Designing Optimal Strategies for Surveillance and Control of Invasive Forest Pests

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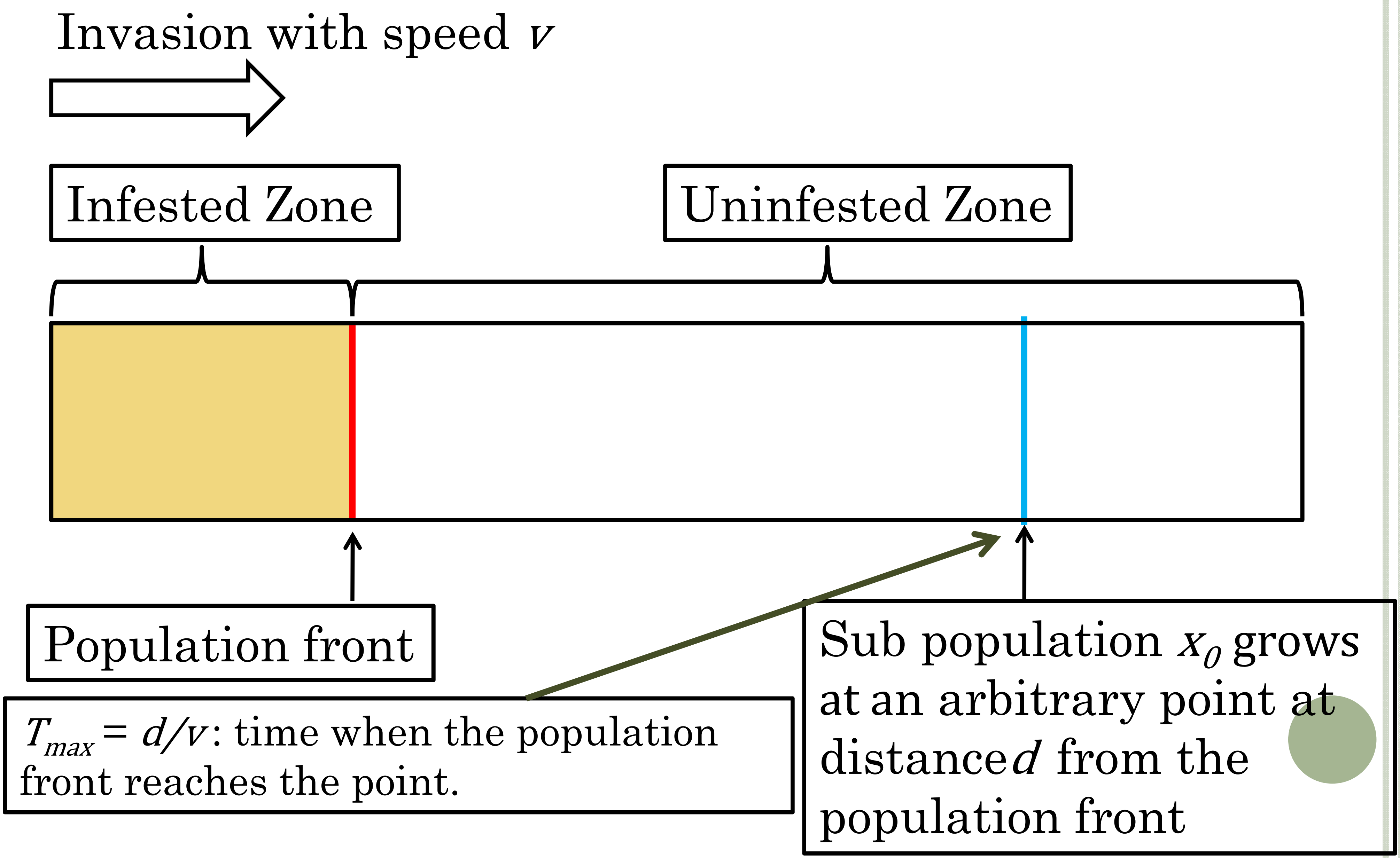
OUTPUTS

- Optimal detection strategies for an established invasive pest
  - Frances Homans and Tetsuya Horie, 2011. *Ecological Economics* 70(6): 1129-1138.
- Assessing the cost of an invasive forest pathogen: A case study with oak wilt.
  - Robert Haight, Frances Homans, Tetsuya Horie, Shefali Mehta, David Smith, and Robert Venette, 2011. *Environmental Management* 47: 506-517.
- Designing Optimal Strategies for Surveillance and Control of Invasive Forest Pests
  - Tetsuya Horie, Ph.D. Dissertation. University of Minnesota, April 2011

Optimal detection strategies for an established invasive pest



Research Questions

- How much effort should be devoted to finding a sub-population growing ahead of an advancing front?
- What is the relationship between optimal detection effort and the distance from the front?

COSTS PRIOR TO DETECTION

Detection costs: $C_1(E) \equiv \int_0^{\tau(E)} \exp(-rt) bE^2 dt$

Damage costs before detection:

$$C_2(E) \equiv \int_0^{\tau(E)} \exp(-rt)(px_0 \exp(at))dt$$

where

E = detection effort level

p = damage coefficient

r = Discount rate

x_0 = initial population size

a = population growth rate

b = detection cost coefficient

τ = date of detection

POST DETECTION COSTS

Optimized damage and management costs:

$$C_3(E) \equiv \exp(-r\tau(E))\,V\left(x(\tau(E)), T_{max} - \tau(E)\right)$$

where

$$V(x(\tau(E)), T_{max} - \tau(E)) \equiv \left\{ \begin{array}{c} \min \int_{\tau(E)}^{T} \exp(-r(t - \tau(E)))(px(t) + cR(t)^2)dt \\ \text{subject to } \dot{x}(t) = ax(t) - R(t) \\ x(\tau) = x(\tau(E)) \\ T - \tau(E) \leq T_{max} - \tau(E) \\ x(T) \geq 0 \\ \tau(E) \text{ is given} \end{array} \right\}$$

R = Removals

T_{max} = Date the main front arrives.

CHOOSE E TO MINIMIZE SUM OF COSTS

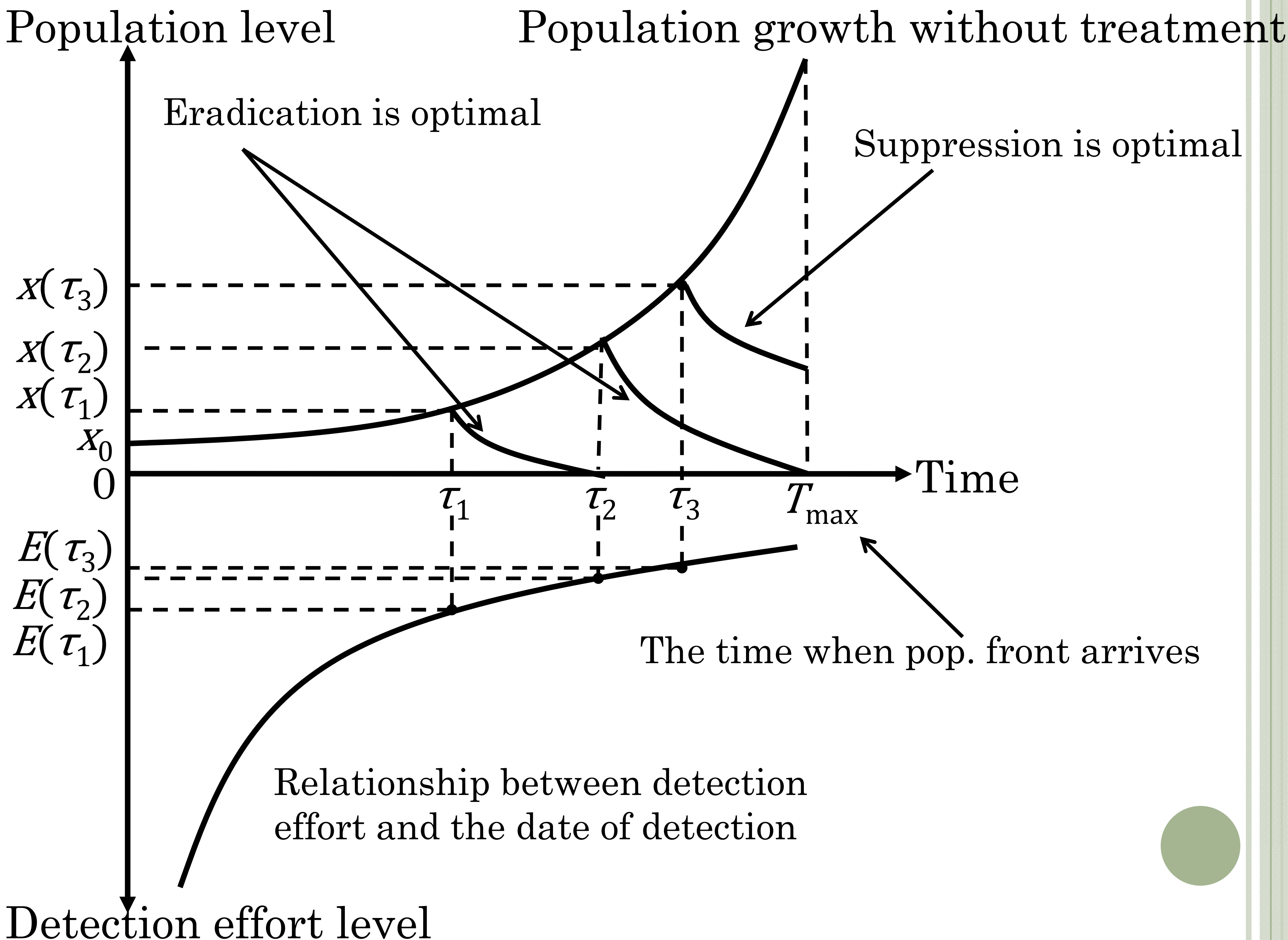
$$\text{Min } C_1(E)+C_2(E)+C_3(E)$$

Detection costs

Damage costs before detection

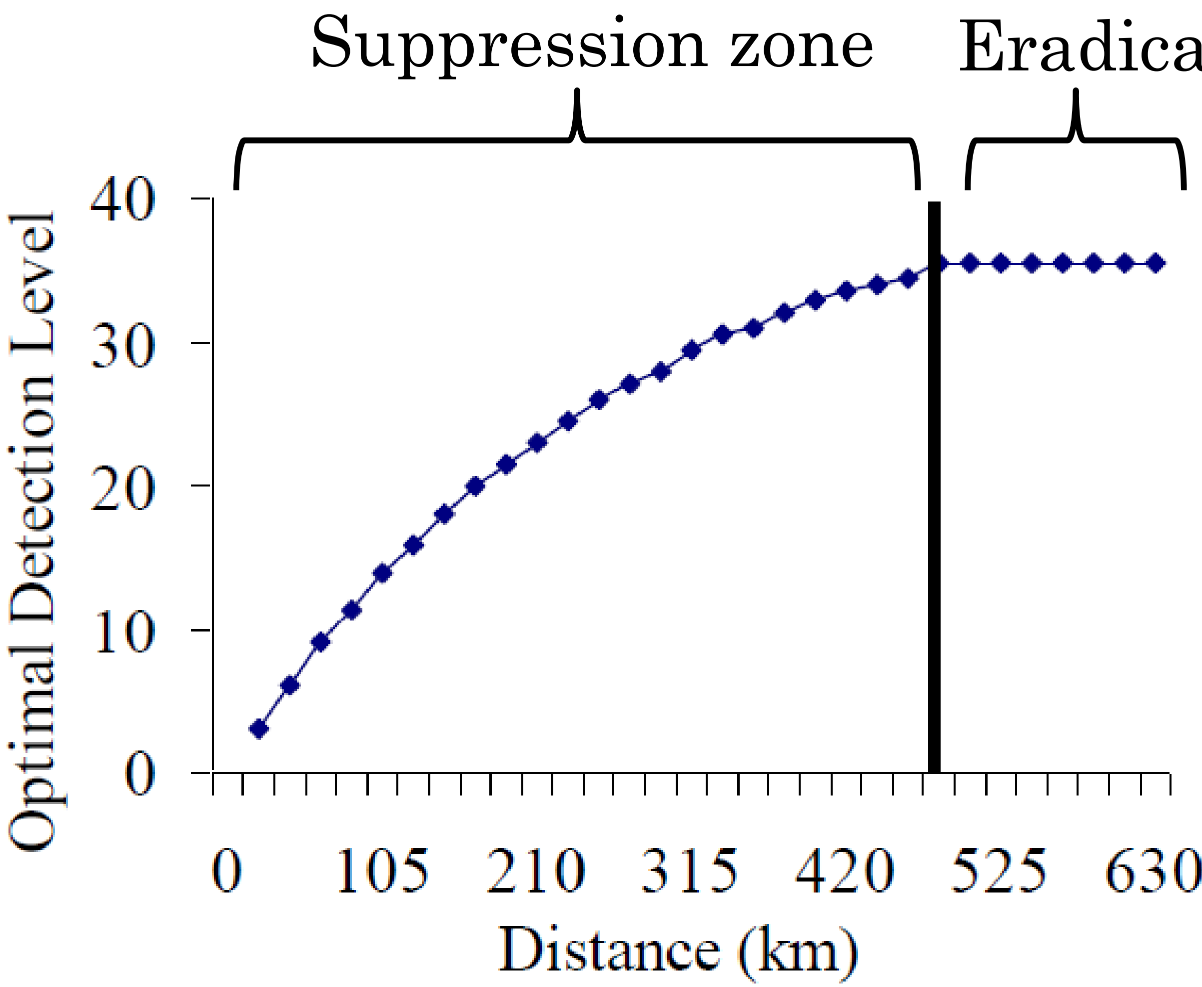
Optimized damage and management costs after detection.

⇨ Optimal detection effort level associated with the optimal treatment strategy upon detection



Population level
Population growth without treatment
Eradication is optimal
Suppression is optimal
$x(\tau_3)$
$x(\tau_2)$
$x(\tau_1)$
x_0
0
Time
τ_1
τ_2
τ_3
T_{max}
$E(\tau_3)$
$E(\tau_2)$
$E(\tau_1)$
The time when pop. front arrives
Relationship between detection effort and the date of detection
Detection effort level

Optimal Detection Effort Levels and Suppression/Eradication Zone



- Suppression zone:
  - Optimal Detection effort level increases with distance from the population front.

- Eradication zone:
  - optimal detection level is constant—eradicate before front arrives

Implications

- Uninfested zone can be divided into two separate zones characterized by the two different treatment strategies
  - eradication zone & suppression zone.
- In suppression zone:
  - As the distance from the population front increases, it is optimal to increase detection effort
- In eradication zone:
  - Optimal detection effort is constant with distance from the front.
- Key insight: detection effort depends on what you'll do (optimally) when you find the pest.

Research on Oak Wilt

- Assessing the cost of an invasive forest pathogen: A case study with oak wilt
  - Key issue—assembling quality data on the forest resource in a metro area
- Optimal strategies for the surveillance and control of forest pathogens
  - Model based on site-selection literature

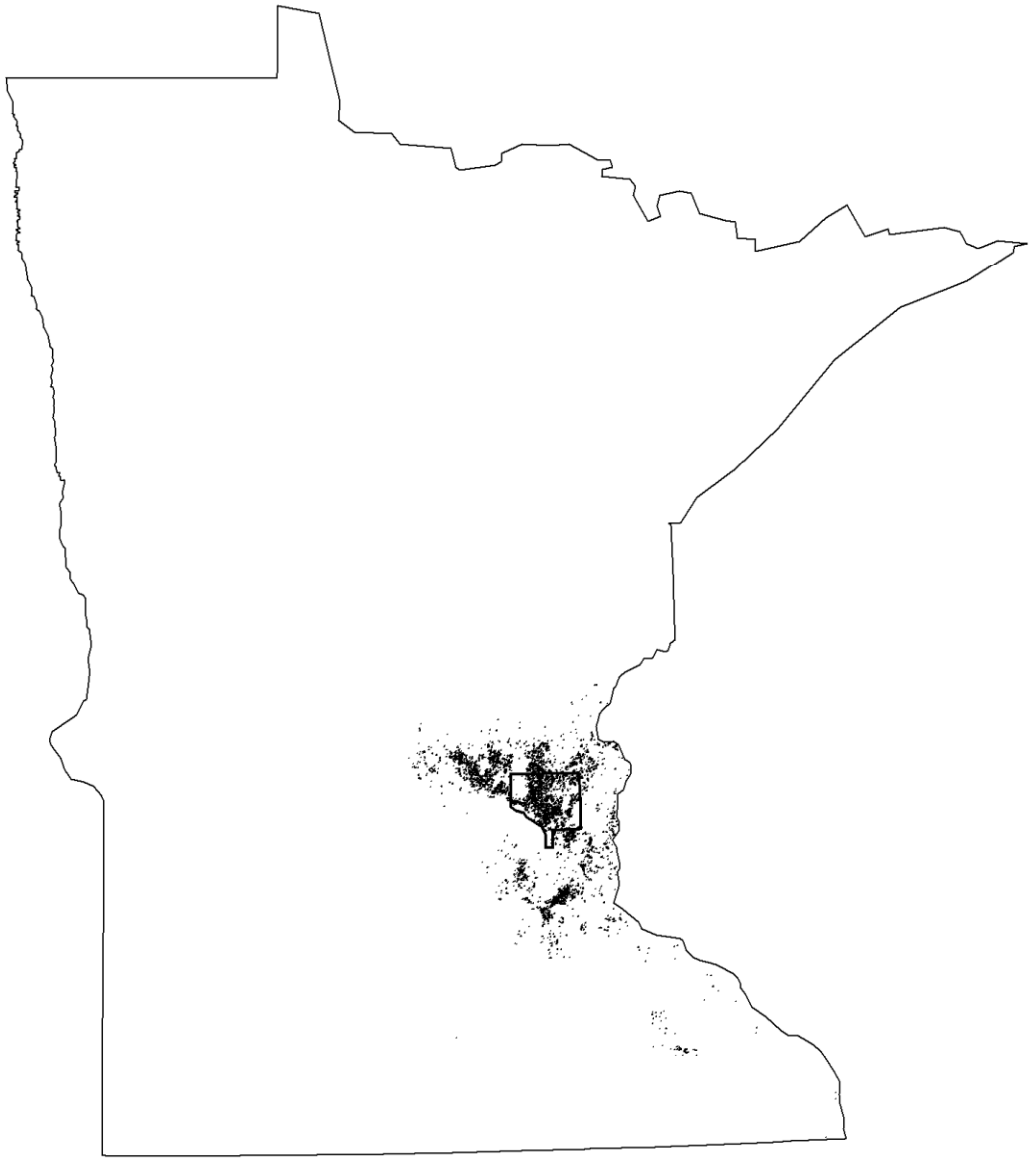
Oak Wilt

- Caused by the fungus: *Ceratocystis fagacearum*
- Always fatal to red oak species
- Spread
  - via root grafts (underground)
  - by an insect vector (overland spread) that feed on spore mats and on freshly wounded trees
- Treatment
  - Removal of infected trees before spore mats develop
  - Trenching around pockets of infected trees
  - fungicide

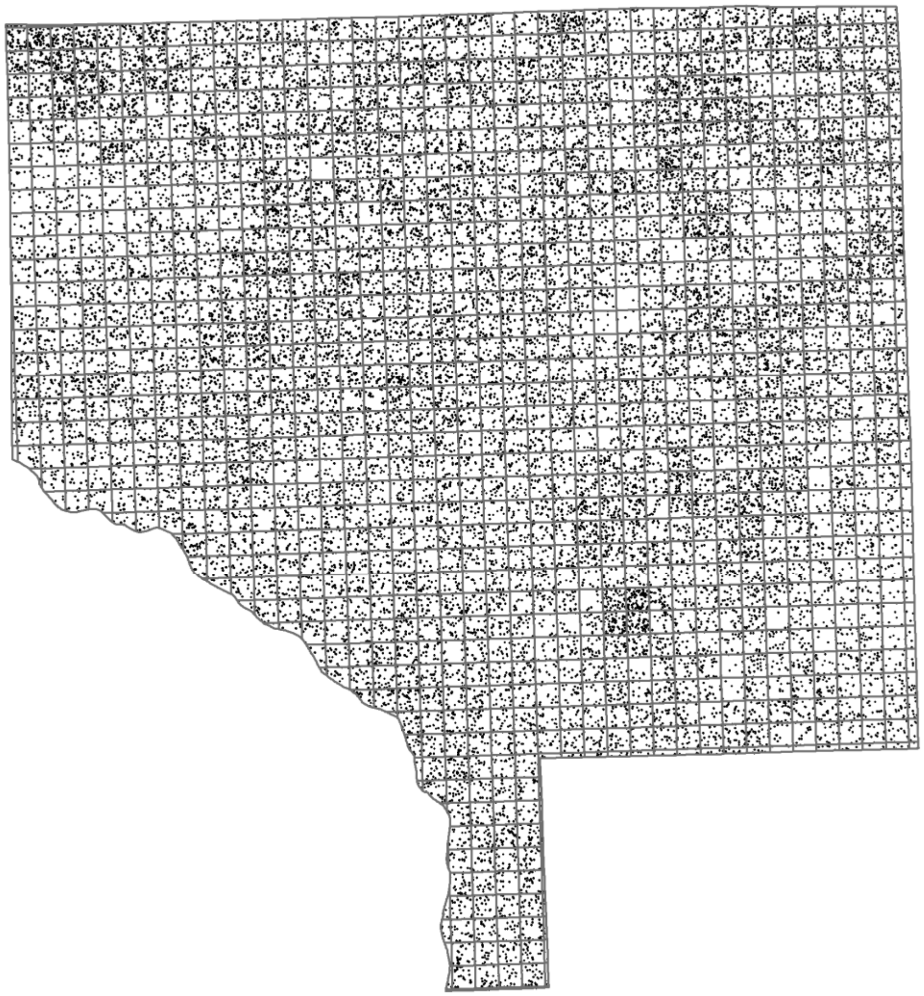
Costs of oak wilt in Anoka County

- Present value of removal costs over a 10 year horizon
- Age class model of oak wilt pockets
  - New pockets establish and grow radially
- Number of newly infected trees depends on density of trees
- Data:
  - Oak wilt pockets: MN-DNR Releaf database
  - Oak density:
    - Minnesota Land Cover Classification System (MLCCS)
    - Forest Inventory Analysis (FIA)
  - Removal rates by land cover type

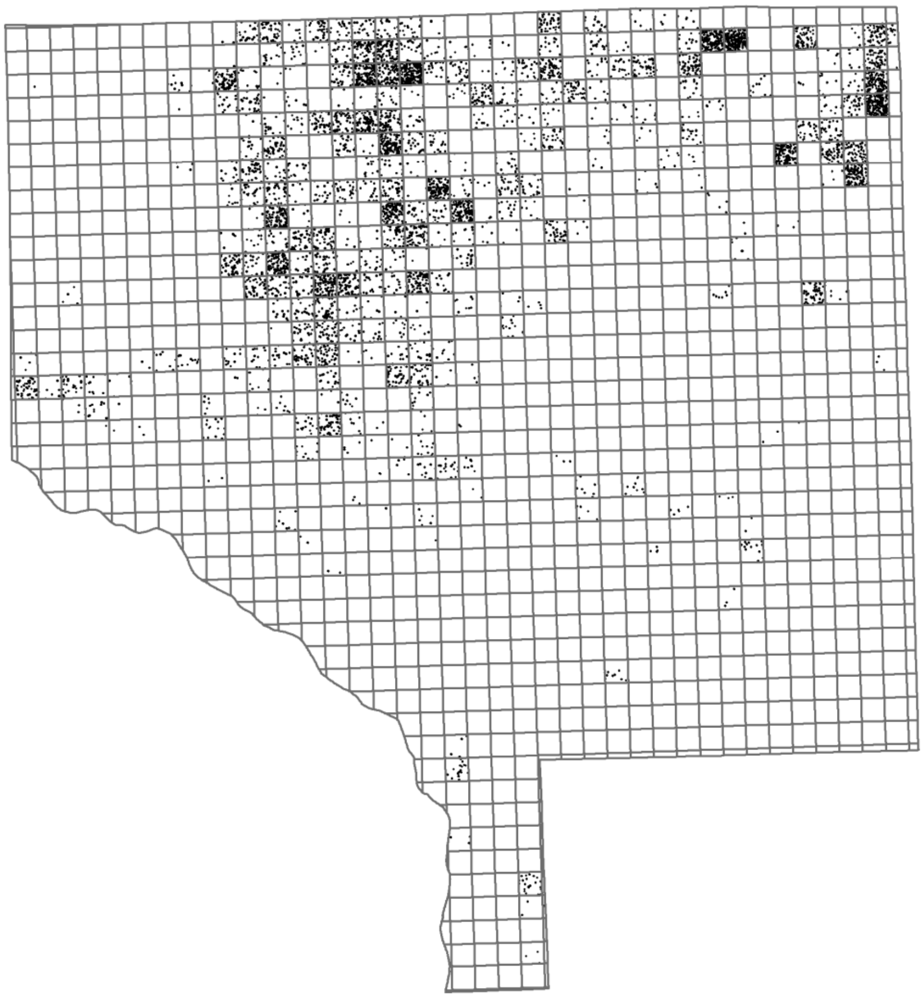
DISTRIBUTION OF INFECTED TREES IN MINNESOTA FROM 2003-2007.



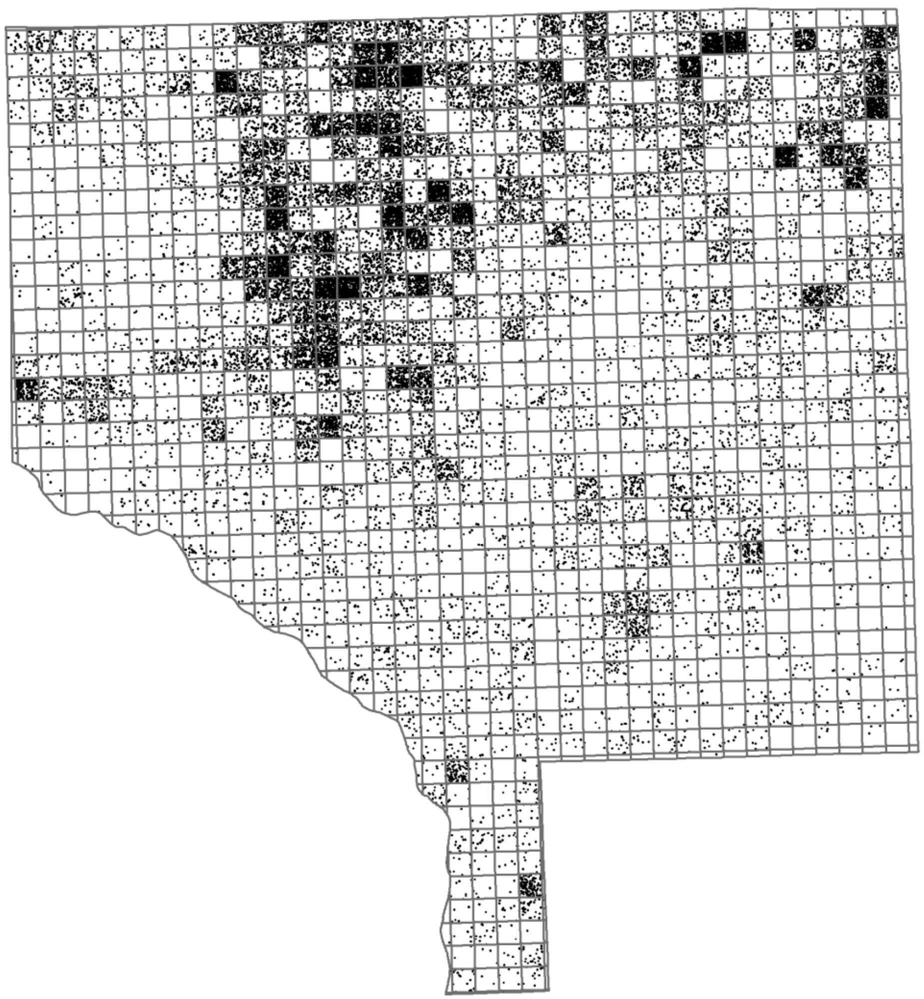
Dot density plot of the initial number of oaks per grid cell



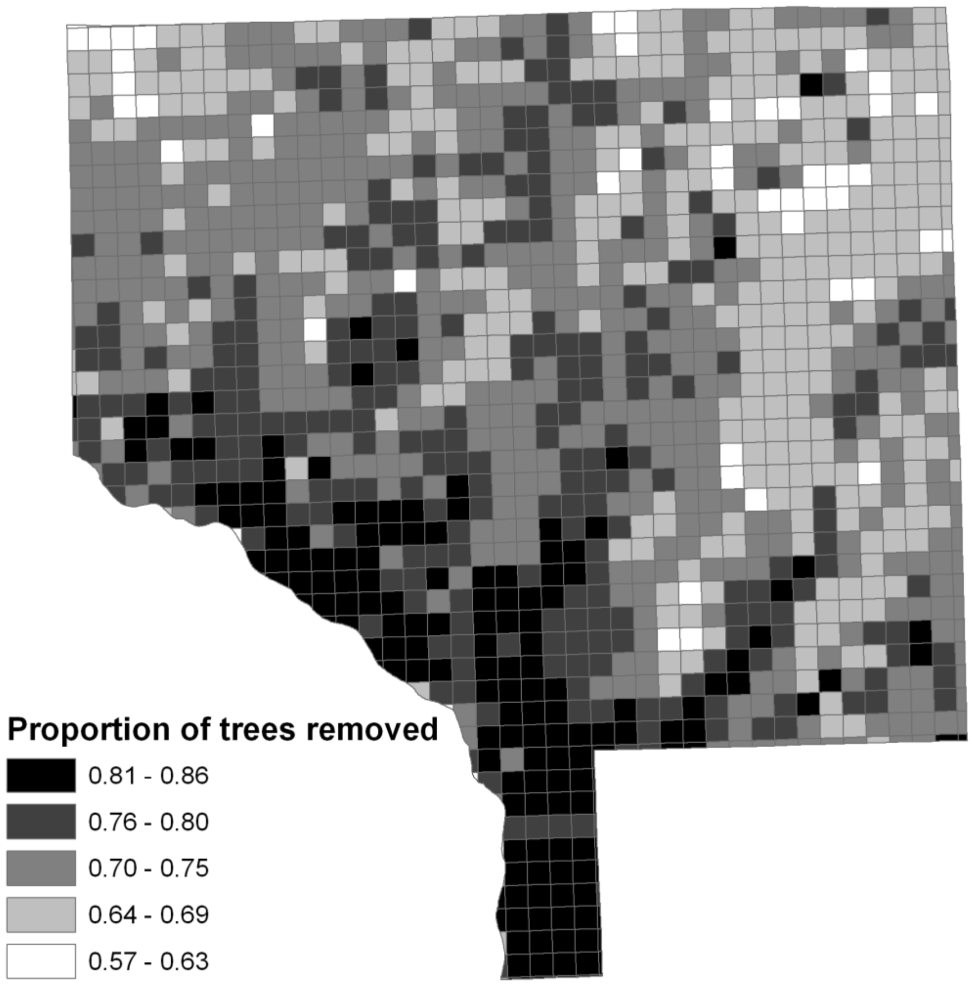
Dot density plot of the initial number of trees infected with oak wilt per grid cell



Dot density plot of the number of trees infected with oak wilt after 10 years per grid cell



Proportion of oak-wilt infected trees likely to be removed



Results

Pocket establishment (pockets h^{-1} yr^{-1})	Pocket radial growth (m yr^{-1}) 2.42	3.47	4.43
	A. Number of trees infected (thousands)		
0.000	76.9	105.6	133.9
0.011	95.7	142.7	193.5
0.015	102.5	156.3	215.0
0.025	119.5	190.0	269.0
	B. Cost of partial removal[b] ($ millions)		
0.000	18.0	24.4	30.6
0.011	22.1	32.4	43.5
0.015	23.5	35.4	48.2
0.025	27.3	42.7	59.9
	C. Cost of complete removal ($ millions)		
0.000	26.0	35.2	44.3
0.011	31.8	46.7	62.7
0.015	33.9	50.9	69.3
0.025	39.2	61.3	86.0

Comments

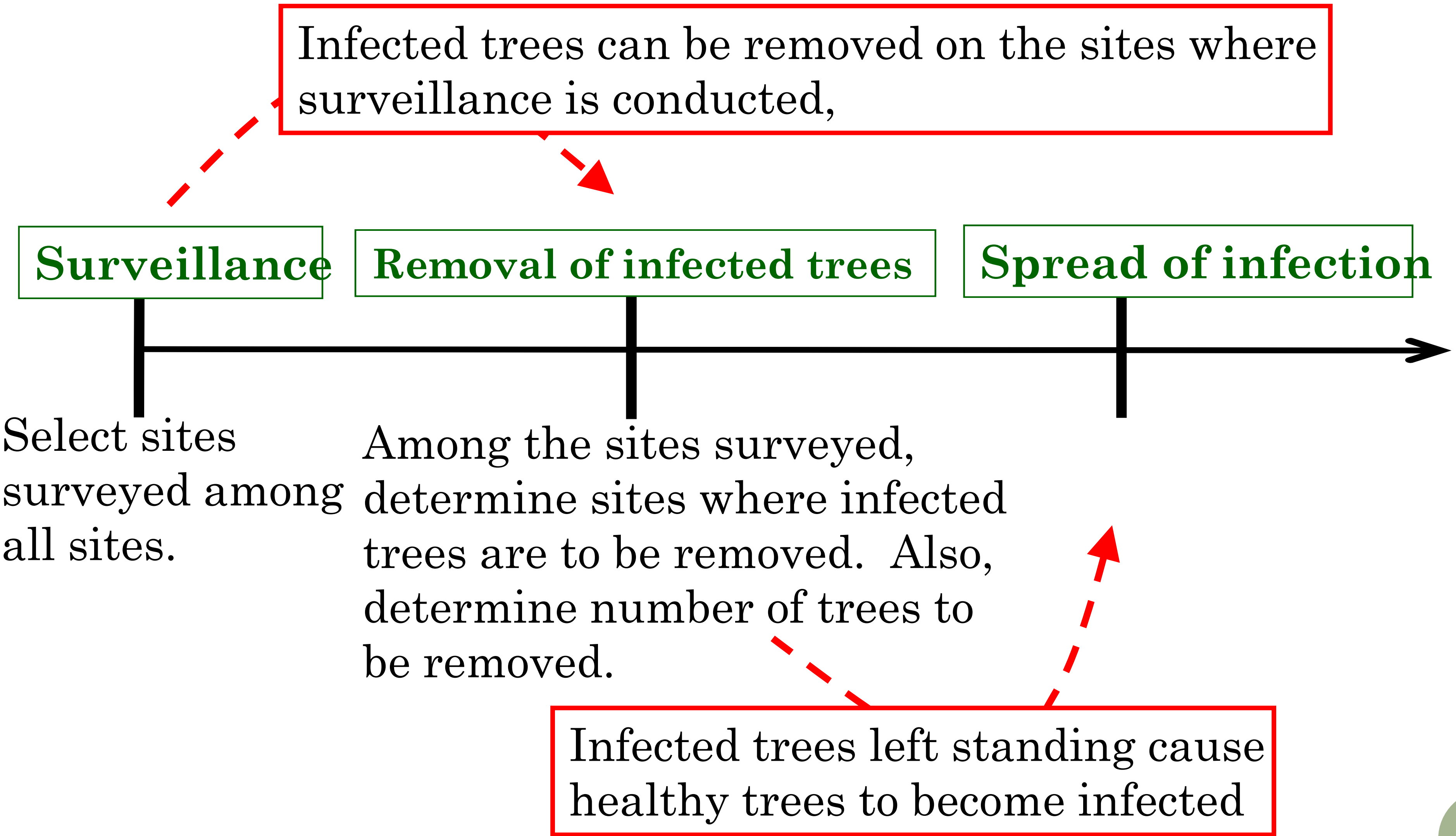
- Conservative estimate of damage costs of oak wilt
  - Just removal costs
  - Partial, not complete, removal of infected trees
  - Per-tree removal cost may be understated in urban landscapes
- Damage costs for base-case parameters still high
  - 5.6 thousand trees infected per year
  - Annual removal cost of $3.5 million for a single county

Management Model

Research Questions:

- What is the optimal spatial allocation of effort to find and control the pest?
- What is optimal allocation of the budget between surveillance and treatment?

Timing of events



Select Sites to survey (X_j) and the number of infected trees to remove (R_j)on the surveyed sites to solve…

$$\min \frac{1}{S}\sum_{s=1}^{S}\sum_{j=1}^{J} Q_j\left(R_j(\theta(s))\right)$$

Minimize the expected number of newly infected trees

Subject to

Infected trees can be removed only at sites where surveillance was conducted

$$0 \le R_j\left(\theta(s)\right) \le X_j\theta_j(s)N_j, \forall j = 1, \cdots, J, \forall s = 1, \cdots, S,$$

$$\textstyle\sum_{j=1}^{J} c_1 X_j N_j + \sum_{j=1}^{J} c_2 R_j(s) \le B, \forall s = 1, \cdots, S,$$

Budget constraint

$$Q_j\left(R_j(\theta(s))\right) = \min\left[\left(1-\theta_j(s)\right)N_j, g\left(\theta_j(s)N_j - R_j(\theta(s))\right)\right],$$

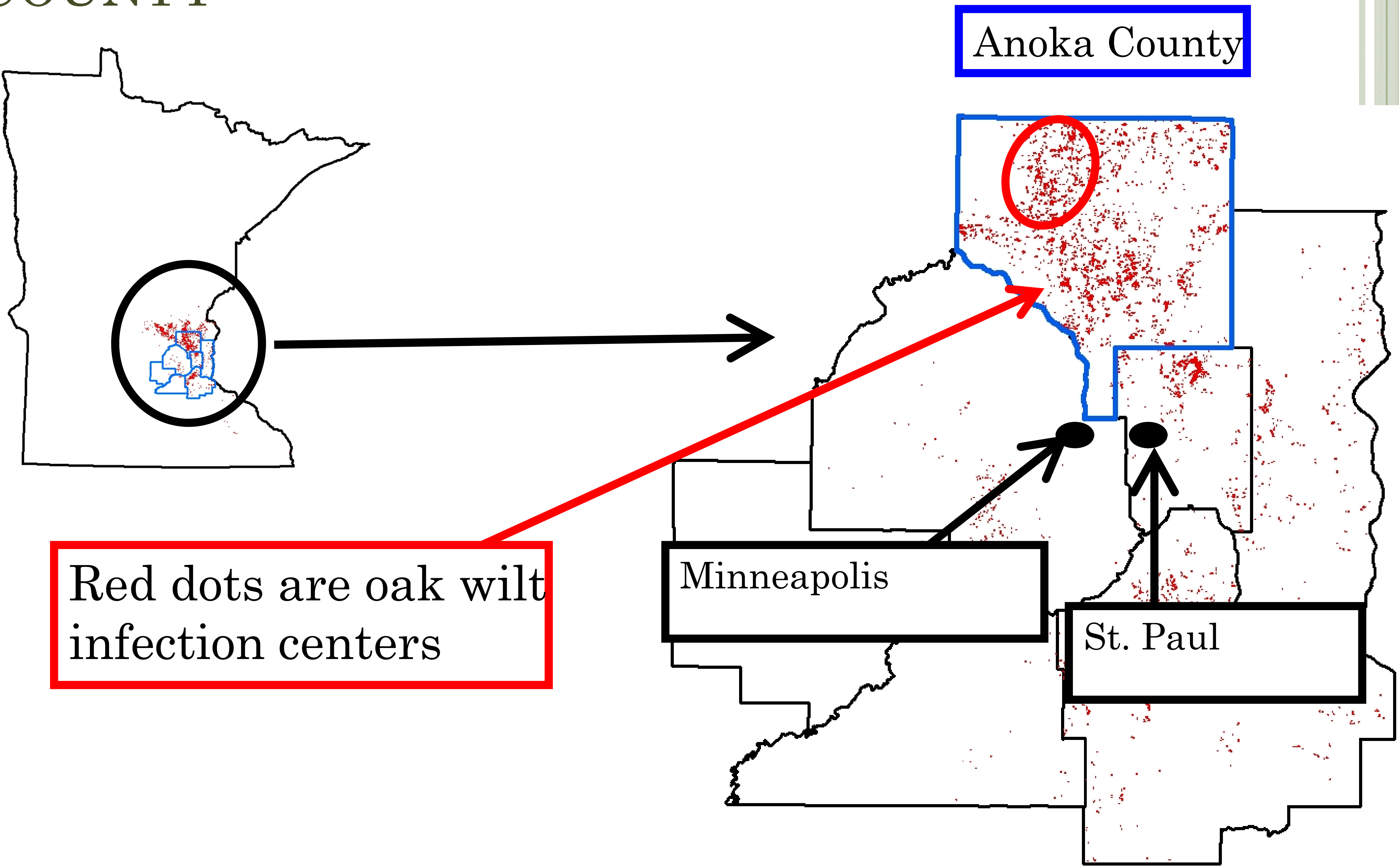
$$\forall j = 1, \cdots, J, \forall s = 1, \cdots, S,$$

Spread of Infection

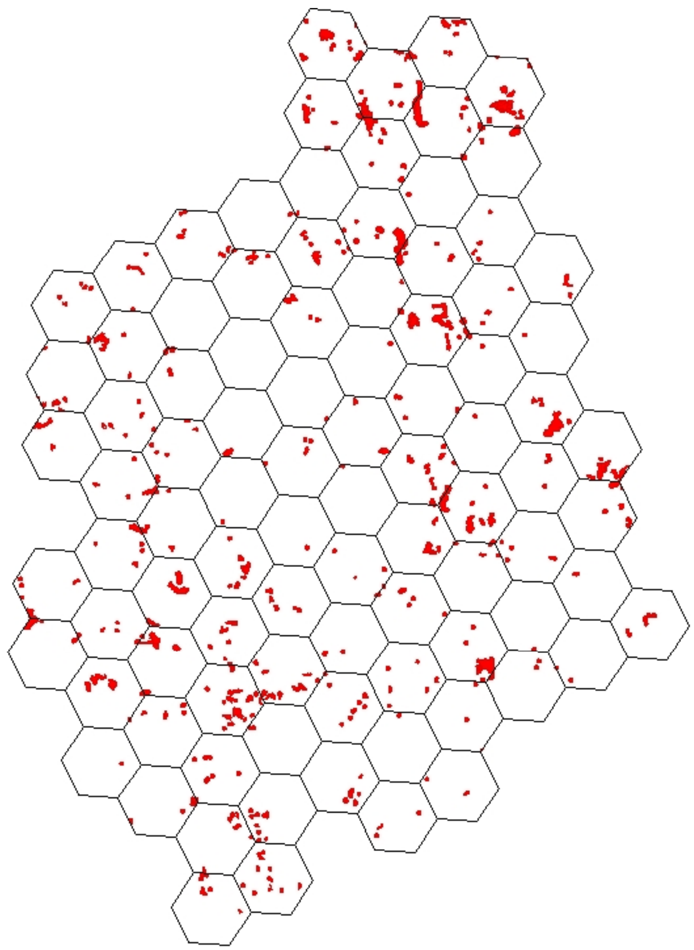
$$X_j \in \{0,1\}, \forall j = 1, \cdots, J.$$

Site selection

FOCUS ON A PART OF NORTHERN ANOKA COUNTY



Selected area in Anoka County is partioned into 90 grid cells



Oak wilt infection
Centers in 2004

Incorporating Uncertainty

1. Generate scenarios

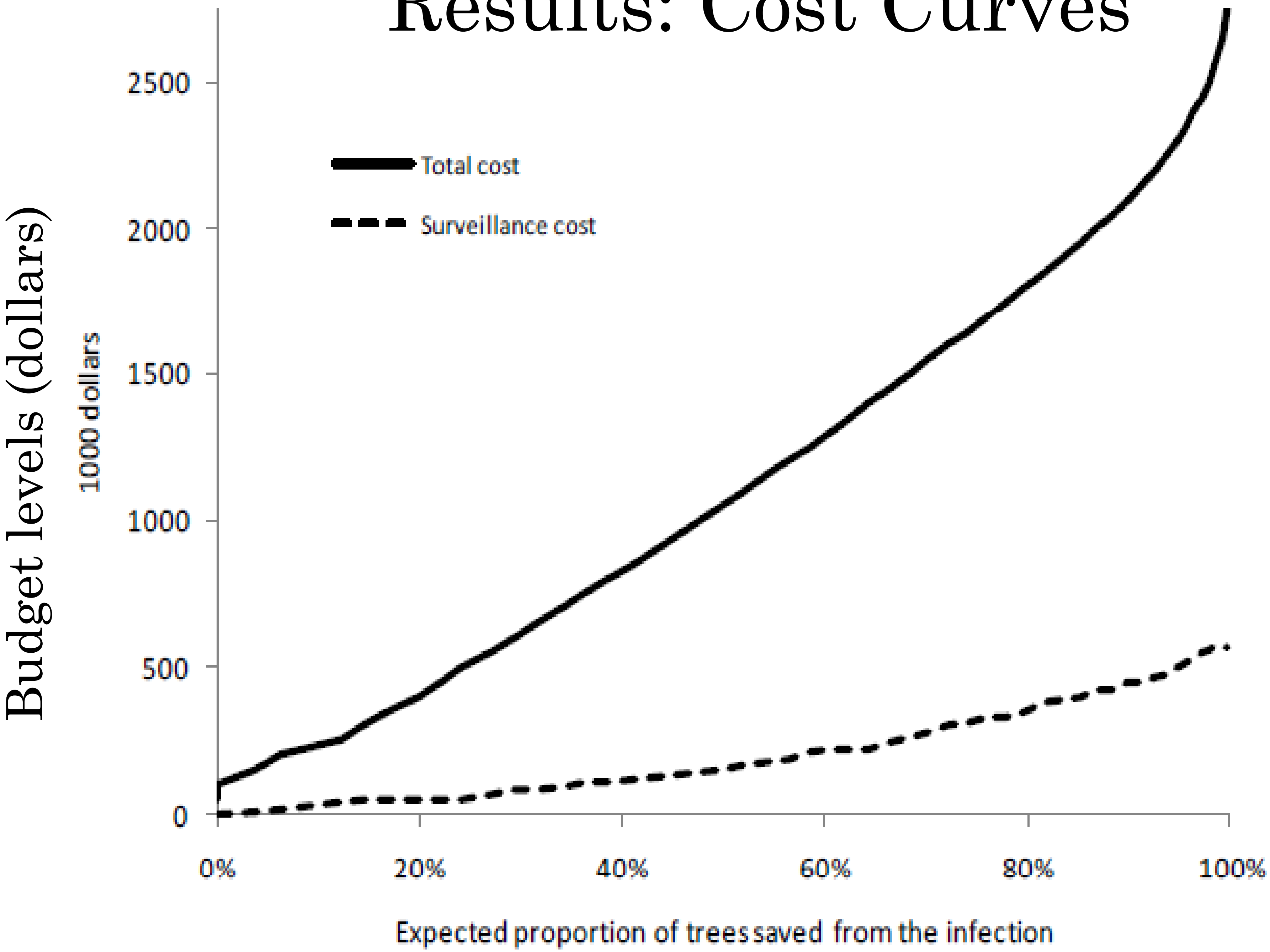
   Use the historical data to create beta distributions of the proportion of infected trees on each site.
2. Draw fractions of infected trees from beta distributions.
3. Assume that those scenarios are equally likely
4. These are scenarios, indexed by *s* in the optimization.

How many scenarios do you need?

The number of sites selected for the surveillanec by the following times within 10 replications	The number of scenarios 100	1000	2000
Low budget level			
Never	51	62	63
Once	9	1	1
Twice	4	0	0
3 times	1	2	1
4 times	2	1	0
5 times	1	1	2
6 times	1	0	0
7 times	2	1	0
8 times	2	0	1
9 times	2	0	0
10 times	15	22	22
Mean of expected numbef of trees saved from infection	69.61	69.39	69.47

Increasing the number of sites which are "Never selected" or "always selected" within 10 replications.

Results: Cost Curves



Characteristics of Sites Surveyed with Priority

Ranking sites by the ratio of the expected number of infected trees to the cost of inspecting every tree on the parcel

$$\frac{N_j \sum_{s=1}^{S} \theta_j(s)}{c_1 N_j}$$

matches the ranking generated by the optimization model well.

Conclusions

- Marginal costs to save healthy trees from infection increases as the targeted percentage of healthy trees increases.
- The proportion of the budget spent on surveillance increases as the targeted percentage of healthy trees increases.
- The ratio of the expected number of infected trees to the cost of inspecting every tree on each parcel generates a ranking similar to the results of the optimization model.
- Generally, site selection models can be fruitfully applied to the invasive species problem when the landscape is heterogeneous.