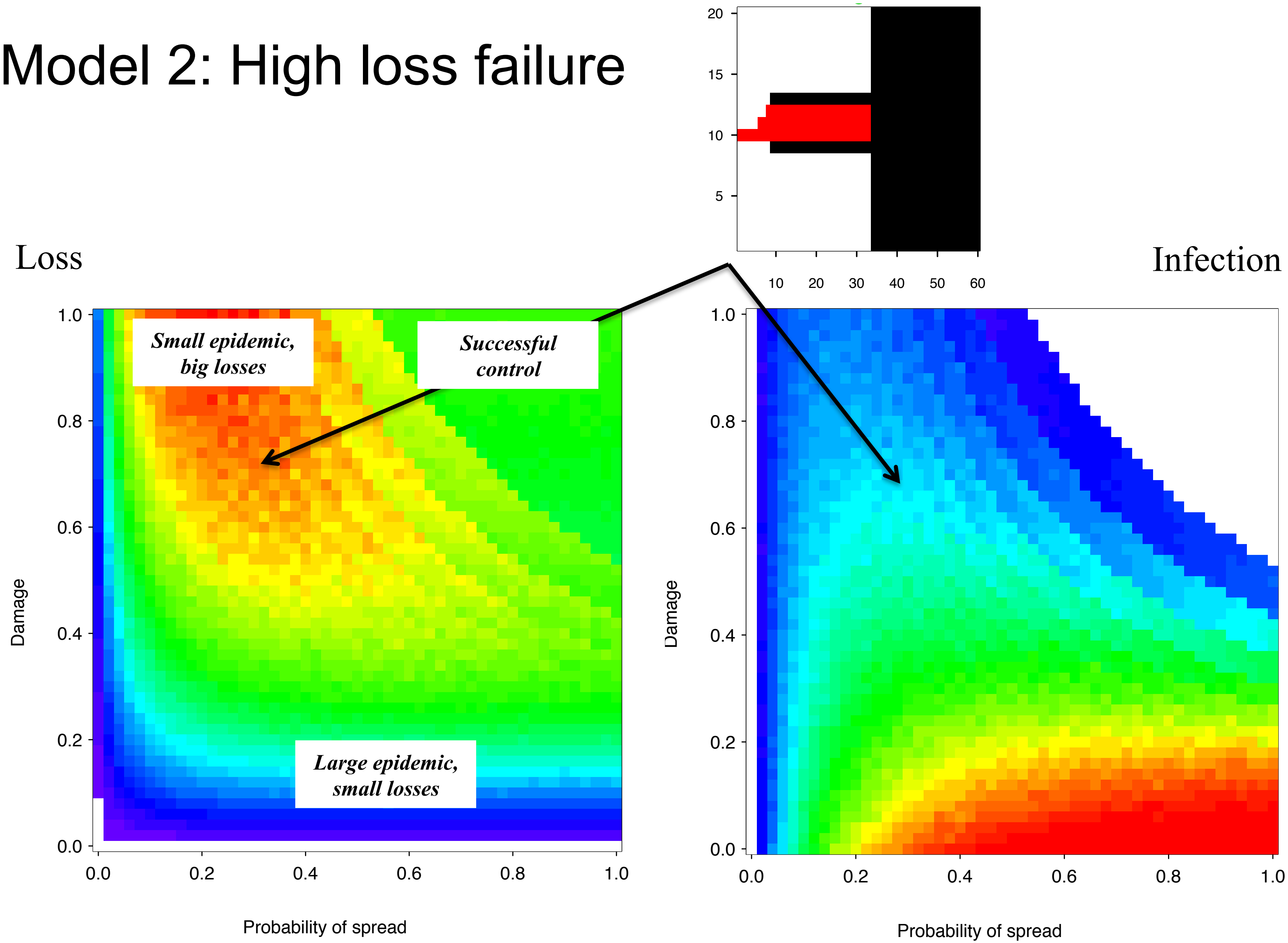
Loss



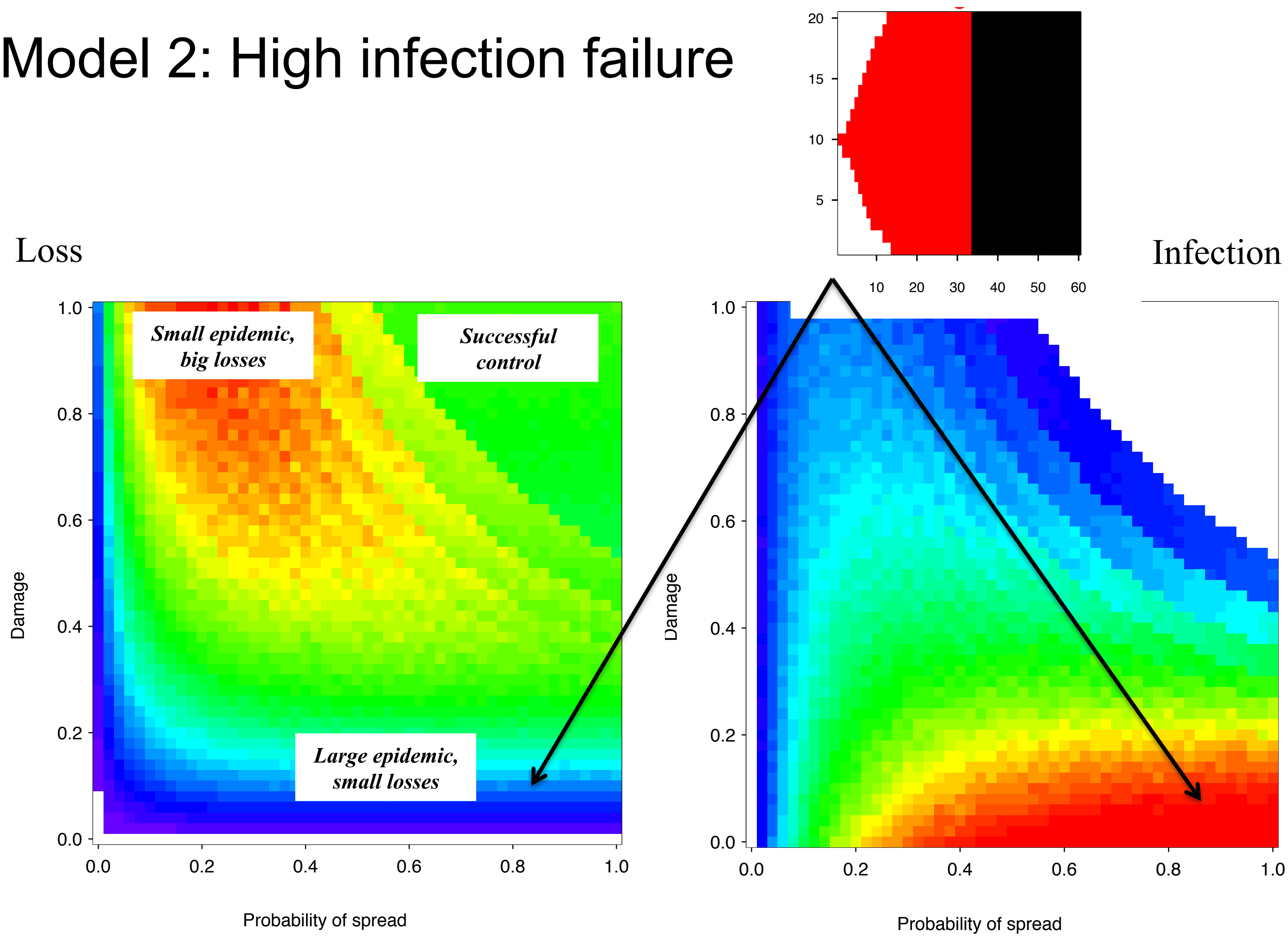
Infection



Model 2: High loss failure



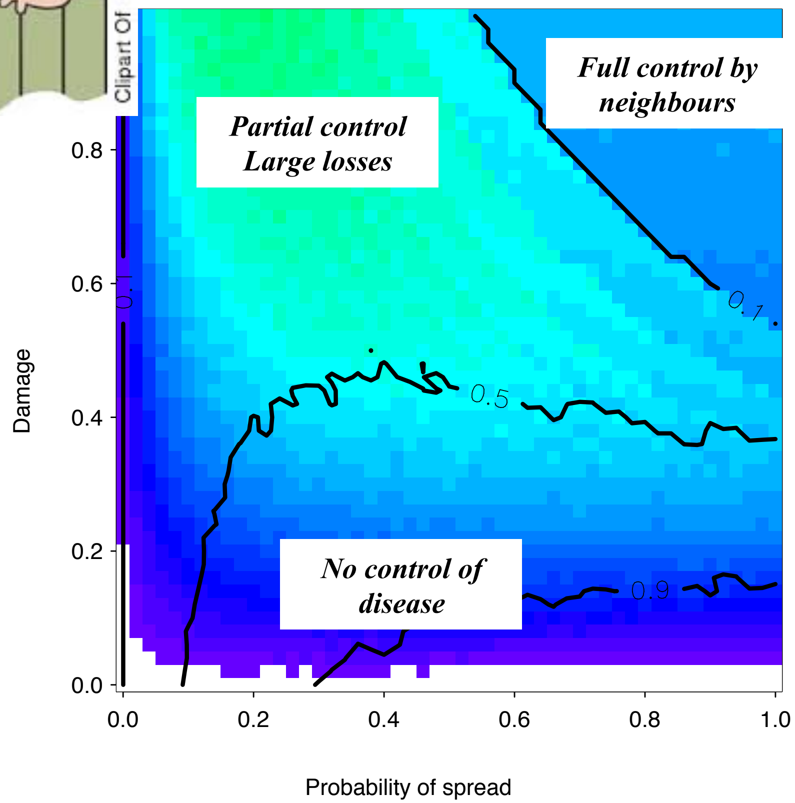
Model 2: High infection failure



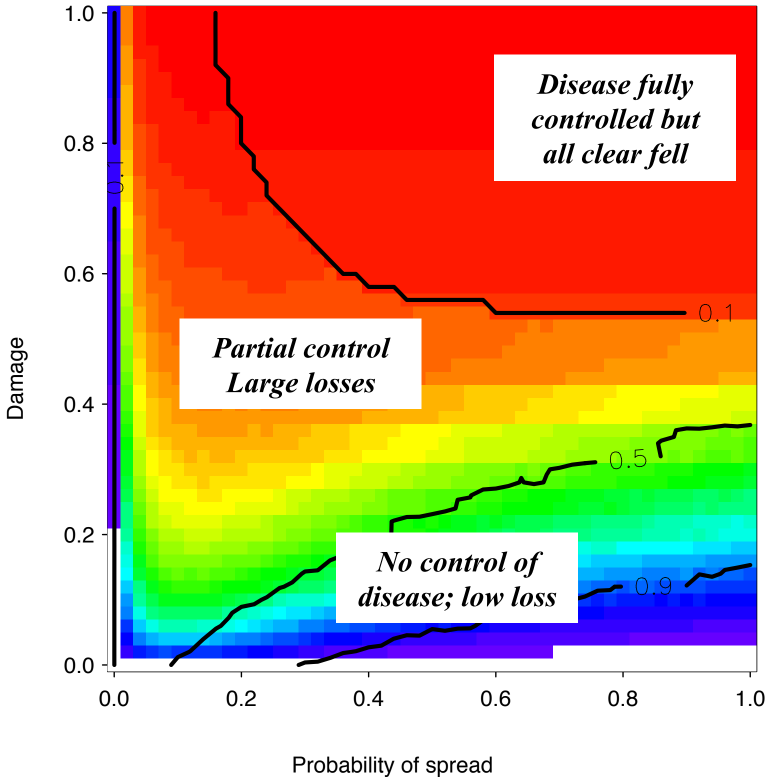
Model 2: Neighbourhood

- Decision under uncertainty
- Spread is local, but decisions can be based on all sites or on neighbourhood
    - Matching scales is important
- Note same colour scale for losses

Losses: only neighbours



Losses: whole population



Model 2: Summary

- Three regions:
    - Successful voluntary control (low rate, high damage)
    - Large outbreak (high rate, low damage)
    - Moderate outbreak with high losses (medium rate, high damage)
- Timing is important (forest either young or close to maturity)
- Knowledge and scale are keys to control
    - Too much leads to panic and overreaction
    - Too little leads to under response
- Extensions:
    - Realistic network
    - Realistic decision making process
    - Trade-off between immediate and long-term risk/profit
    - Subsidies
    - Game theoretical approach

Conclusions

- Most epidemics originate from economic decisions and result in economic losses
- Modelling provides a tool to link economic decisions to epidemiology and to forest management

- Trade-offs:
  - Control now to prevent potential disease outbreak in the future
  - Control costs vs costs of disease spread
  - Affected by perception of risk and information

- Questions:
  - Are people (managers, politicians, public) aware of the trade-offs?
  - How do we communicate these trade-offs?
  - How do people resolve these trade-offs?
  - How do people resolve uncertainties?

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