# Spatio-Temporal Modeling of Asian Citrus Canker Risks: Implication for Indemnification Fund and Insurance Program Premiums

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# Overview

- Increased integration of world markets & international mobility of goods and people
  - heightened concerns regarding harmful invasive species

- Threat is substantial to agriculture & some significant damages have occurred in U.S. agriculture

# Overview…

- Current response has been to provide ***ad hoc*** disaster assistance targeted to specific commodities and/or regions
- An alternative strategy might involve either a ***fund*** or ***insurance program*** to protect producers from risks associated with specific invasive specifies

# Objectives: Two Fold

- Evaluate economic issues in design of voluntary insurance and mandatory check-off programs

- Statistical modeling of the risks associated with an infestation aimed at pricing insurance or determining optimal check-off contribution rates
  - Case study: Asiatic canker in Florida citrus

# Objectives….

- To model contamination risks and expected losses for a ***representative*** producer
- Attention to exogenous factors associated with transmission including
  - important characteristics of land and farms (i.e., proximity to infected areas)
  - weather (i.e., moisture and wind)
  - migrant labor and harvesting crews
- Statistical models explicitly measure spatial patterns of risks and transmission

# Usefulness of this Work

- Should be of interest to state and federal policy-makers currently faced with developing ways to manage these risks
- An indemnification involving insurance or check-off could be independent of government support or partially subsidized
- These "self-help" alternatives recognize that some of the risk should be *internalized* (or borne) by those who have the most to lose and not entirely borne by the taxpayer

# Premium or Check-off Rate Needed to Cover Expected Losses?

- Under both scenarios the key parameter is the appropriate premium or check-off rate that will cover *expected* losses
- Need to develop methods of measuring the risks associated with these losses
- Analogous to deriving measures of the *actuarially fair insurance rate* that would be needed to operate a specific peril program

# Case Study: Citrus Canker in FL

- Large concern to Florida's citrus
  - first found in 1912 and declared eradicated by 1933.
  - discovered again in 1986 (Manatee County) and was declared eradicated in 1994. Re-emerged 3 years later.

- Most recent outbreak in residential citrus trees (Dade County) discovered Sept of 1995
  - initially infected area 36.3 km*2
  - triggered quarantines and destruction of citrus stocks
  - removed or cut back 1.5 million commercial citrus and 600,000 infected or exposed dooryard trees
  - infected area increased to 1,701 km*2 by March 2002
  - state-wide the quarantine area is presently 2590 km*2

- Spatio-temporal aspects of transmission especially interesting for evaluating risk

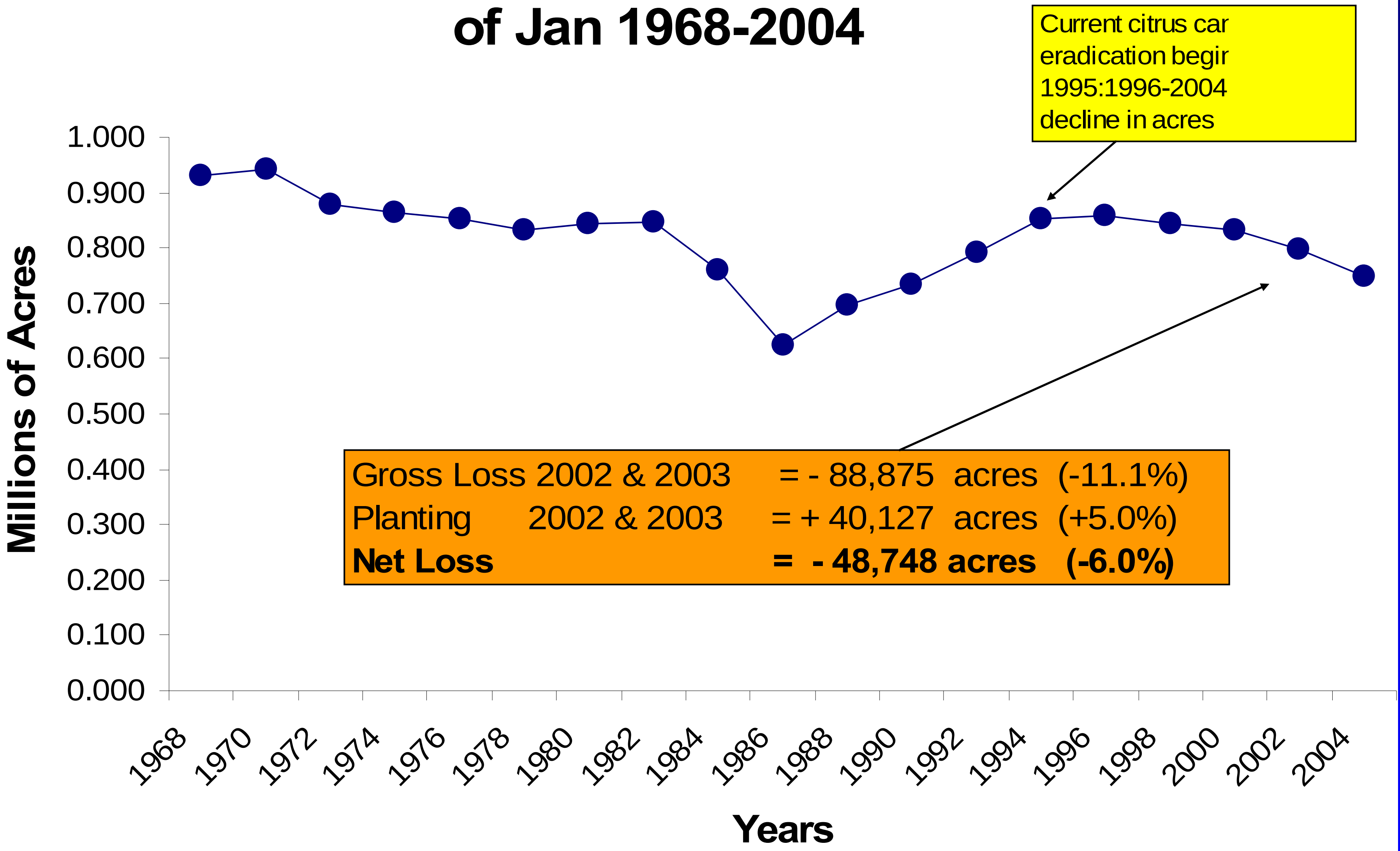
# Citrus Canker

www.doacs.state.fl.us/pi/canker/photos.html

# Citrus Canker

- Most commercial citrus varieties in FL are quite susceptible to citrus canker (especially lime and grapefruit)
- Can cause defoliation and fruit drop
- Remaining fruit are can be unmarketable or much less valuable
- Spring and summer rains combined with wind speeds in excess of 18 mph can greatly increase the spread of canker
- Spread of canker can be also be influenced by the insect's feeding activities which create wounds that expose tissues to splashed inoculums

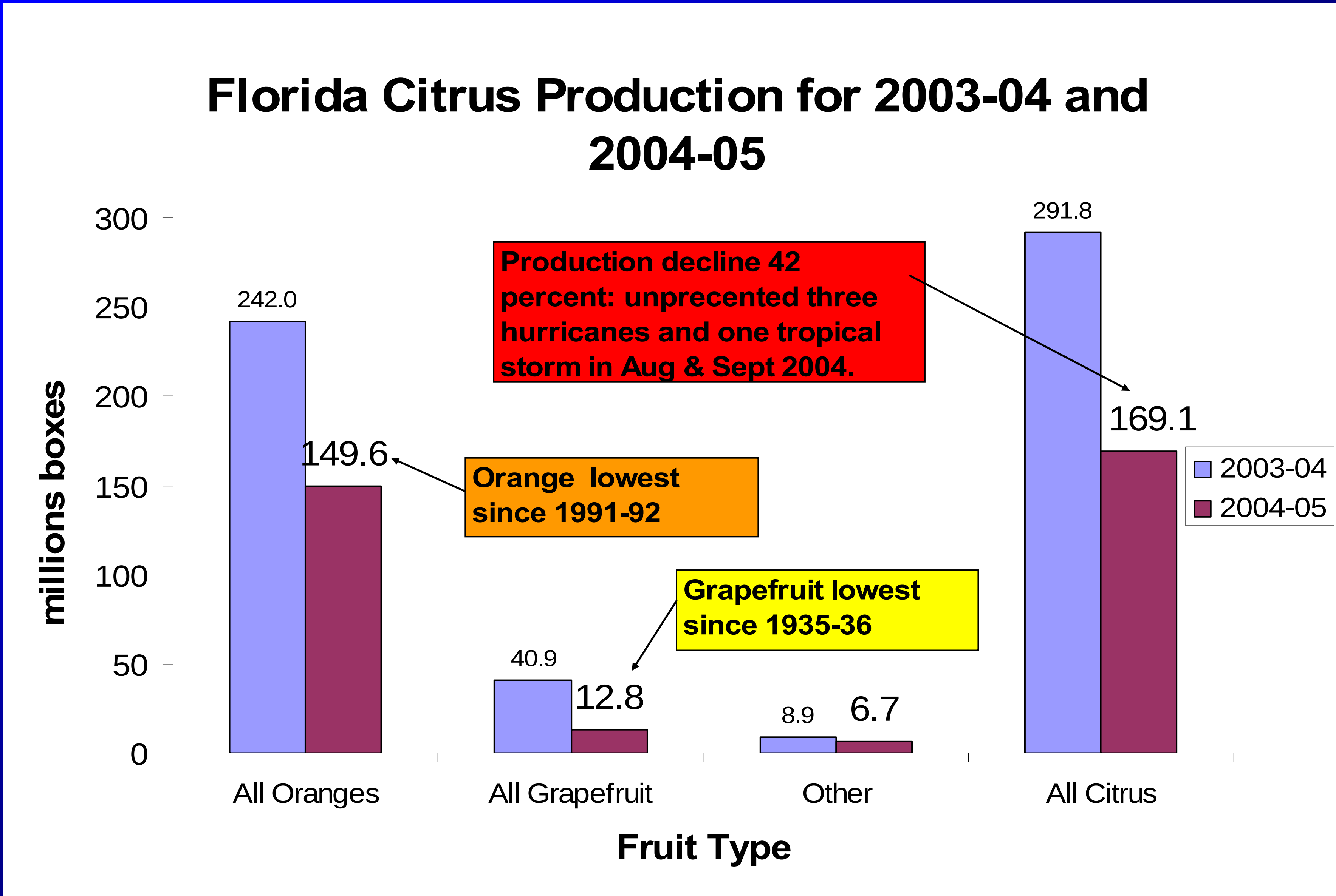
# Florida Citrus: Acres in commercial groves as of Jan 1968-2004

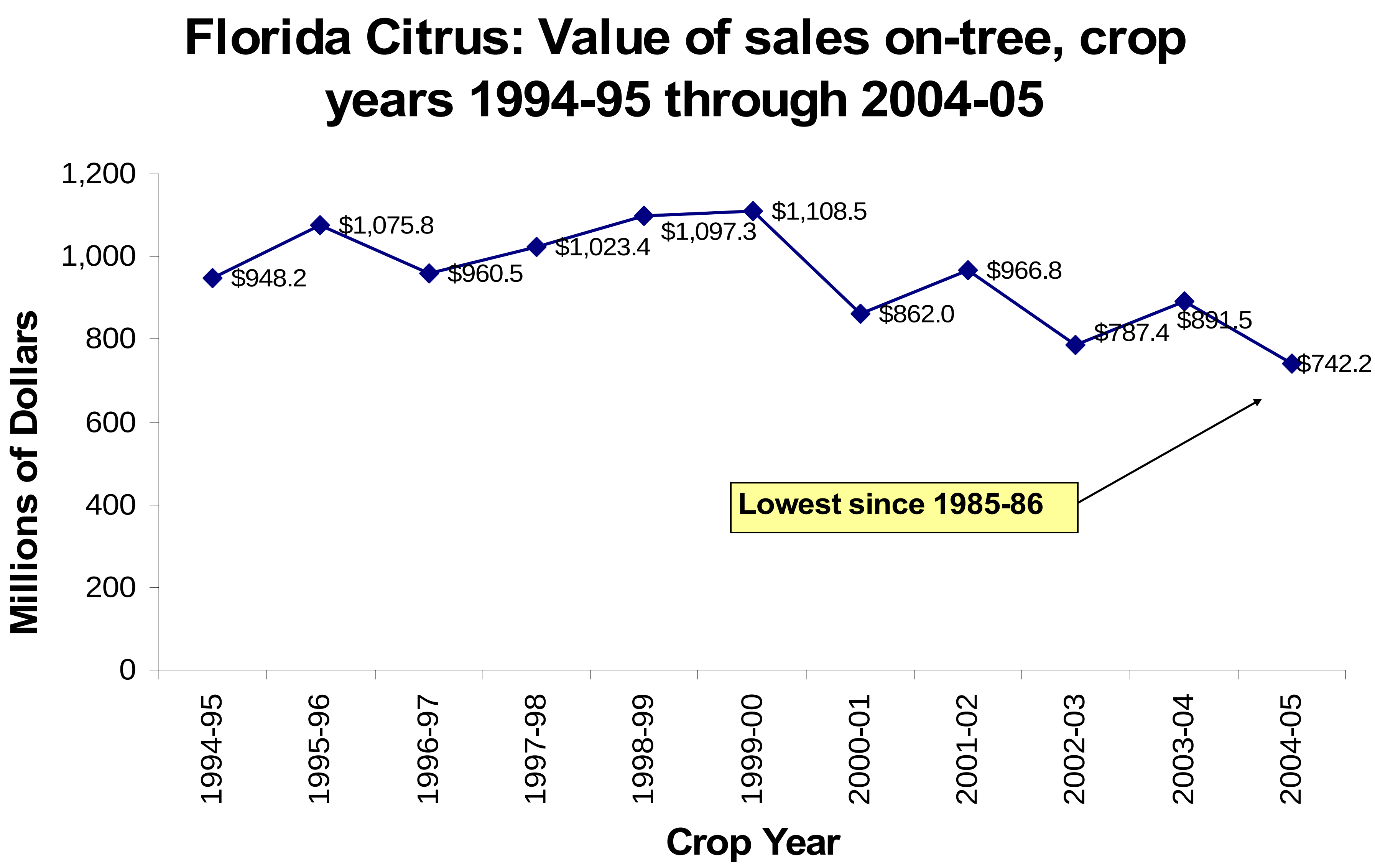


# Citrus Production in Florida

- 291.8 mill. boxes in 2003-04
  - 242.0 mill. boxes of oranges (82.9%)
  - 40.9 mill. boxes of grapefruit (14.0%)
  - 8.9 mill. boxes of other types of fruit (3.1%)

- 748,555 acres of commercial groves in 2004
  - largest growing state in the U.S. accounting for 79% of total U.S. production


Florida Citrus Production for 2003-04 and 2004-05
millions boxes
300
250
200
150
100
50
0
242.0
149.6
40.9
12.8
8.9
6.7
291.8
169.1
Production decline 42 percent: unprecented three hurricanes and one tropical storm in Aug & Sept 2004.
Orange lowest since 1991-92
Grapefruit lowest since 1935-36
2003-04
2004-05
All Oranges
All Grapefruit
Other
All Citrus
Fruit Type




Source: 2003-04 Citrus Summary, FL Agricultural Statistics Service; Florida Citrus 2004-05 Summary USDA-NASS

# Existing Government Programs: Production and Tree Replacement

## [$4,963-$10,507 per acre]

Table 1: Lost Production Payment and Tree Replacement by Variety

| Citrus Varieties | Lost Production Payment[a] [a] | Max. Tree Replacement[b] [b] | Combined [a]+[b] |
|---|---|---|---|
| | | *Dollars Per Acre* | |
| Limes | 6,503 | 4,004 | 10,507 |
| Orange, valencia, and tangerine | 6,446 | 3,198 | 9,644 |
| Orange, navel* | 6,384 | 3,068 | 9,452 |
| Grapefruit | 3,342 | 2,704 | 6,046 |
| Other mixed citrus | 3,342 | 2,704 | 6,046 |
| Tangelos | 1,989 | 2,964 | 4,953 |

Source: USDA-APHIS (2002)

*Includes early and midseason oranges

a. Per acre loss in the net present value; Tree replacement cost has been deducted; Per-acre income is determined by yield per tree (# boxes) multplied by the price of a box less production costs per tree; the cash flow per tree is multiplied by the number of trees to determine per-acre net income.

b. Based on up to a $26 per tree allowance; Per acre caps were calculated by $26 times the varietal average number of trees per acre; The $26 per tree allowance covers land preparation, replacement tree, labor for planting, and maintence until the tree become productive.

# Scientific Work

- Epidemiology of citrus canker involves bacteria spreading from lesions during wet weather
  - –short distances by splash
  - –medium-long distances by windblown rain,
  - –all ranges by humans (Graham et. al. 2004)

- Tissue age and temperatures are significant determinants in disease development (Verniere, Gottwald, and Pruvost 2003)

- Disease can spread from 12 to 3,474 meters in a period of 30 days. Rapid spread across a region with wind followed by a filling in of disease on remaining infected susceptible trees over time with less intense rains (Gottwald et. al. 2002)

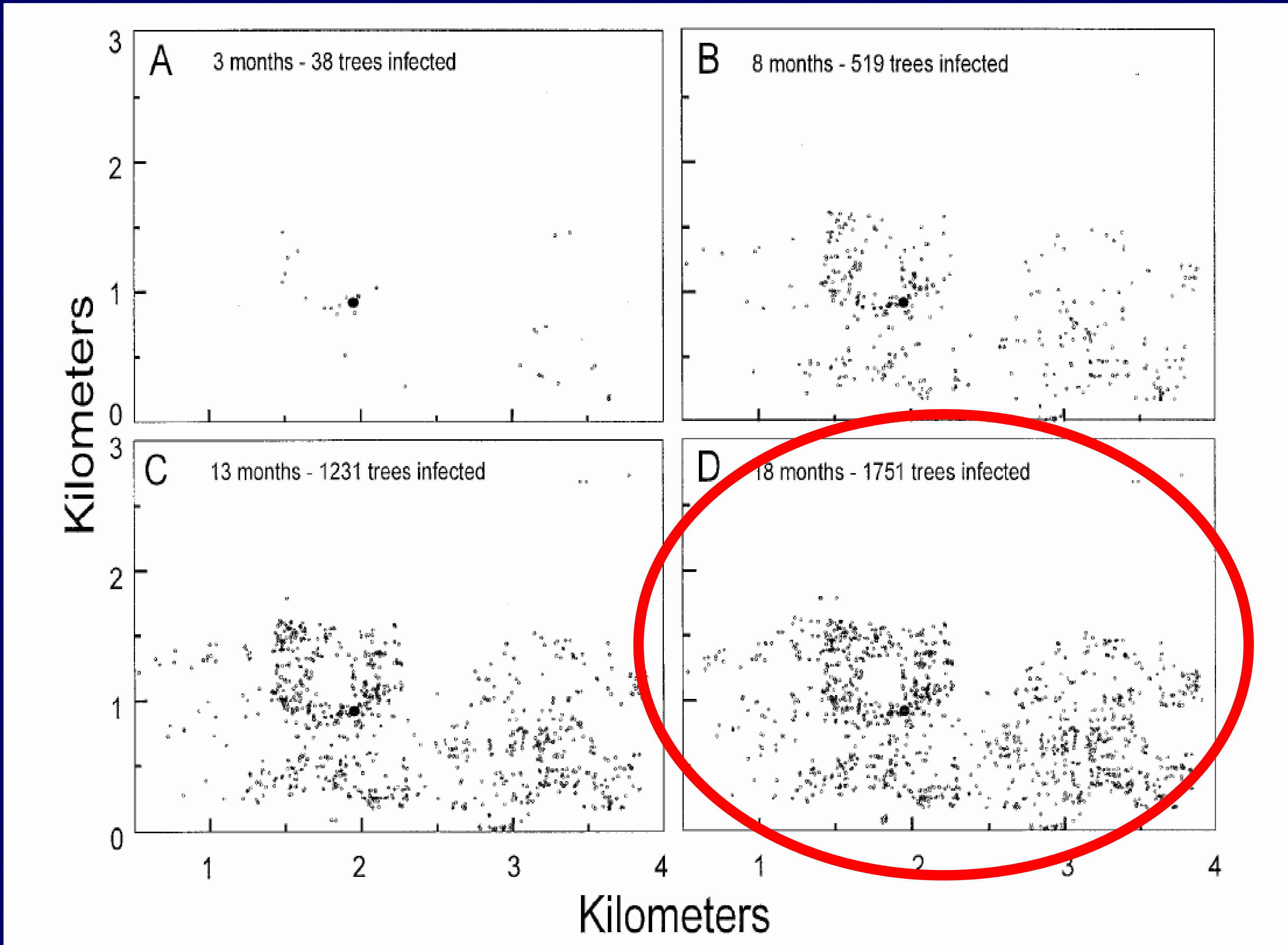
# Initial scientific approach to 1995 infestation

- Based on evidence from Argentina data mandated removal and destruction of trees within a *125 foot radius*
  - ineffective and disease continued to spread
- Gottwald et. al. (2001) spelled out 3 specific reasons calling into question this rule:
  - Spread in early 1990's more than 2,600 ft
  - Catastrophic weather has been documented to spread bacterium 7 miles
  - Failed to reduce the progress

# Epidemiological investigation of dispersal in subtropical urban Miami setting

- Revealed how contagious this disease can be with a single infected tree spreading to 1,751 trees infected over 18 months in a region of 12 square kilometers (3km by 4 km)

- Gottwald et. al (2001) reports the investigation
  - –lasted 18 months
  - –involved 19,000 healthy and diseased dooryard citrus
  - –four areas accounting for 10 miles



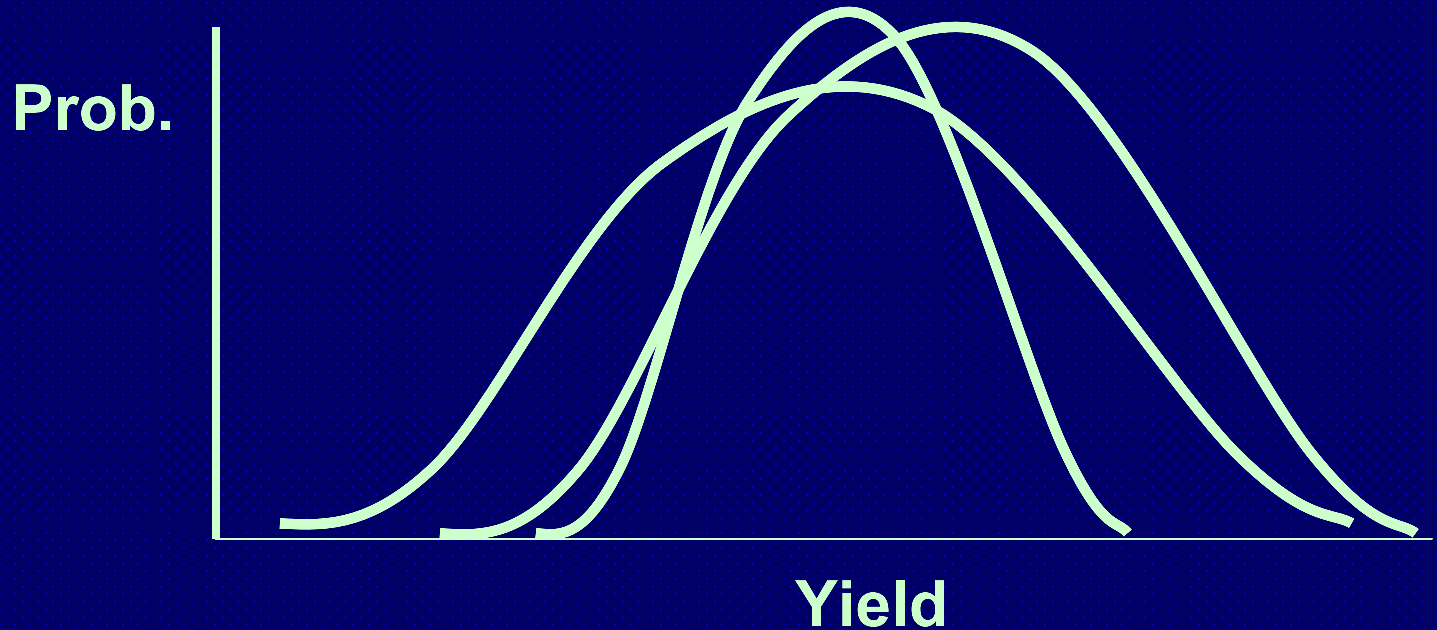

**Source: Gottwald et. al. (2001)**

# Modified Eradication Program

- February 2000 the Florida  Commission Agriculture announced the implementation of a more stringent eradication program to go into effect April 1, 2000
  - removal of all trees within a *1900 feet radius* of infection
  - decontamination of works and equipment moving between groves
  - $100 voucher for residents
  - public relation program

# Research Methods

- Measuring the risk requires measuring the ***conditional* probability density** underlying risks (e.g., yield losses due to the specific peril under consideration)



# Indemnities & Costs

- For a program that reimburses producers for outcomes ($y$) that are less than a certain proportion ($\lambda$) of the expected value (mean) ($\mu$)

$$\text{Indemnities} = p\,(\max\{(\lambda\mu - y), 0\})$$

$p$ the price at which losses are compensated

# Premium or Check-off Rate

- Insurance program or check-off requires a premium or mandated contribution rate determined by *expected payouts*

- For price=1, expected loss is given by

$$E(L)=Prob(y<\lambda\mu)[\lambda\mu-E(y|y<\lambda\mu)]$$

# Premium or Check-off Rate

- E(Loss) = Pr(loss)*(Loss|Loss Occurs)

- Define *F(.)* and *f(.)* to be the cumulative probability distribution functions (cdf) and the probability density function (pdf) and the premium or check of rate (*R*) can be shown to be equal to

$$E(Loss) = \int_0^{\lambda\mu} f(y)dy \bullet \left[ \lambda\mu - \frac{\int_0^{\lambda\mu} f(y)ydy}{\int_0^{\lambda\mu} f(y)dy} \right]$$

$$= F(\lambda\mu) \bullet \left[ \lambda\mu - \frac{\int_0^{\lambda\mu} f(y)ydy}{F(\lambda\mu)} \right]$$

$$R = \frac{E(Loss)}{\lambda\mu}$$

# In Bond-Type Program:

- All-or-nothing indemnity– simplifies the problem somewhat
- Appropriate for canker in that any exposure means total loss

E(Loss) = Pr(loss)*Payment

where Payment = Fixed amount paid if exposed

# Challenging Modeling Questions

- What is the appropriate form of the distribution [f(y)]?
- Are parametric densities appropriate or are less restrictive techniques preferred?
- What factors should the distribution be conditioned on?
- What are the spatial-temporal relationships associated with the invasive species?

# Model to Estimate the Density Functions in a Localized Area

Localized Probability Density Functions $\mathrm{f}(y_i)$

$$f(y_{i,t}) = f(y_{i,t} \mid y_{i,t-k}, y_{j,t-k}, \boldsymbol{\theta}) + \varepsilon_{i,t}$$

*where*

$i = 1, \ 2, \ldots\ldots N (localized\ square\ blocks)$

$t = 1, \ 2, \ \ldots\ldots T \ (periods)$

$\boldsymbol{\theta}$ = vector of exogenous factors

$\varepsilon_{i,t}$ = error term

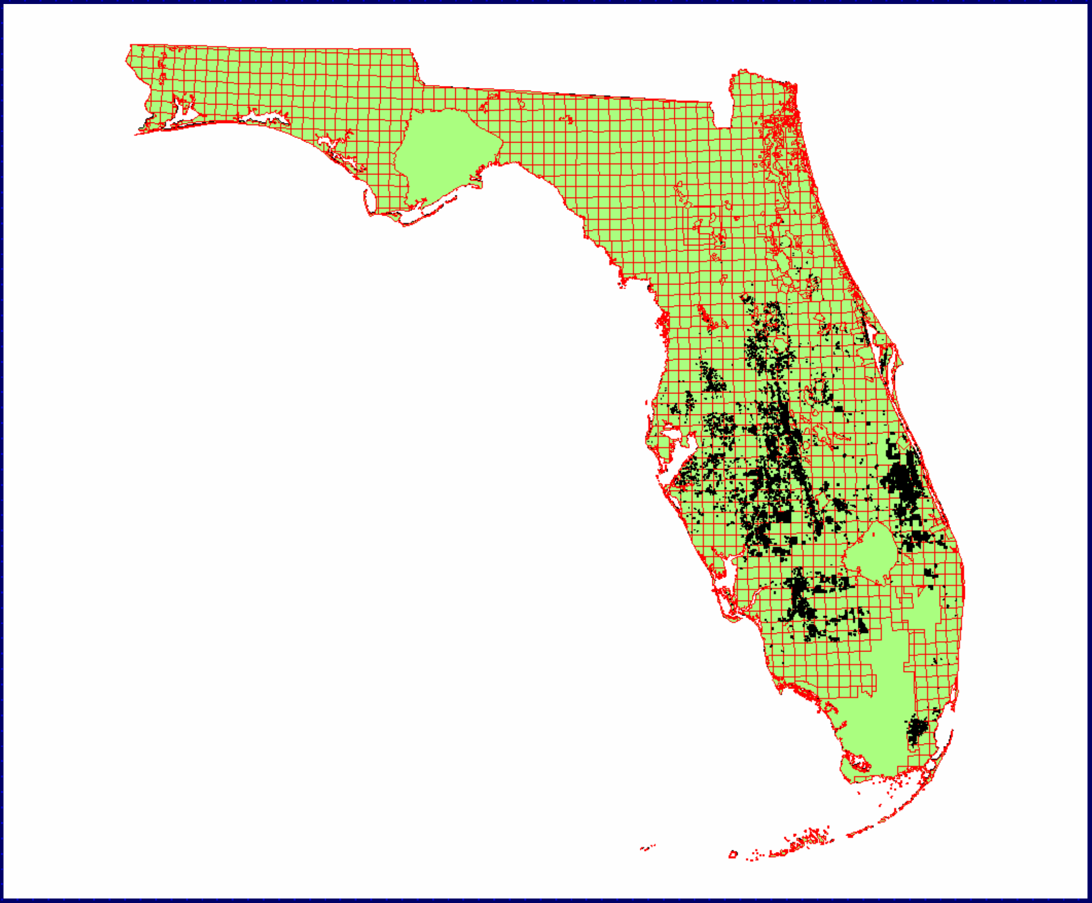
# Florida Survey Data

- Florida has "Citrus Canker Eradication Program"
- Unit of inspection = commercial "multiblock"– a geographic unit (grove)– averages 16 acres
- Involves periodic inspections (average of 1.3 times per year, min=1, max=24).
- We consider 338,226 inspections over the 1998-2005 period (2005 dropped for now)

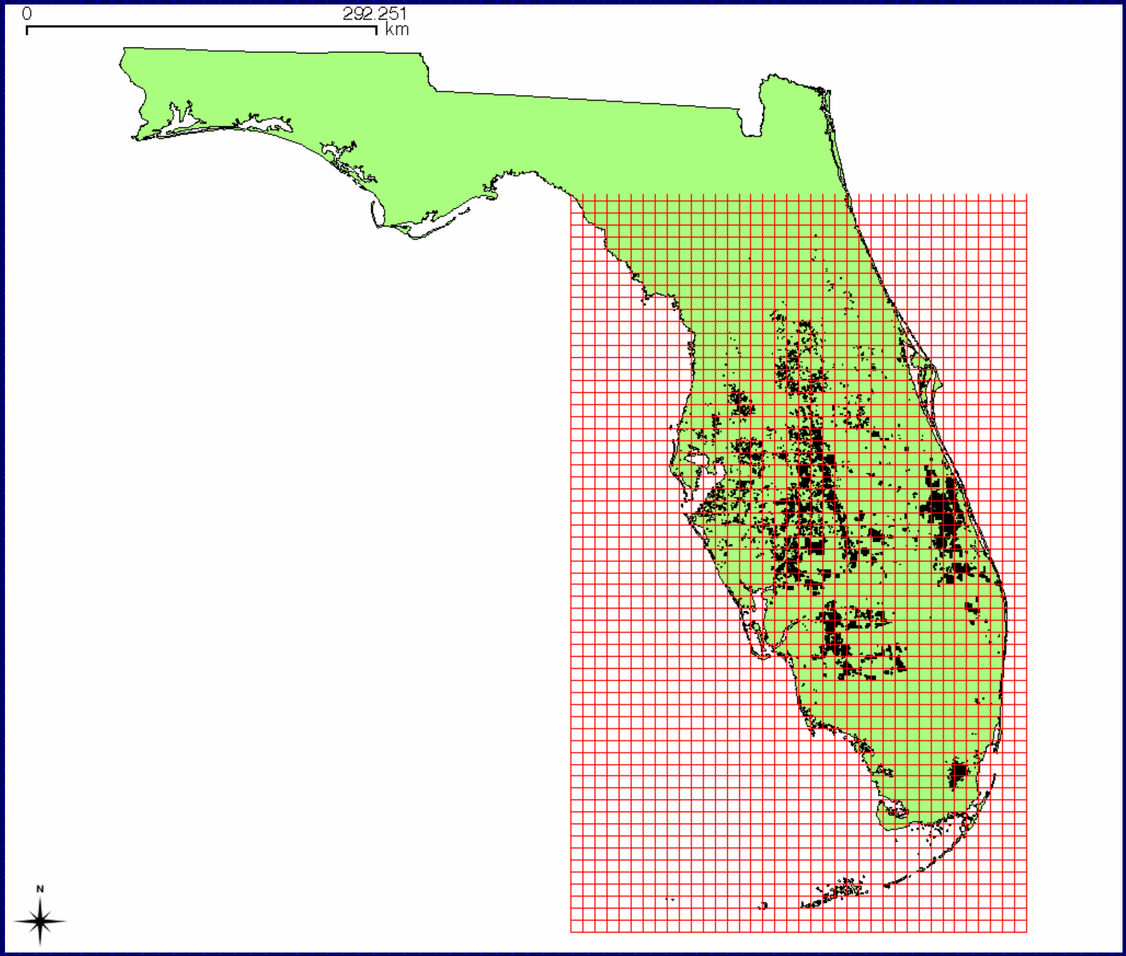
# Operational Considerations

- What is the unit of insurance?
  - Multiblock (volatile rates)
  - Some level of aggregation (define units of homogenous risk) *
- How do we measure risk?
  - Consider only the histories of actual exposures (may ignore information)
  - Consider conditioning variables that may add information*

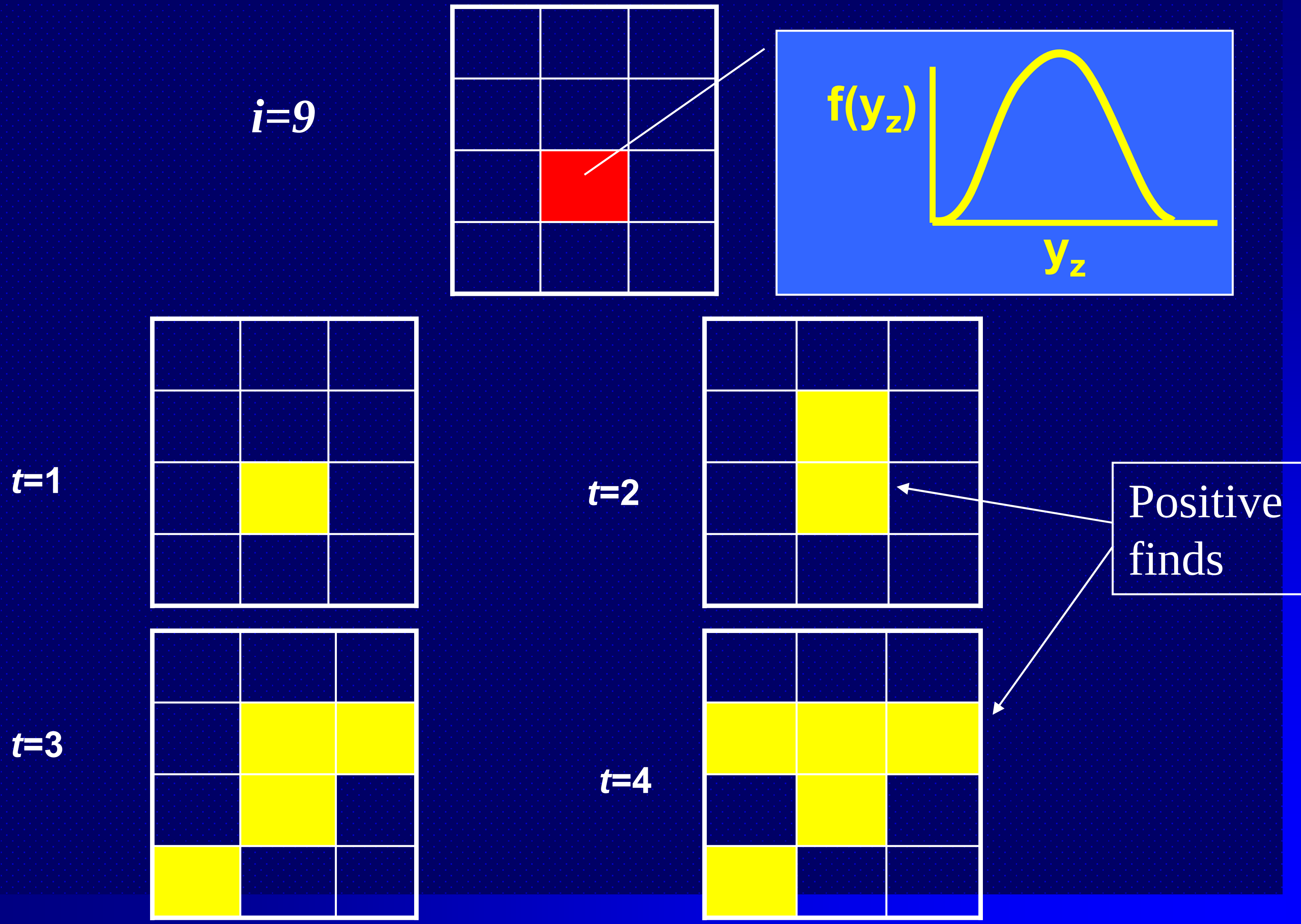
# Possible Aggregations: TRS



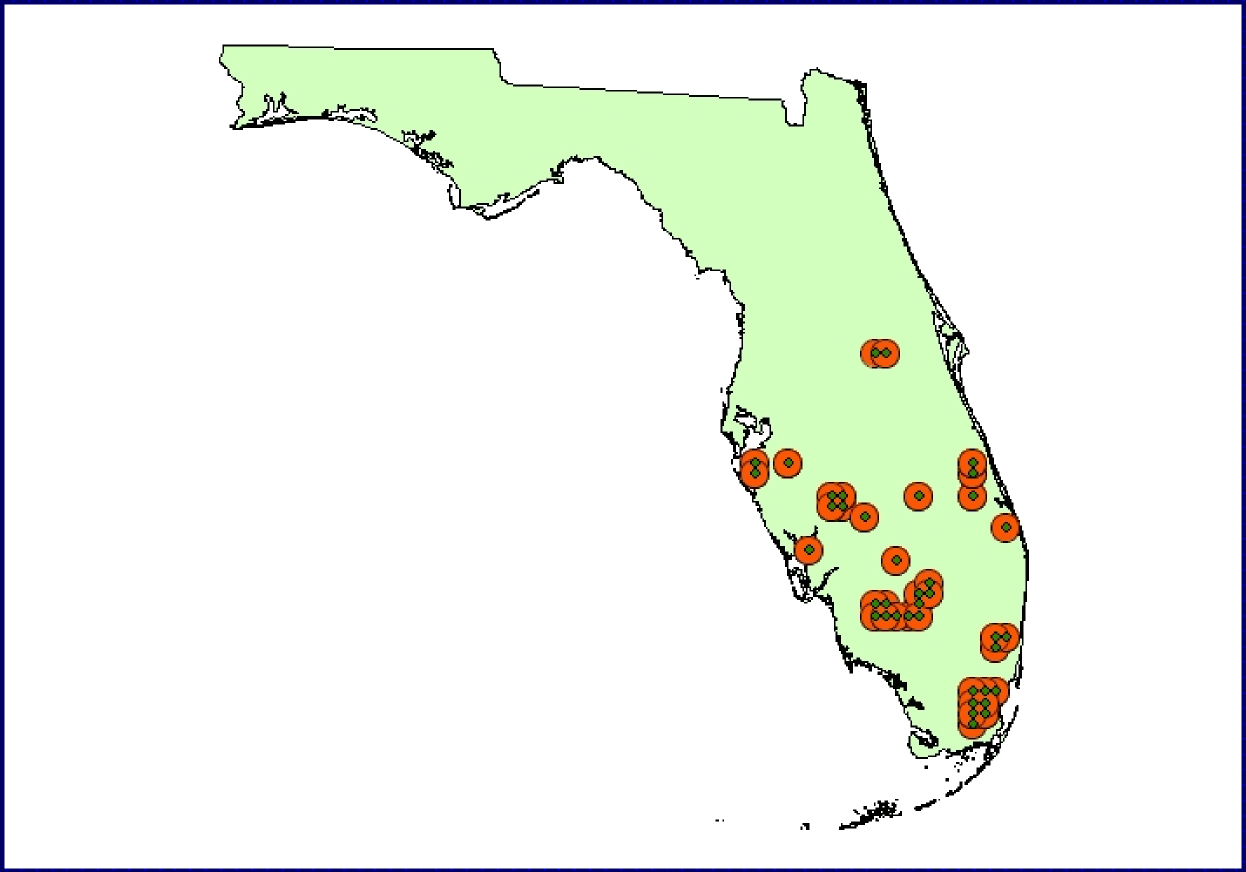
# A Rectangular Grid (10km$^2$)



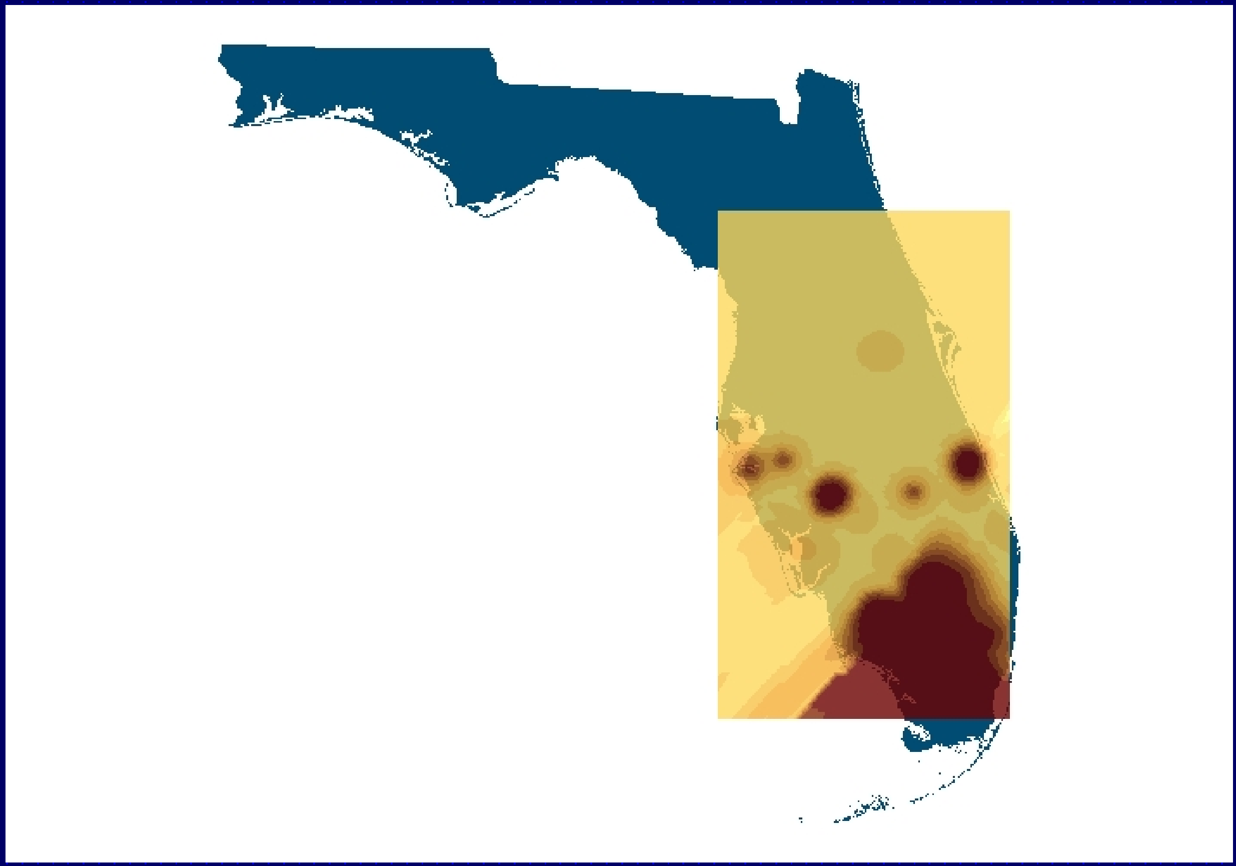
# Spatio-Temporal Impacts of $y_{i,t}$



# Positive Finds



# Kriging Probabilities From Actual Counts



# Alternative: Use Risk Models

- Two approaches:
  - –Binary (probit) model of exposure
  - –Count data model (Poisson) of number of exposures
- Two measures:
  - –Number of positive finds
  - –Number of positive multiblocks (any positive find over past 2 years)

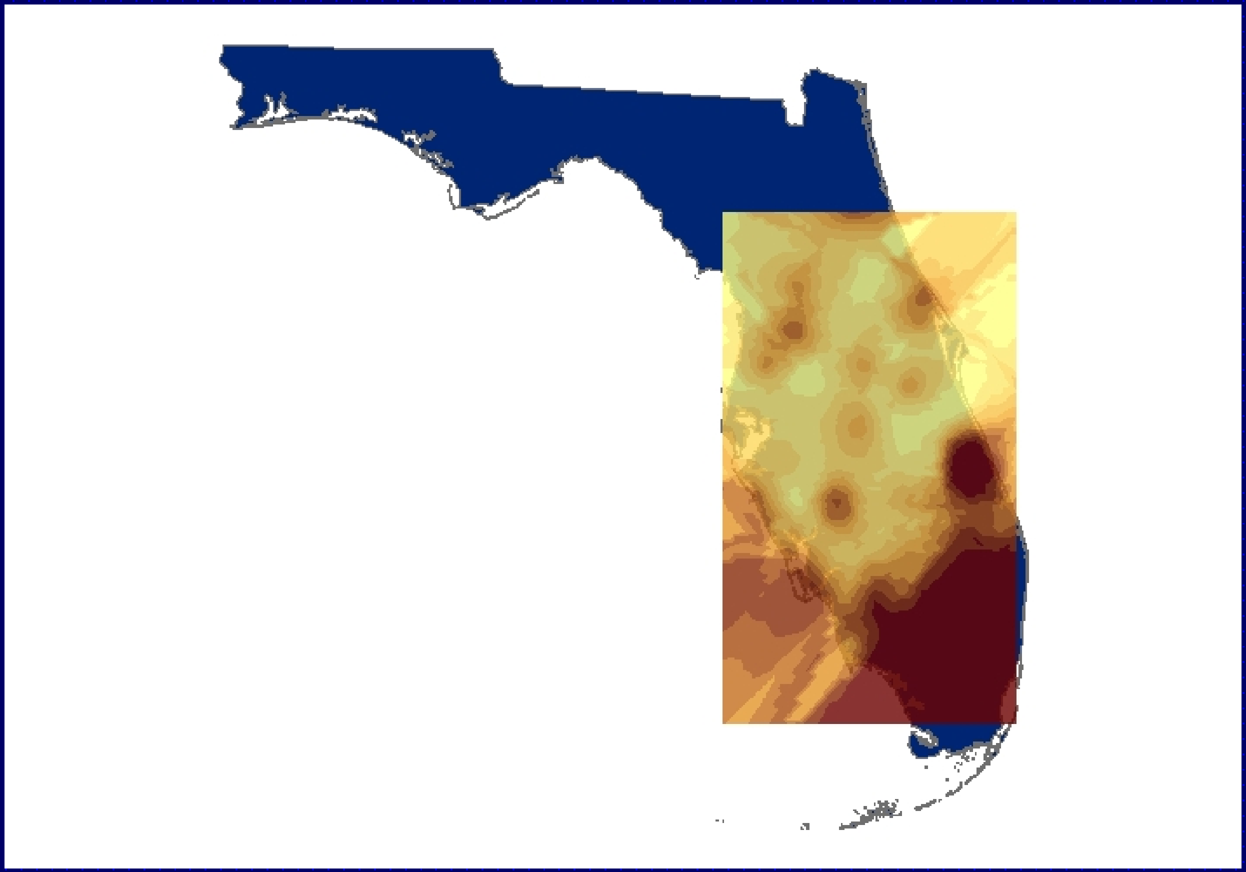
# Conditioning Variables

- Makeup of the grove
  - Some fruits much more vulnerable
  - Limes=>Lemons=>Grapefruits=>Oranges
- Unused area (a buffer?)
- Acreage of fruit (increases risk)
- Status of neighbors in t-1
  - We consider sum of positives for all units with centroids within 30 km radius

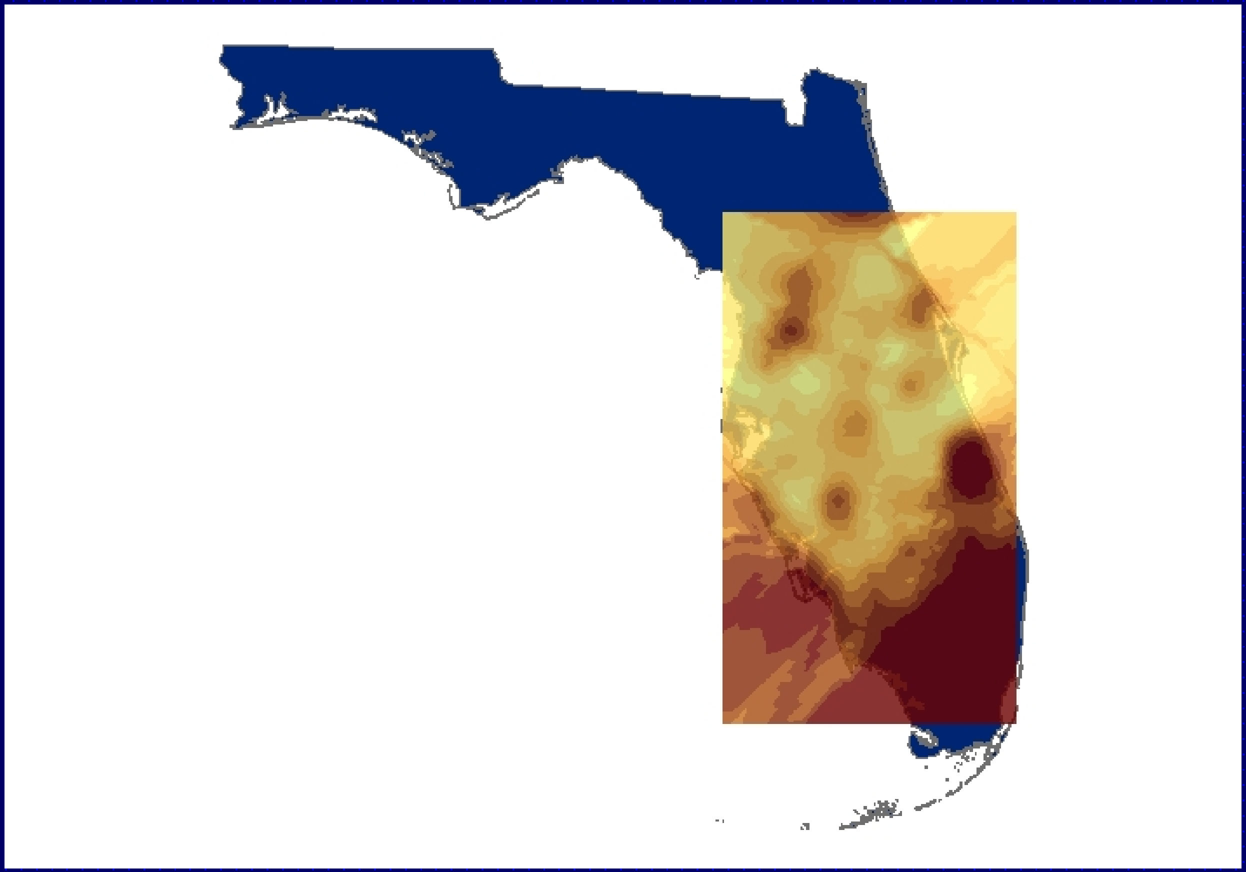
# Model Results:

- Varieties have major influence on probability--risk runs (riskiest to least risky)
  - "Other Fruits" (residual category), Grapefruits, Tangerines, and Oranges
  - Larger groves more susceptible
- Spatio-temporal effect significant– positive neighbors raises risks
- Effects largely similar across alternative models

# Probit Predicted Probability Surface



# Poisson Probability (1-Pr(y=0)) Surface



# Insurance Parameters

- Premium Rate = $Pr(y \geq 0) * Pr(unit=1 | y \geq 0)$
- Models give us $Pr(y \geq 0)$
- We need $Pr(unit=1 | y \geq 0)$
  - We use simple empirical probability– average proportion of positive multiblocks in positive units (this will be refined)
- For positives $Pr(unit=1 | y \geq 0) = .0776$
- For positive finds $Pr(unit=1 | y \geq 0) = .0519$

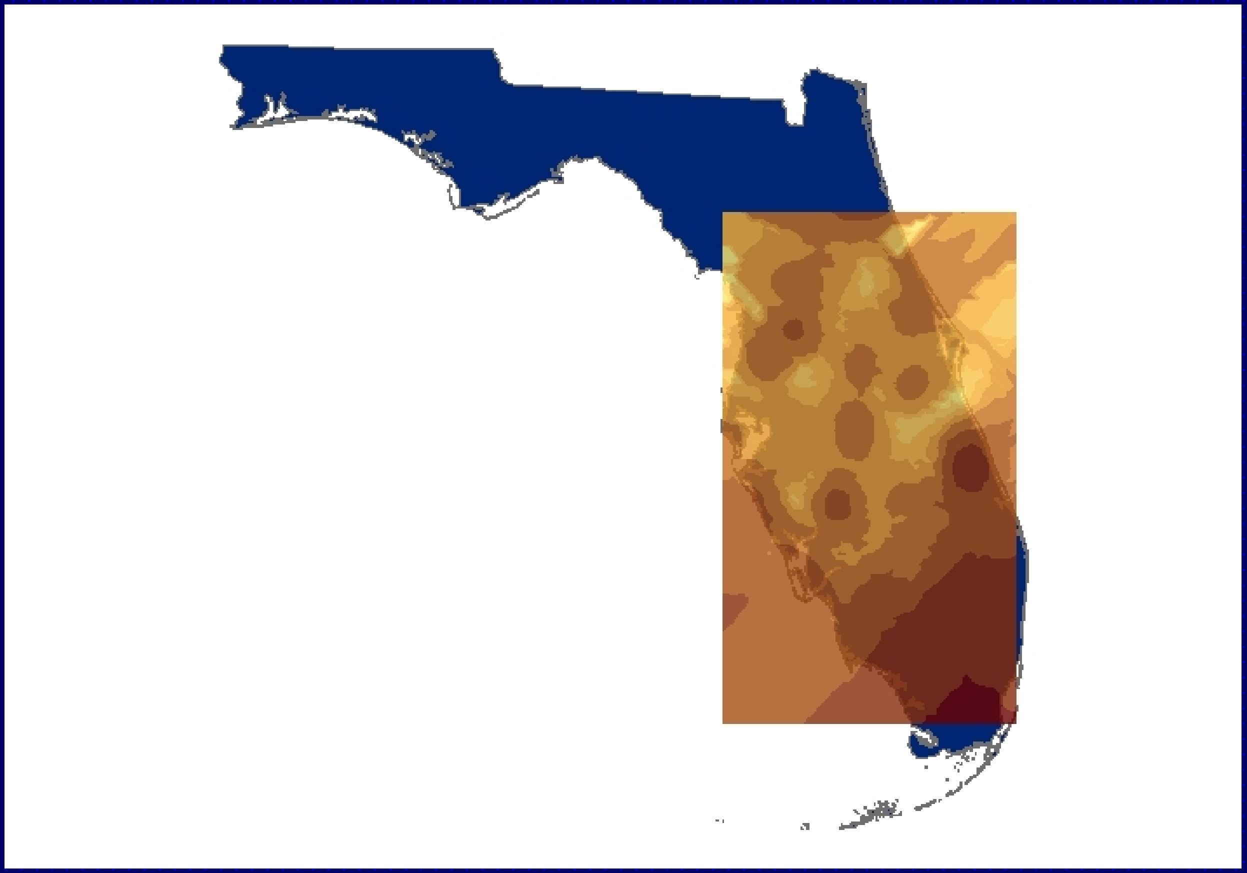
# Insurance Parameters

- For bond value = $B, premium should be:
- Rate * $B
- Risk is exogenous to bond value—that is, without moral hazard (if value too high, insureds may cheat and change probability)
- Our evaluations suggest approximate NPV of an acre of stock and foregone production is about $10,000

# Premiums ($/acre)

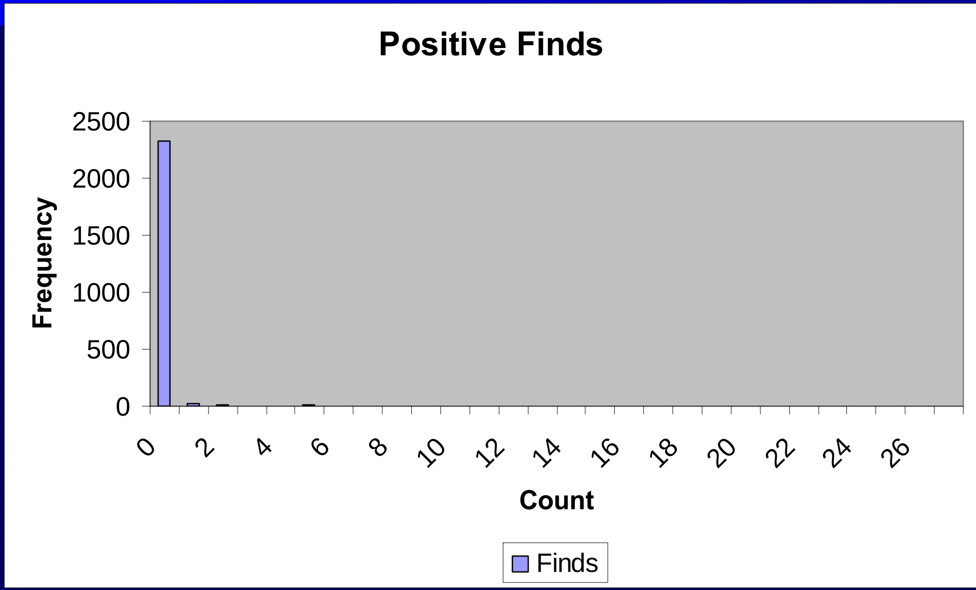
| Model | Average | Std. Dev. | Min | Max |
|---|---|---|---|---|
| Probit | $44.53 | $62.67 | $10.43 | $746.22 |
| Poisson | $229.63 | $176.68 | $38.74 | $776.00 |

# Spatial Variability of Premiums

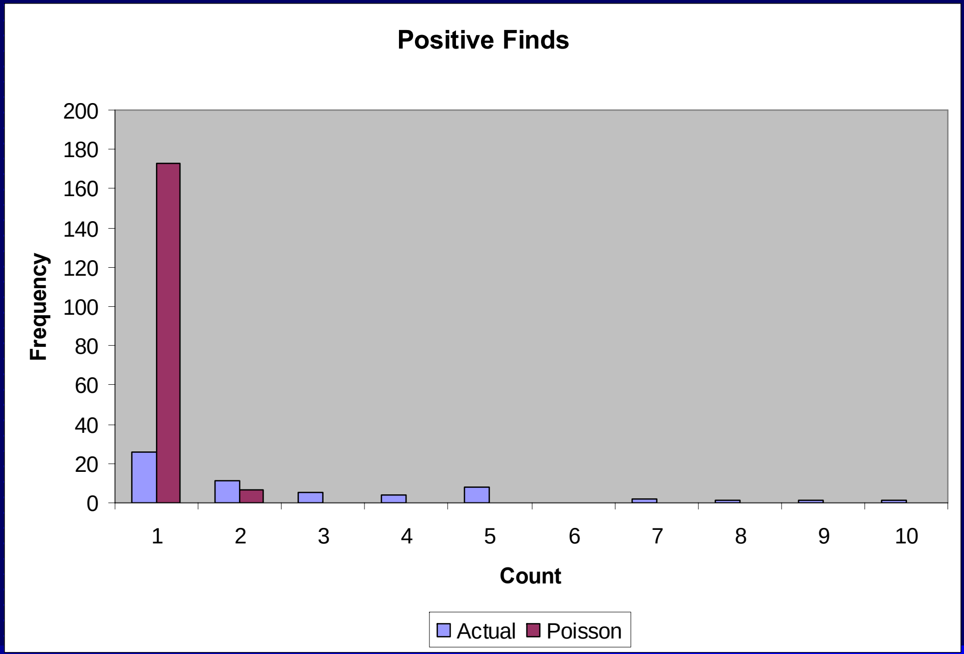


# The Zero Inflation Problem

- In fact, we have a preponderance of zeros in the data—canker is a rare but catastrophic event
- This may make standard count data estimators subject to biases
- Alternative estimators:
  - Zero-inflated Poisson
  - Zero-inflated Negative-Binomial
  - others




Entire Distribution




Lower tail, actual and Poisson prediction

# Zero-Inflated Count Models

Zero-Inflated Poisson

$$Pr(Y=0) = \phi + (1-\phi)e^{-\theta}$$

$$Pr(Y=y) = (1-\phi)\frac{e^{-\theta}\theta^{y}}{y!}, \text{ for } y = 1, 2, \ldots$$

We define $\phi = 1 - F(X\beta)$ against convention so that a positive event corresponds to $y > 0$.

Zero-Inflated Negative Binomial

$$Pr(Y=0) = \phi + (1-\phi)t^{k}$$

$$Pr(Y=y) = (1-\phi)\begin{pmatrix} y+k-1 \\ y \end{pmatrix} t^{k}(1-t)^{y}, \text{ for } y = 1, 2, \ldots$$

We assume a standard normal for $F(\cdot)$ and thus a probit for the inflation equation.

# New Premiums ($/acre)

| Model | Average | Std. Dev. | Min | Max |
|---|---|---|---|---|
| ZIP | $47.30 | $62.28 | $10.96 | $741.66 |
| ZINB | $153.35 | $97.04 | $7.82 | $726.19 |

# Summary and Conclusions

- Models of citrus canker risk indicate that risk varies by
  - Fruit variety
  - Unit Size
  - Unused acreage
  - Spatio-temporal patterns of infection

# Summary and Conclusions

- Models suggest actuarially fair premium and contribution rates for insurance fund
- Models need refinement:
  - –Reconcile differences in risk measures between alternative models
  - –Consider alternative measures of spatio-temporal risks and unit sizes (i.e., 30 km radius)
- We hope to obtain complete 2005 data to model effects of 2004 hurricanes
- Extend to the new threat: "Greening Disease"