Pro-Poor Avian Influenza Inception Meeting ,

Chiang Mai Thailand, December 2007

“Models of Avian Influenza in Commercial Poultry”

Gary Smith MA (Oxon), MA (Cantab), D.Phil

Chief, Section of Epidemiology and Public Health,

University of Pennsylvania,

School of Veterinary Medicine

Who am I?

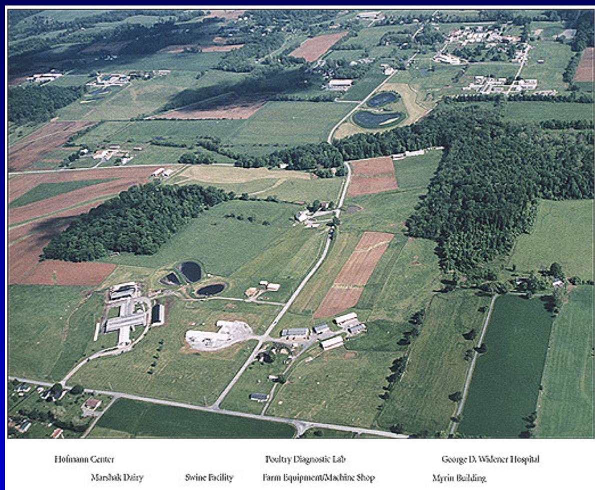
- Use mathematical models of disease transmission to examine technical aspects of disease control
  - Rank strategies in order of efficacy (according to various definitions of success)
  - Evaluate the “effort” required to control disease

- Use models to advise farmers about control strategies
- Use models to inform policies on disease control.
- Lots of experience of the diseases of ruminants in North and South America, Australia, Africa.
- Lots of experience of poultry disease in North America.

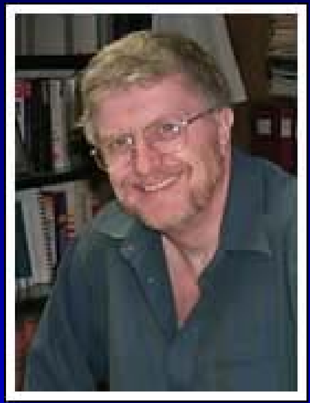
Who do I represent?

The US Group

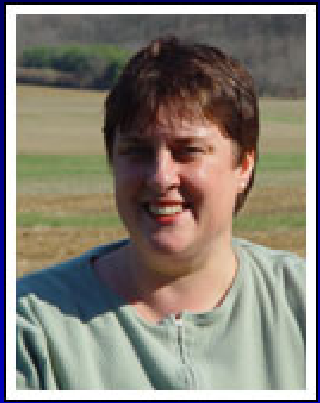
(The University of Pennsylvania School of Veterinary Medicine)



New Bolton Center. The rural campus of the University of Pennsylvania School of Veterinary Medicine



Dr Gary Smith



Dr Helen Aceto

Seth Dunipace

Max Poulan

Dr Chris Rorres

…instructing Terry Jones in the fine art of stealing beer.

Penn Veterinary Medicine

The UK Group

(The University of Warwick Department of Biological Sciences, & The Mathematics Institute)

Dr Matt Keeling

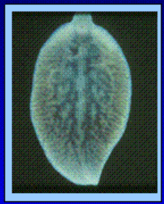
Dr. Michael Tildesley

WARWICK

What we work on…

Fasciola hepatica model

(flukes to miracidia)



$$\frac{dP}{dt} = k\rho\beta_2 HC - \mu_1 P \qquad \text{Flukes}$$

$$\frac{dF}{dt} = \lambda_1 P - \gamma F - \mu_2 F \qquad \text{Eggs in feces}$$

$$\frac{dE}{dt} = \gamma\Delta F - \delta_1 E - \mu_3 E \qquad \text{Eggs on pasture}$$

$$\frac{dM}{dt} = \delta_1 E - \beta_1 SM - \mu_4 M \qquad \text{Miracidia}$$

Rabies in raccoons

$$\frac{dX}{dt} = a(X+I+V) - \beta XY - \gamma XN - (b+\nu+c)X$$

$$\frac{dH_1}{dt} = \rho\beta XY - \gamma H_1 N - (b+\sigma+c)H_1$$

$$\frac{dH_2}{dt} = (1-\rho)\beta XY - \gamma H_2 N - (b+\sigma+c)H_2$$

$$\frac{dY}{dt} = \sigma H_1 - \gamma YN - (b+\alpha+c)Y$$

$$\frac{dI}{dt} = \sigma H_2 - \gamma IN - (b+c)I$$

$$\frac{dV}{dt} = \nu X - \gamma VN - (b+c)V$$

, Smith G. & McAllister F. (1989) Mathematical model for the population biology of raccoon rabies in the mid-Atlantic states. American Journal Veterinary : 2148-2154.

Vaccination coverage required to protect African ape populations against Ebola?

Some "back-of-the-envelope" calculations

$$p = 1 - \frac{1}{R_0} = 1 - \frac{N_T}{K}$$

Gorillas	$p = 1 - \frac{0.74}{1.69} = 0.56$	$R_0 = 2.28$
Chimpanzees	$p = 1 - \frac{0.03}{0.28} = 0.89$	$R_0 = 9.33$

Indices of abundance/km data from Lossi Sanctuary in the Republic of Congo before (2000) and after (2003) the Ebola outbreak. (Leroy et al., 2004, Multiple Ebola Virus Transmission Events and Rapid Decline of Central African Wildlife. Science 303 387-390).

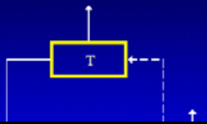
Whirling Disease in trout

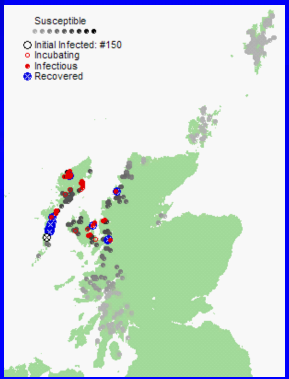
$$\frac{dP_1}{dt} = \beta_2 FTD_1 - F\sum_{i=0}^{\infty} \mu(i)ip(i) - \mu_1 P_1$$

$$\frac{dS}{dt} = \mu_1 P_1 + F\sum_{i=0}^{\infty} \mu(i)ip(i) - \beta_3 WS - \mu_3 S$$

$$\frac{dP_2}{dt} = \beta_3 WSD_2 - \mu_2 P_2$$

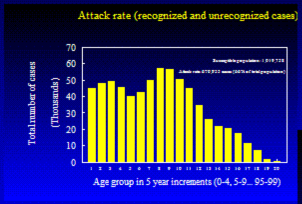
$$\frac{dT}{dt} = \lambda P_2 - \beta_2 FT - \mu_4 T$$



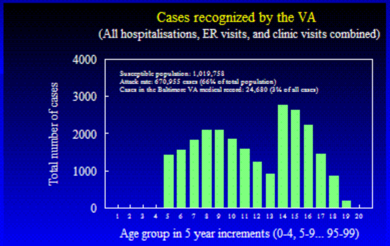


Infectious Salmon anemia

Simulated ILI epidemic in Baltimore



Only 24,680 of 670,955 (3%) cases are recognized by the VA medical system, and the age- (and gender-) structure of the recognized cases is very different



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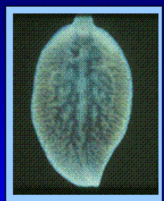

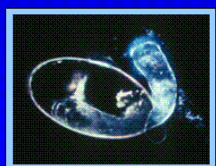

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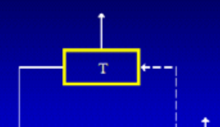

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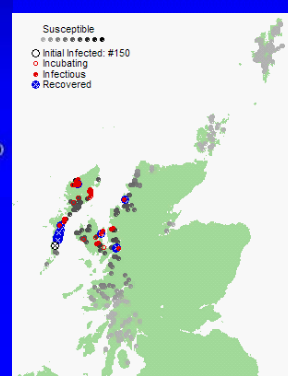

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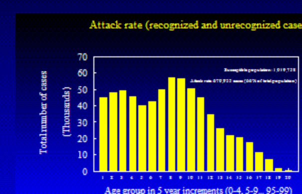

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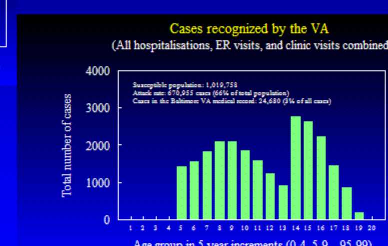


Models of Infectious Disease Agent Study (MIDAS) is a collaboration of research and informatics groups to develop computational models of the interactions between infectious agents and their hosts, disease spread, prediction systems, and response strategies. The models will be useful to policymakers, public health workers, and other researchers who want to better understand and respond to emerging infectious diseases

What is our role in MIDAS?

Both the US and the UK groups have modeled infectious disease in human populations - but our main focus is on infectious disease in animals (wild and domestic), so why are we part of MIDAS?

Failure to adequately control large scale epidemic disease in animals has multiple consequences

- Direct losses
- Indirect multiplier effects (to ag-related industries, trade, tourism)
- Multiple opportunities for fraud and other criminal acts
- Logistical, environmental, social and political difficulties associated with the disposal of carcasses
- Controversy concerning methods and loss of confidence in Government
- Public anxiety about the risk of zoonotic disease and real disease problems even when dealing with non-zoonotic diseases.
- Damaging academic controversy

OK, a man walks into a bar, right?

OK, a man walks into a bar, right?

This guy is the very first infectious case

R_0, the basic reproductive number

"The average number of secondary infections caused by a single typical infected individual among a completely susceptible population"

$R_0 = 3$

If R0 > 1, epidemic takes off,

If R0 <1, no major epidemic occurs

Timothy C. Germann, Kai Kadau, Ira M. Longini, Jr., and Catherine A. Macken (2006) Mitigation strategies for pandemic influenza in the United States. Proceedings of the National Academy of Science, 103: (15) 5935–5940

How do we know an epidemic has begun?

- Probabilistic models allow us to calculate the value of R_0 provided it is is below one. We can fit the model to chains of infection in people…
- These models only fail to fit when the R_o increases above 1.
- So when we cannot get a good fit to the data, we know that something has changed for the worse.

What is our main focus?

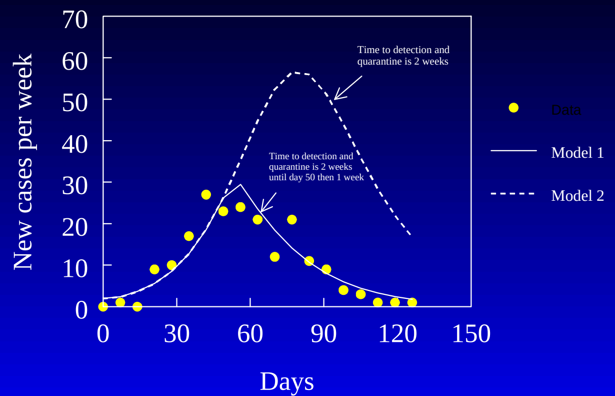
- We have completely ignored strategies to reduce bird to human infection

- We have focused on strategies that deprive the virus the opportunity to replicate – ie we are in the business of preventing and curtailing epidemics

Between-flock
LPAI and HPAI epidemics

LPAI (H7N2) outbreak in Virginia(2002)

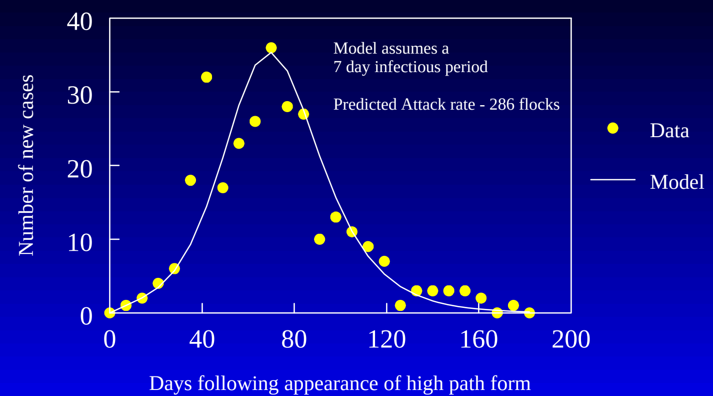
Actual and predicted curve



Akey BL (2003) Low pathogenicity (H7N2) avian influenza outbreak in Virginia during 2002.Avian Diseases 47: 1099-1103

HPAI (H5N2) outbreak in Pennsylvania (1983-1984)

Actual and predicted epidemic curve



Epidemic data from Buisch WW, Hall AE, McDaniel HA (1984) 1983-1984 Lethal avian inflenza outbreak Proceedings of the United States Animal Health Association 88: 430-446. Epidemic model: G. Smith, unpublished work.

Basic reproduction number was 1.9 initially, dropping to 0.85 after intensification of surveillance

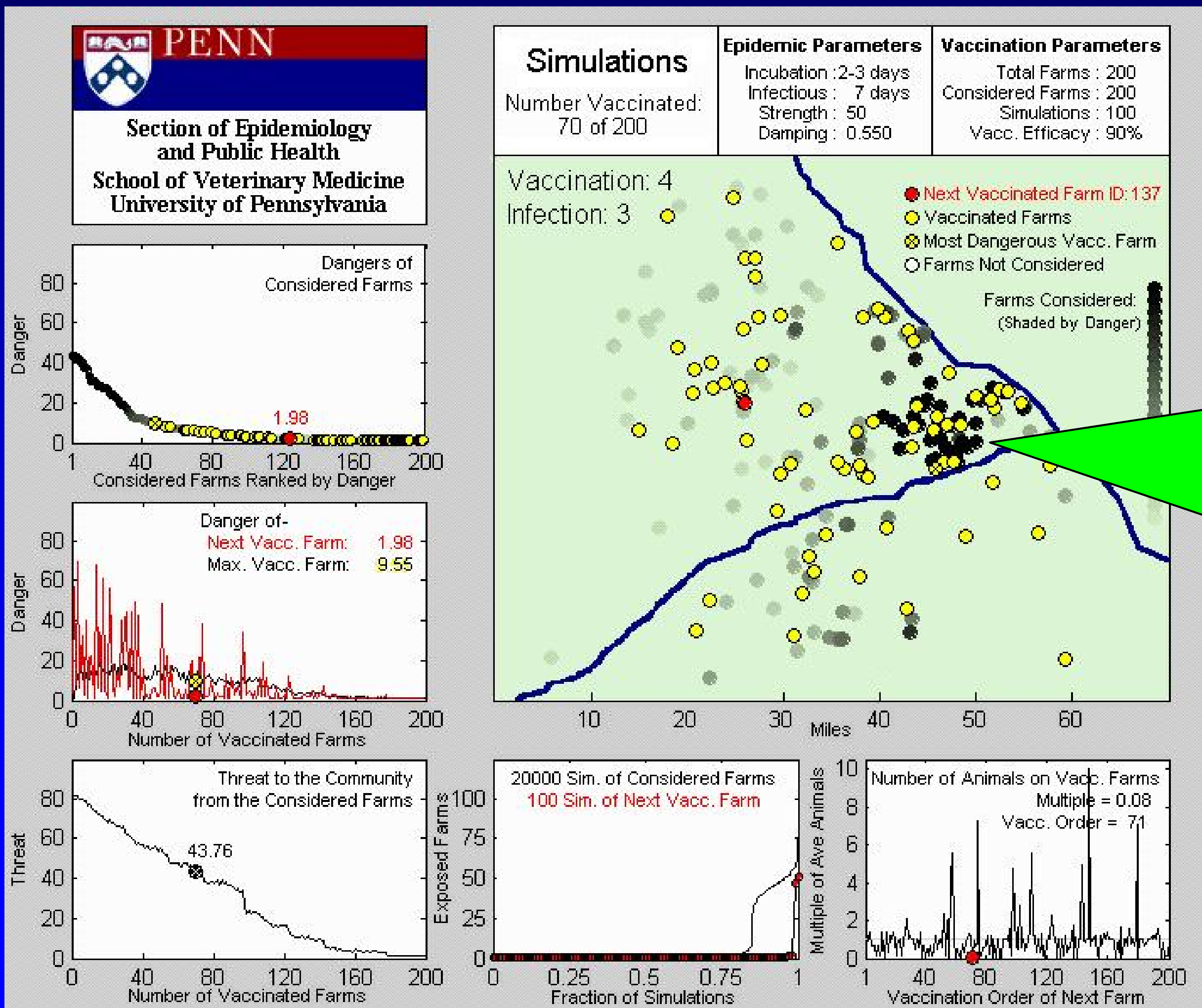
Basic reproduction number 1.5

Notice, the values of R_0 were similar!

Smith (unpublished results)

MIDAS

To systematize our thinking we have used “game theory” to see how different vaccination strategies fare when pitted against different sorts of disease introductions



In the “game” we have set 5 possible vaccination strategies against 6 possible infection strategies

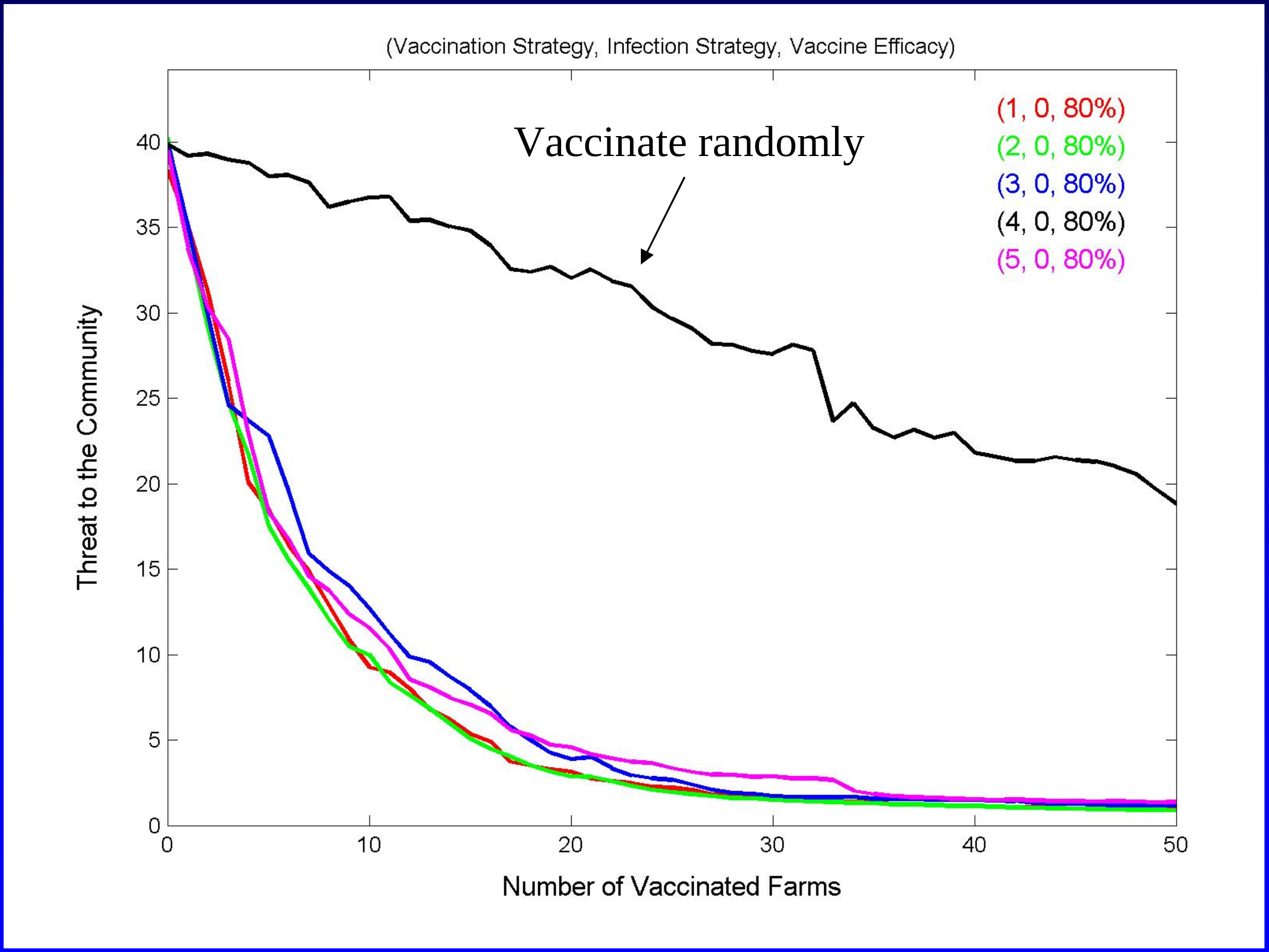
This frame looks at the just one of the possible combinations…

Vaccination Strategy: Vaccinate 70 farms at random.

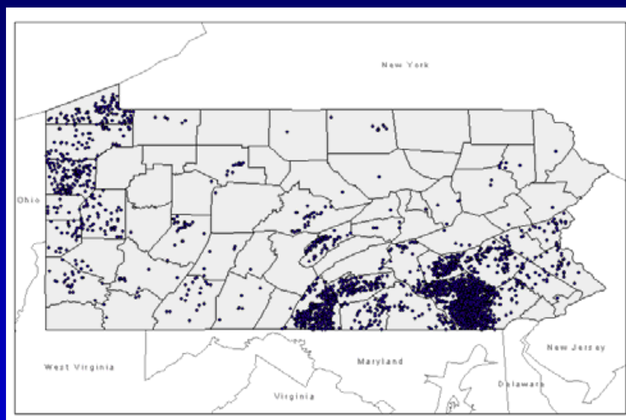
Infection Introduction Strategy:

Infect the most “dangerous” farm

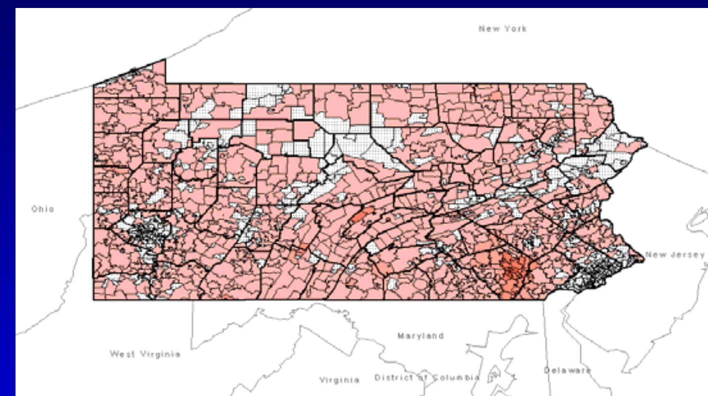
If you have any information about what makes one farm more dangerous than another – use it!



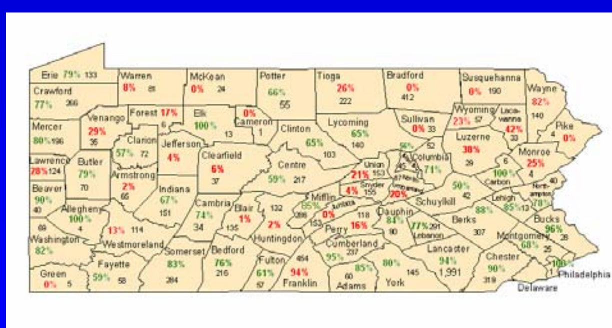
We need maps of where the farms are located, but mapping the location of farms is hard!



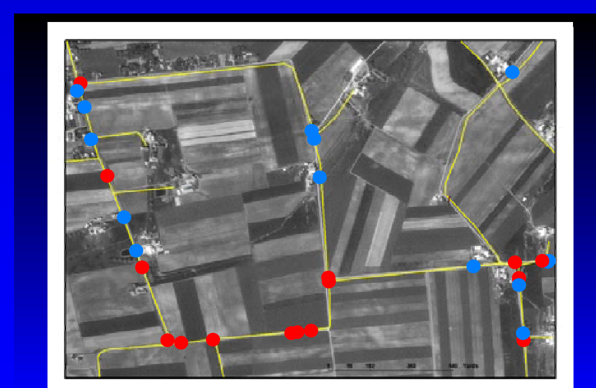
Location of dairy farms based on a geocoded list



Density of dairy farms based on the 2000 US census (by county)



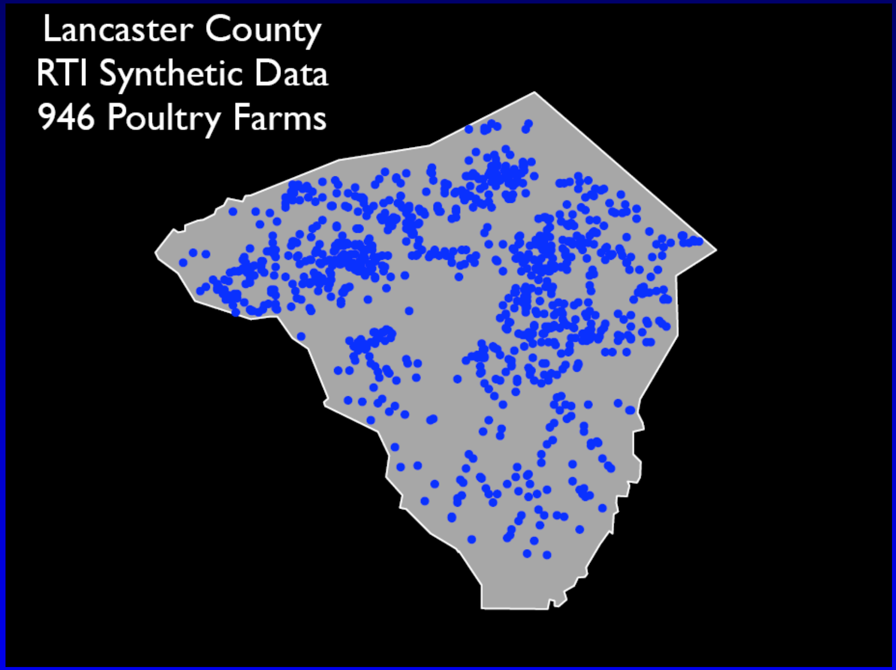
How many have we missed?



Comparisons with “ground truth data have revealed severe problems with GIS software…

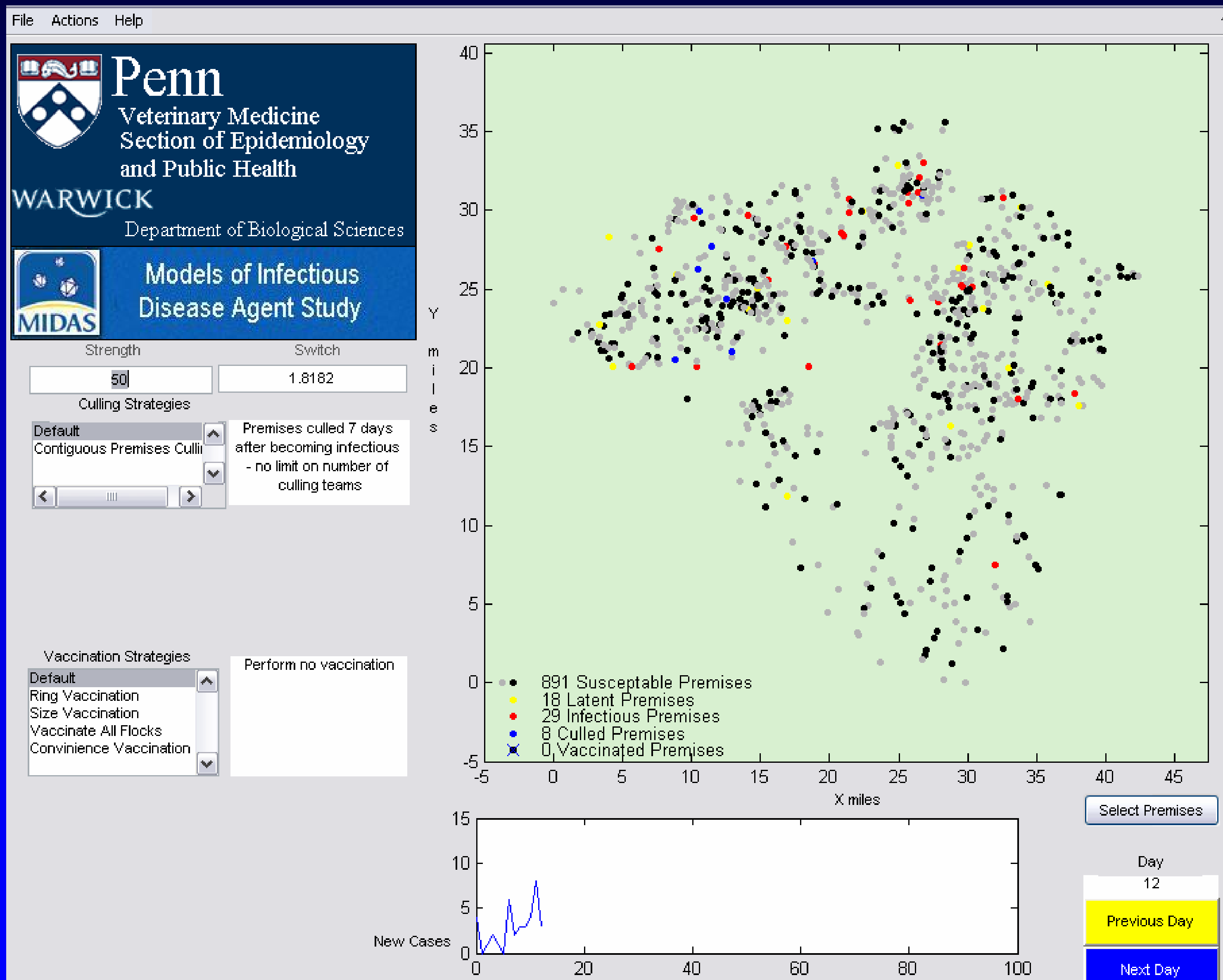
A synthetic map using AgCensus data?

- Work “backwards” from the public domain data in the 2002 Ag Census…
- The Census tells us the number of flocks in each zip code…
- Made “educated guesses” about the location of those flocks at county level...



Projected location of commercial flocks in Lancaster County

Dunnipace S, Bruhn M, Wheaton W, Smith G. (unpublished work)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Strength
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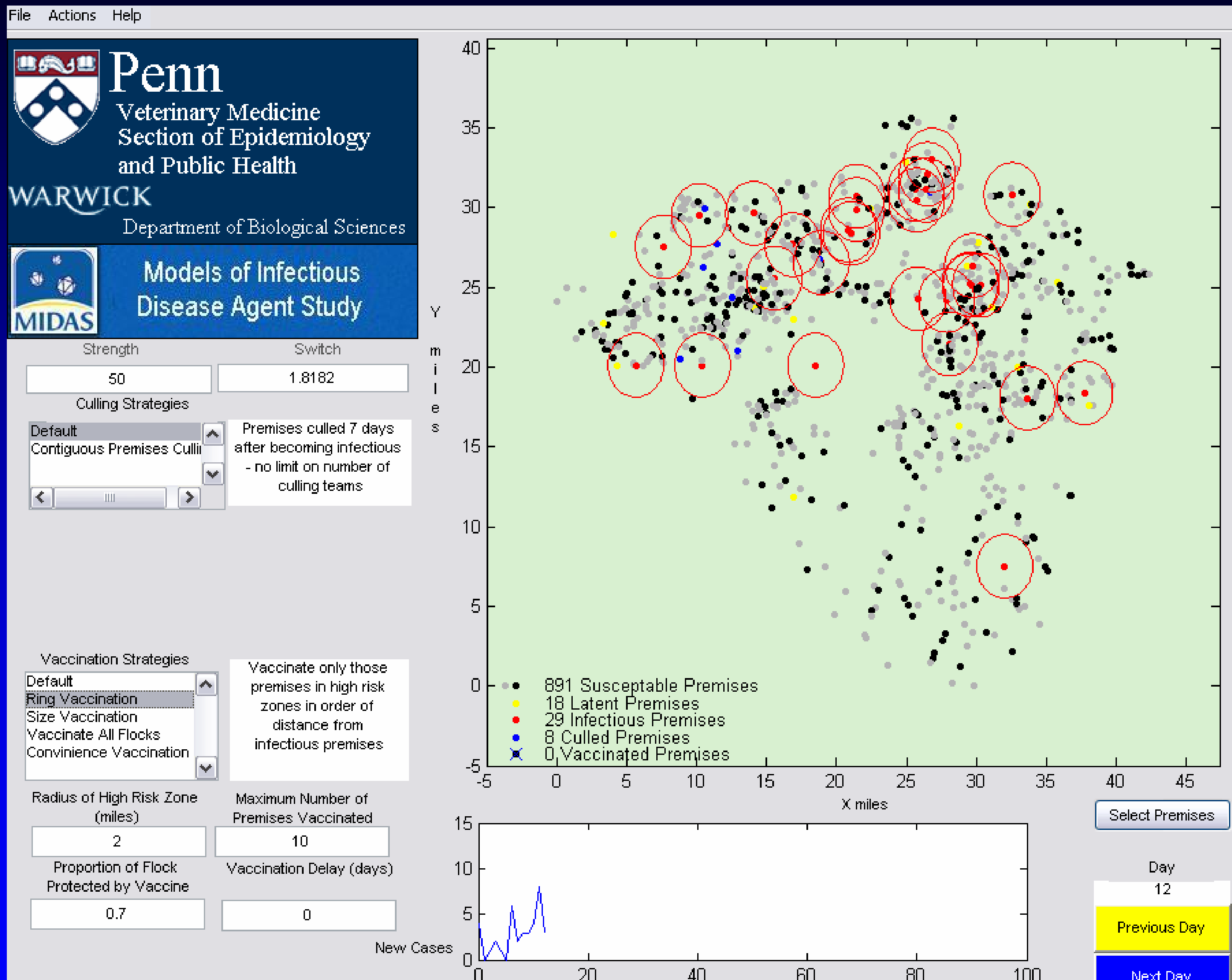
Culling Strategies
Default
Contiguous Premises Culli
Premises culled 7 days after becoming infectious - no limit on number of culling teams
Vaccination Strategies
Default
Ring Vaccination
Size Vaccination
Vaccinate All Flocks
Convinience Vaccination
Perform no vaccination
Y miles
X miles
891 Susceptable Premises
18 Latent Premises
29 Infectious Premises
8 Culled Premises
0 Vaccinated Premises
Select Premises
New Cases
Day
12
Previous Day
Next Day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Radius of High Risk Zone (miles)
2
Maximum Number of Premises Vaccinated
10
Proportion of Flock Protected by Vaccine
0.7
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