Modeling Highly Pathogenic Avian Influenza in the US Poultry Industry

Year End Report 2006-2007

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October 15, 2007

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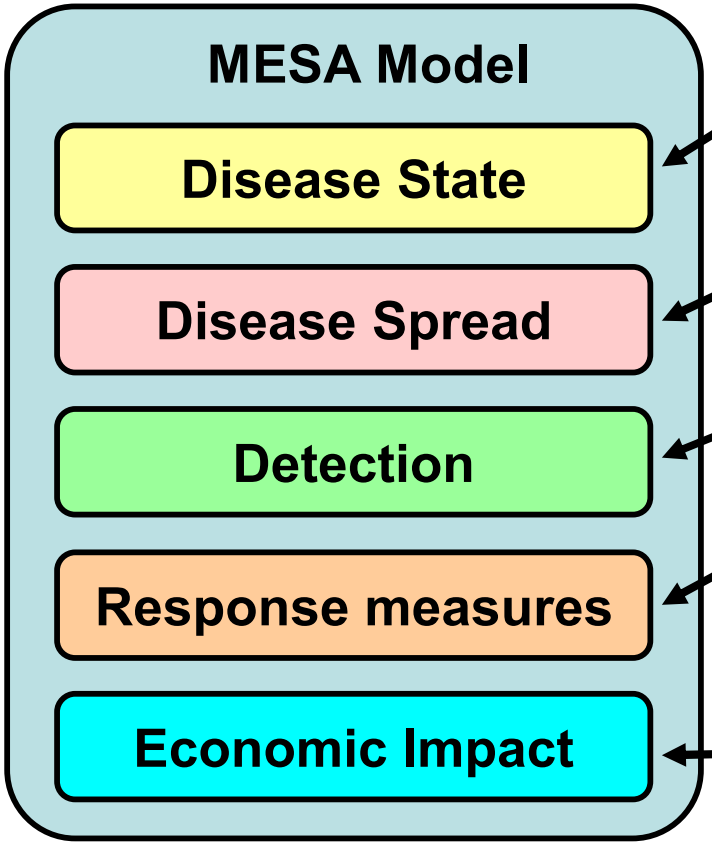
UCRL-TR-23501

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Outline

- **Parameterization of MESA disease spread model for HPAI**
  - **Parameters for disease spread**
  - **Response parameters including vaccination**
- **Scenarios for HPAI introduction into poultry**
- **Results**
  - **Size and duration of outbreaks**
  - **Vaccination and diagnostic demands**

MESA has been parameterized for HPAI



SLIR-based (intra-herd) disease model for each individual facility

Disease spread between facilities by direct and indirect contacts using agent-based engine

Detection of infected facilities leads to response measures

Response measures include quarantine, movement controls, vaccination, depopulation

Economic impact includes livestock industry losses and cost of control measures

Parameters depend on facility type

MESA: Multiscale Epidemiologic/Economic Simulation and Analysis
SLIR: susceptible, latent, infected, recovered

MESA facility types are derived from NASS data

Table egg breeders
168 farms, 2.0 million birds

Large broiler breeders
(160,000 hens)

162 farms, 25.9 mil birds

Small broiler breeders
(12,000 to 100,000 hens)

2,256 farms, 24.7 mil birds

Large hatcheries
(>900,000 hatched)

11 farms, 22.6 mil birds

Small hatcheries

931 farms,
15.0 mil birds

Large hatcheries
(<900,000 hatched)

321 farms, 666.1 mil birds

Small hatcheries

5,004 farms,
143.1 mil birds

Large pullets
(>100,000 sold)

137 farms, 24.7 mil birds

Small pullets

12,077 farms,
68.5 mil birds

Large grow-outs
(>500,000 sold)

5,303 farms, 760.0 mil birds

Small grow-outs
(2,000 to 500,000 sold)

15,838 farms,
656.3 mil birds

Large layers
(>100,000 hens)

424 farms, 225.8 mil birds

Small layers
(50 to 100,000 hens)

12,740 farms, 53.4 mil birds

Game fowl breeders

6,018 farms,
0.9 mil birds

"Poultry, other"
(show/exhibition??)

7,722 farms, 0.7 mil birds

Large turkeys
(>100,000 sold)

710 farms,
47.9 mil birds

Small turkeys
(2,000 to 100,000 sold)

9,209 farms,
44.8 mil birds

Backyard high risk

52,329 farms,
1.0 mil birds

Live bird markets

396 markets

Swap meets

89 swap meets

Backyard turkeys

6,851 farms,
0.3 million birds

Backyards low risk

257,972 farms,
4.9 mil birds

Backyards NASS

87,531 farms,
1.5 mil birds

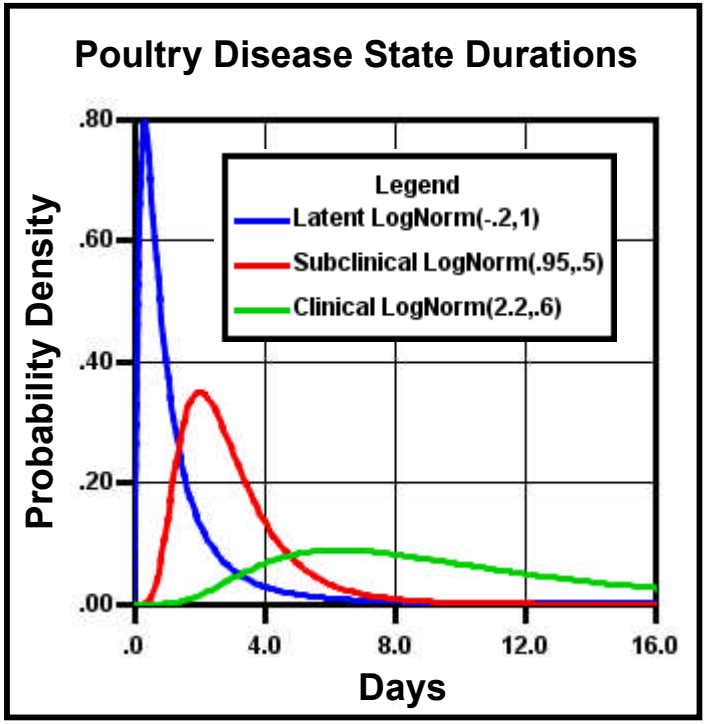
Ducks

26,065 farms,
3.8 mil birds

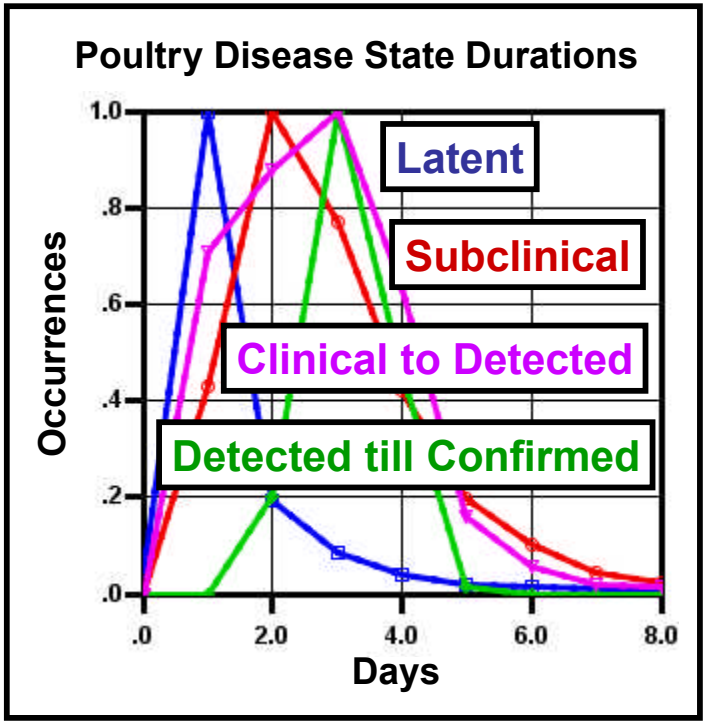
Geese, pheasants,
pigeons, quail, emus,
ostriches

37,027 farms,
7.8 mil birds

Disease Parameters for Poultry

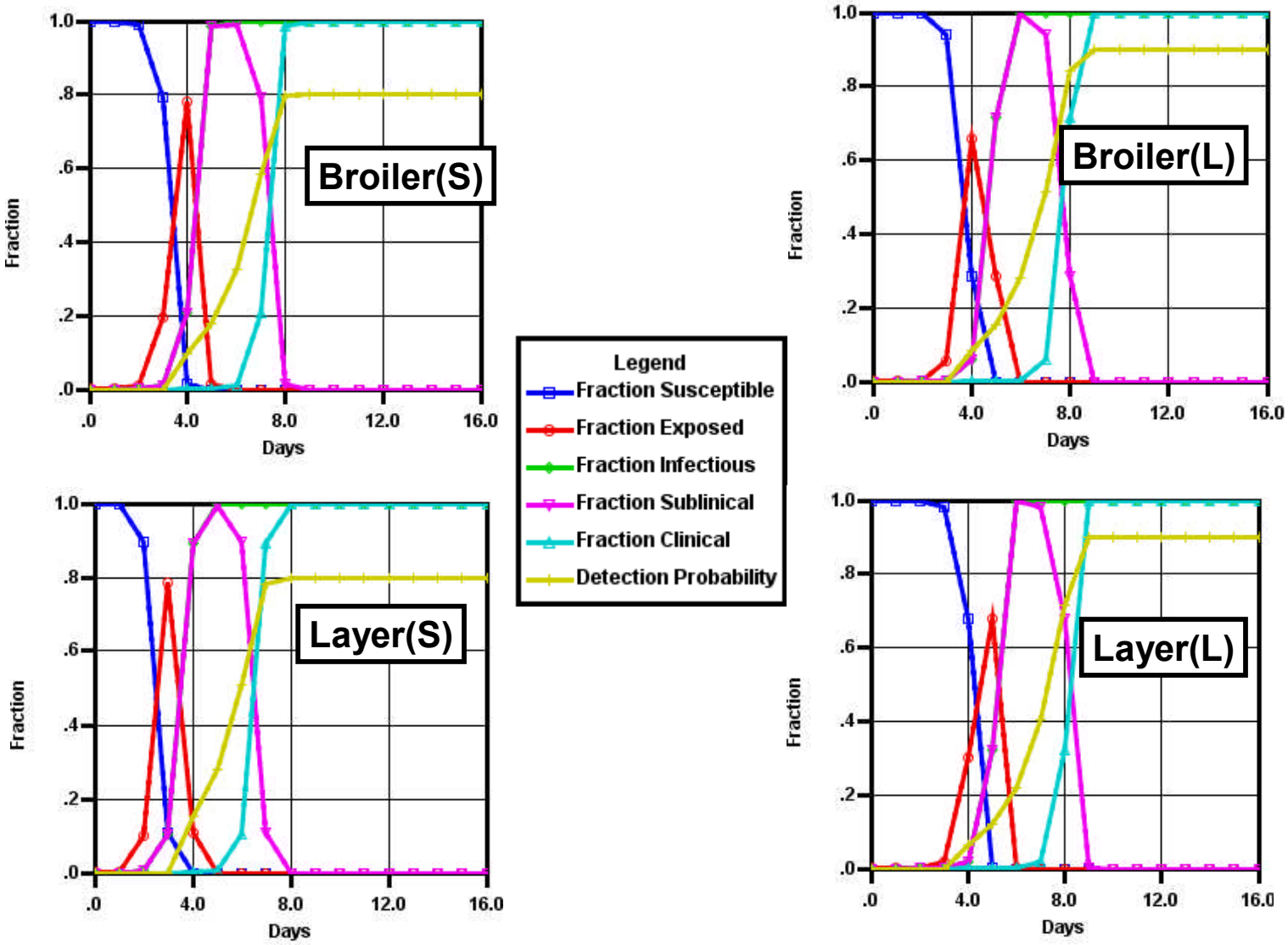


Input parameters

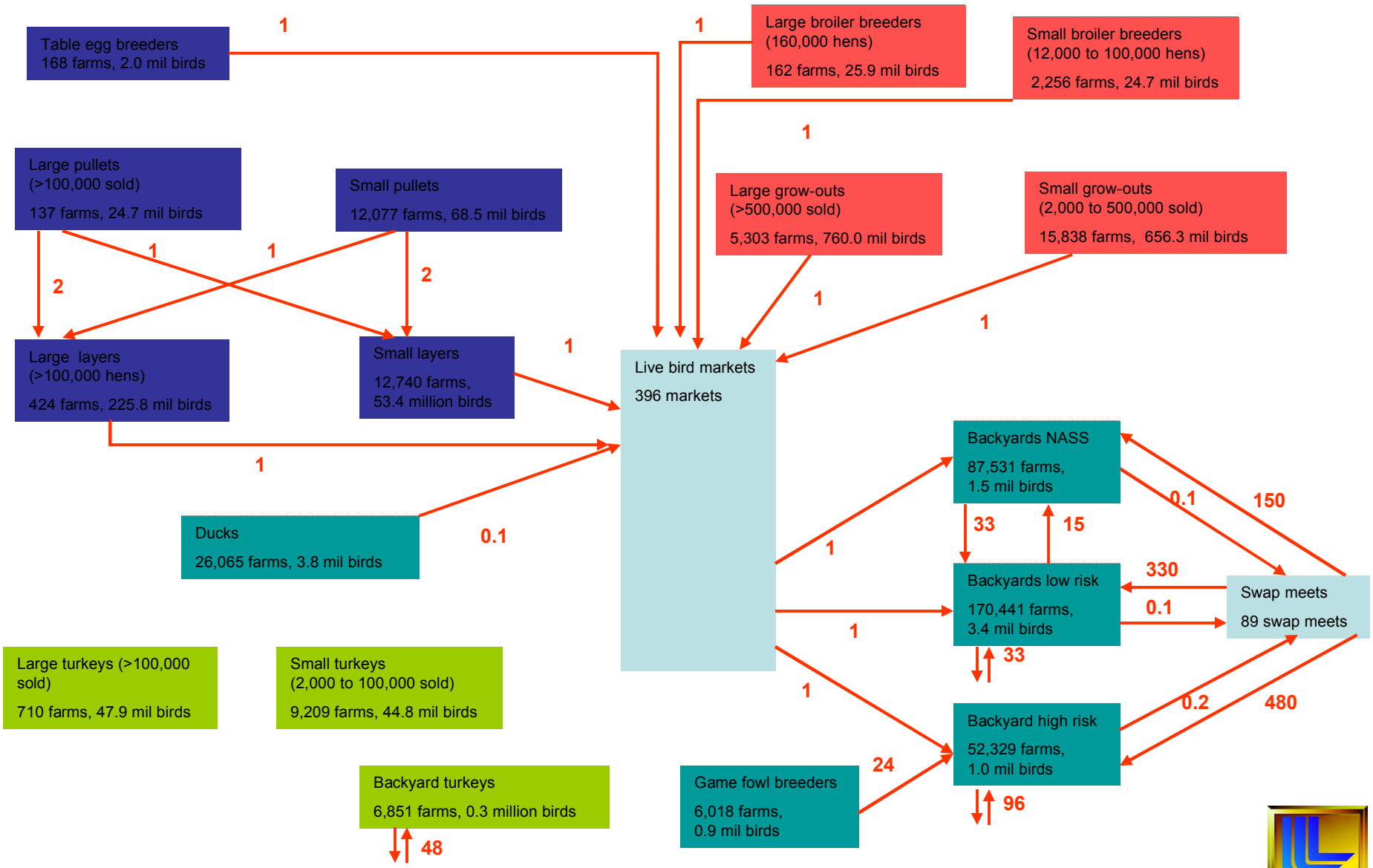


Output effects

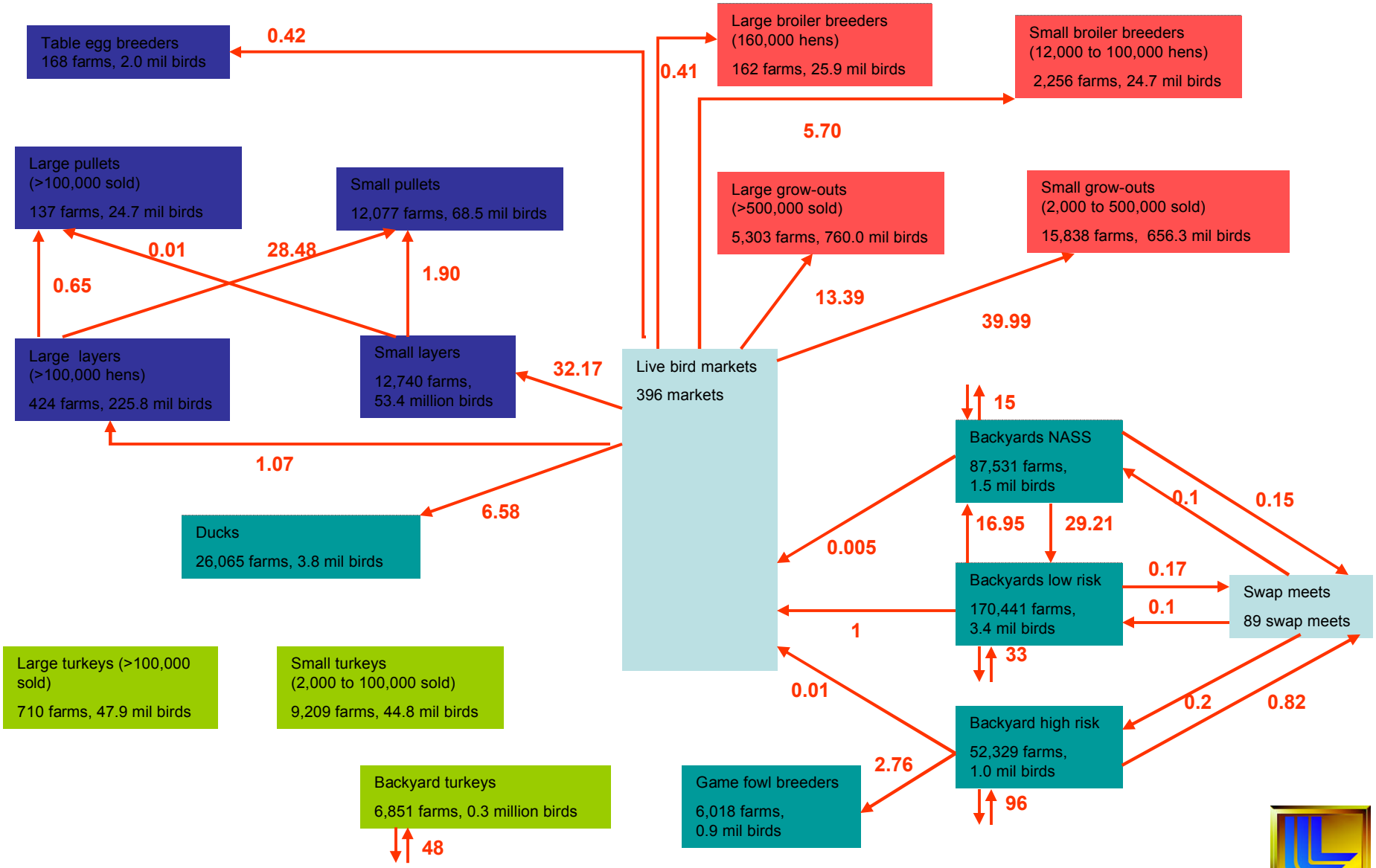
Intraherd Disease Spread and Detection



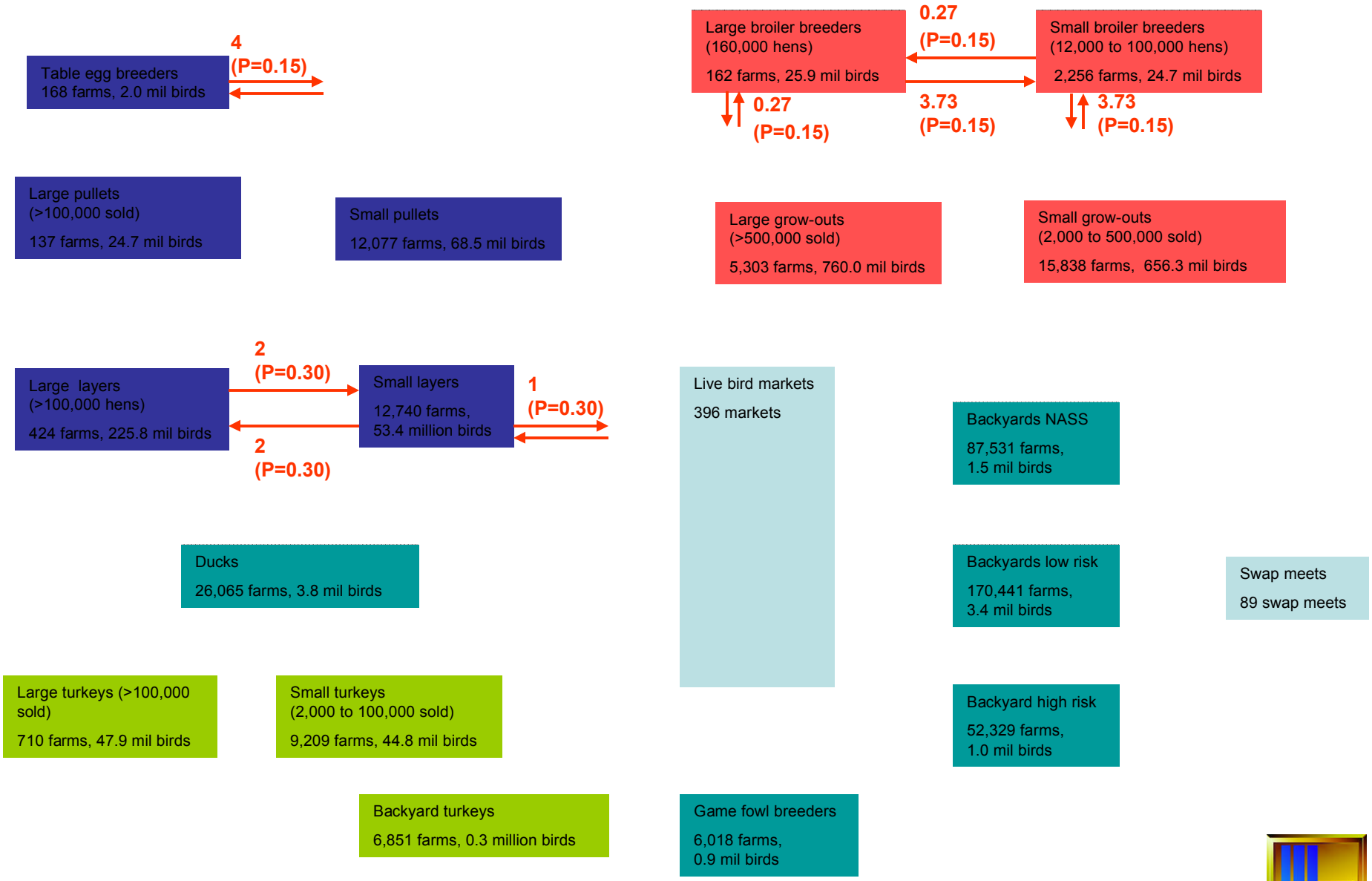
MESA contacts/yr “direct” (P=0.90)



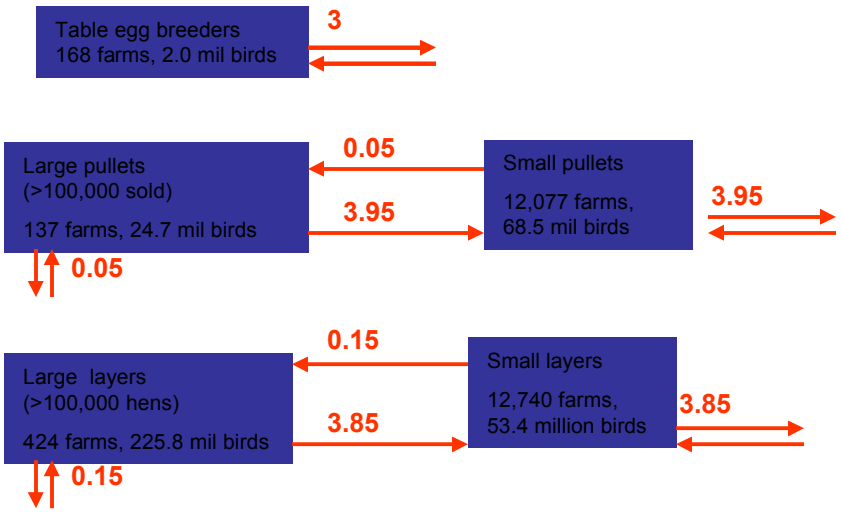
MESA contacts/yr “indirect due to direct” (P=0.25)

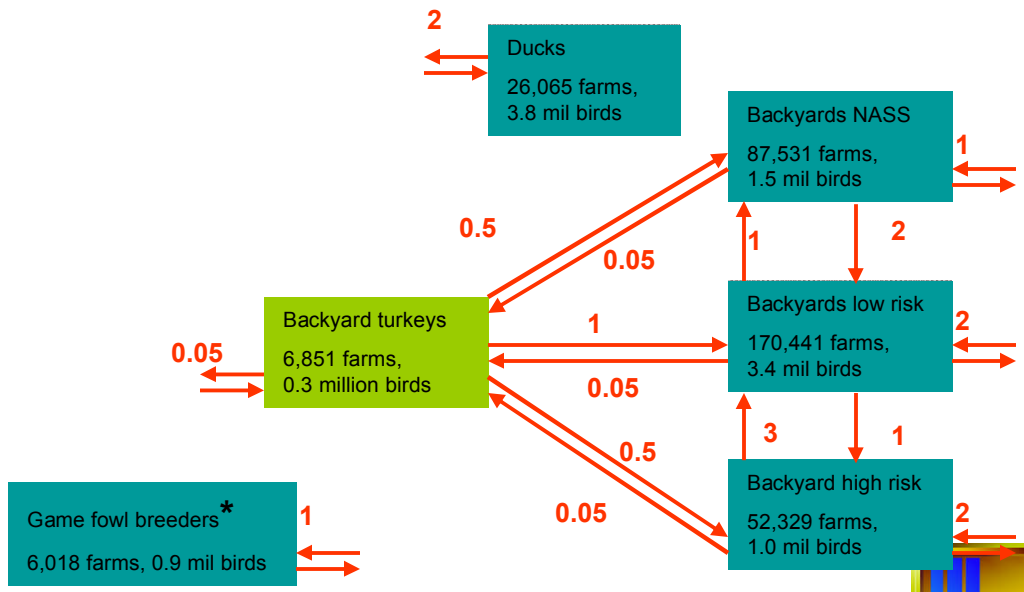


MESA contacts/wk “indirect due to eggs”



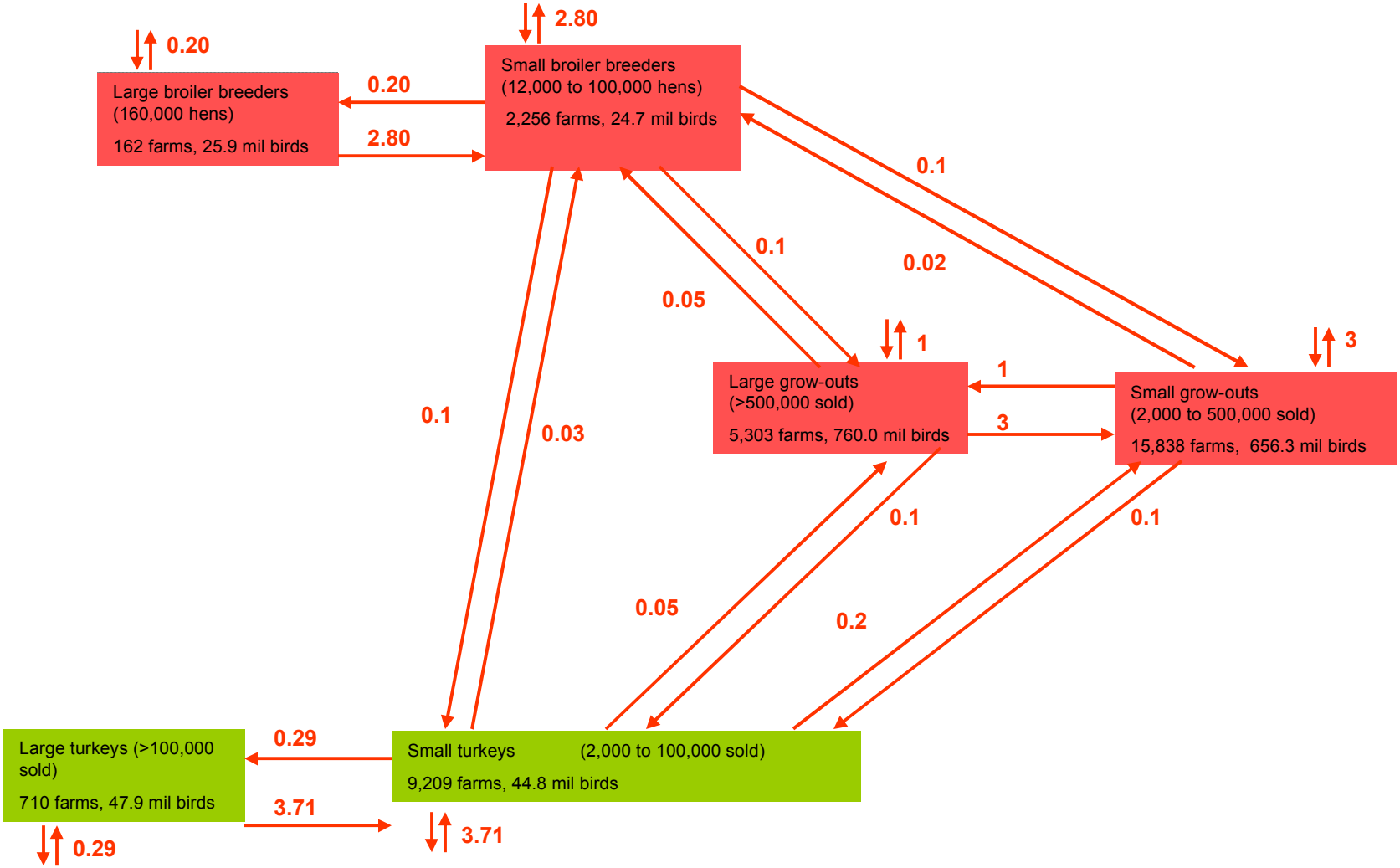
MESA contacts/wk “indirect, other” (P=0.25)
Part 1: Table egg type facilities and backyards



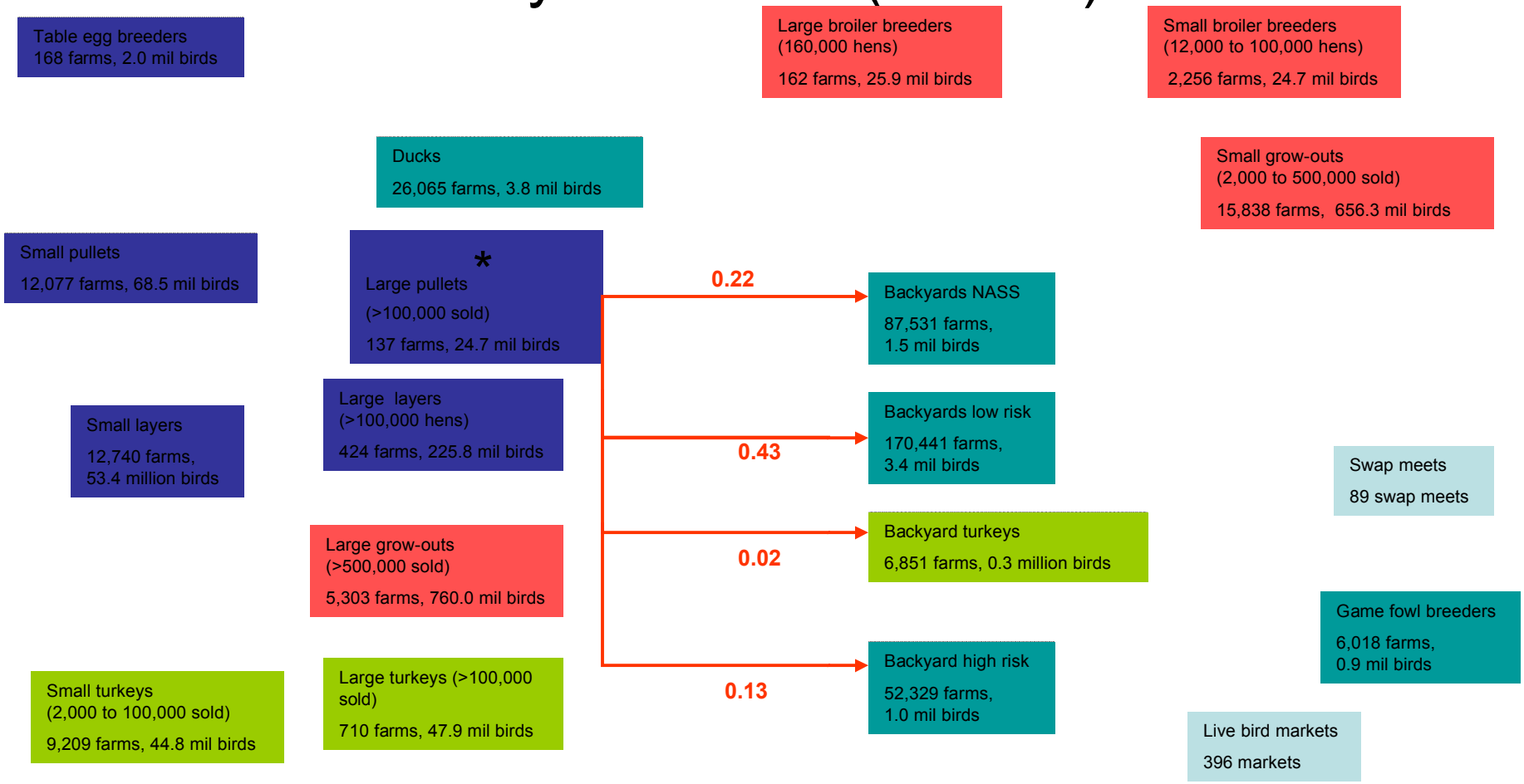


* Contact structure also applies to geese, pheasants, pigeons, quail, emus, ostriches, and “poultry, other”

MESA contacts/wk “indirect, other” (P=0.25)
Part 2: Broilers and turkeys



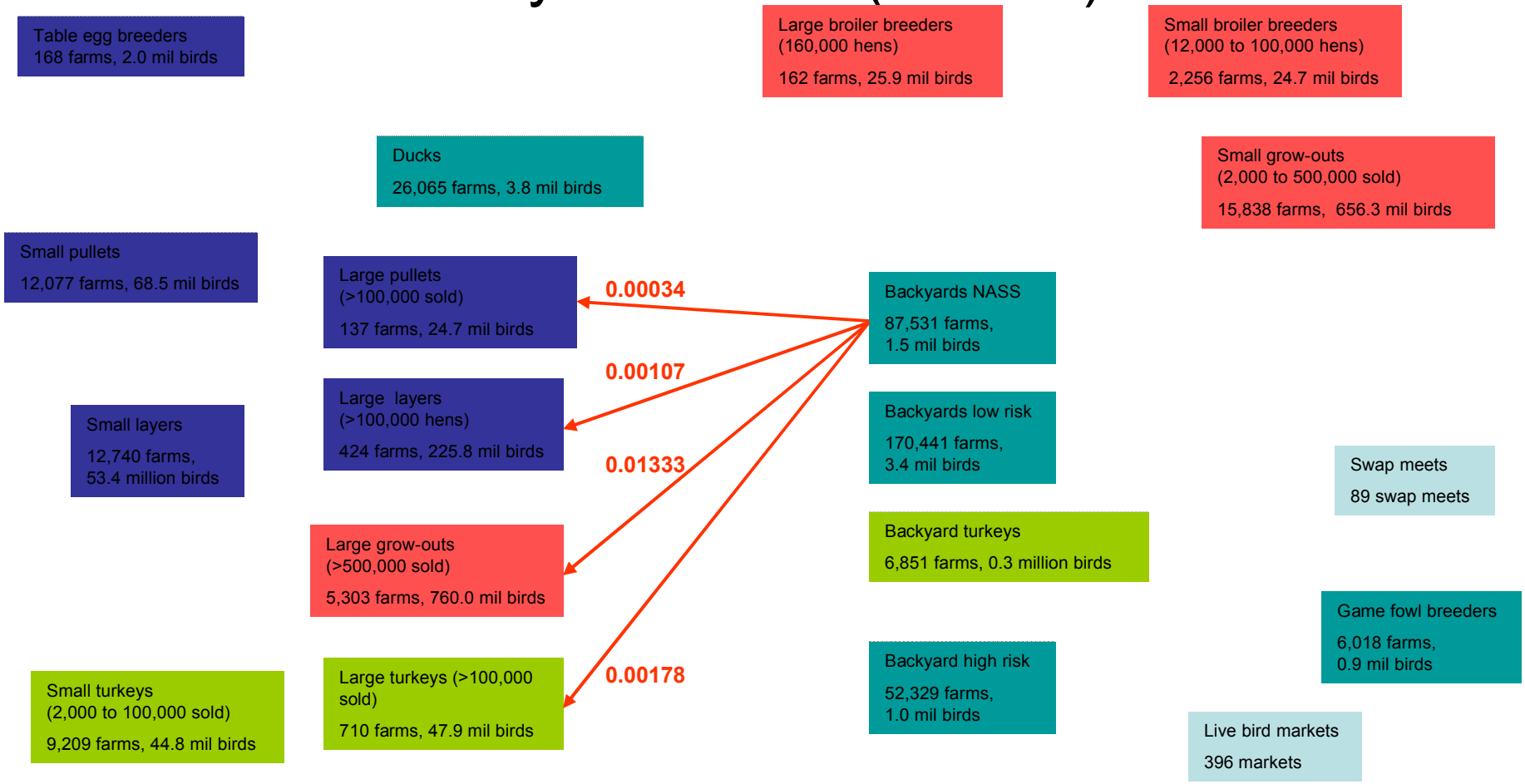
MESA contacts/wk "indirect due to workers with backyard flocks" (P=0.50)



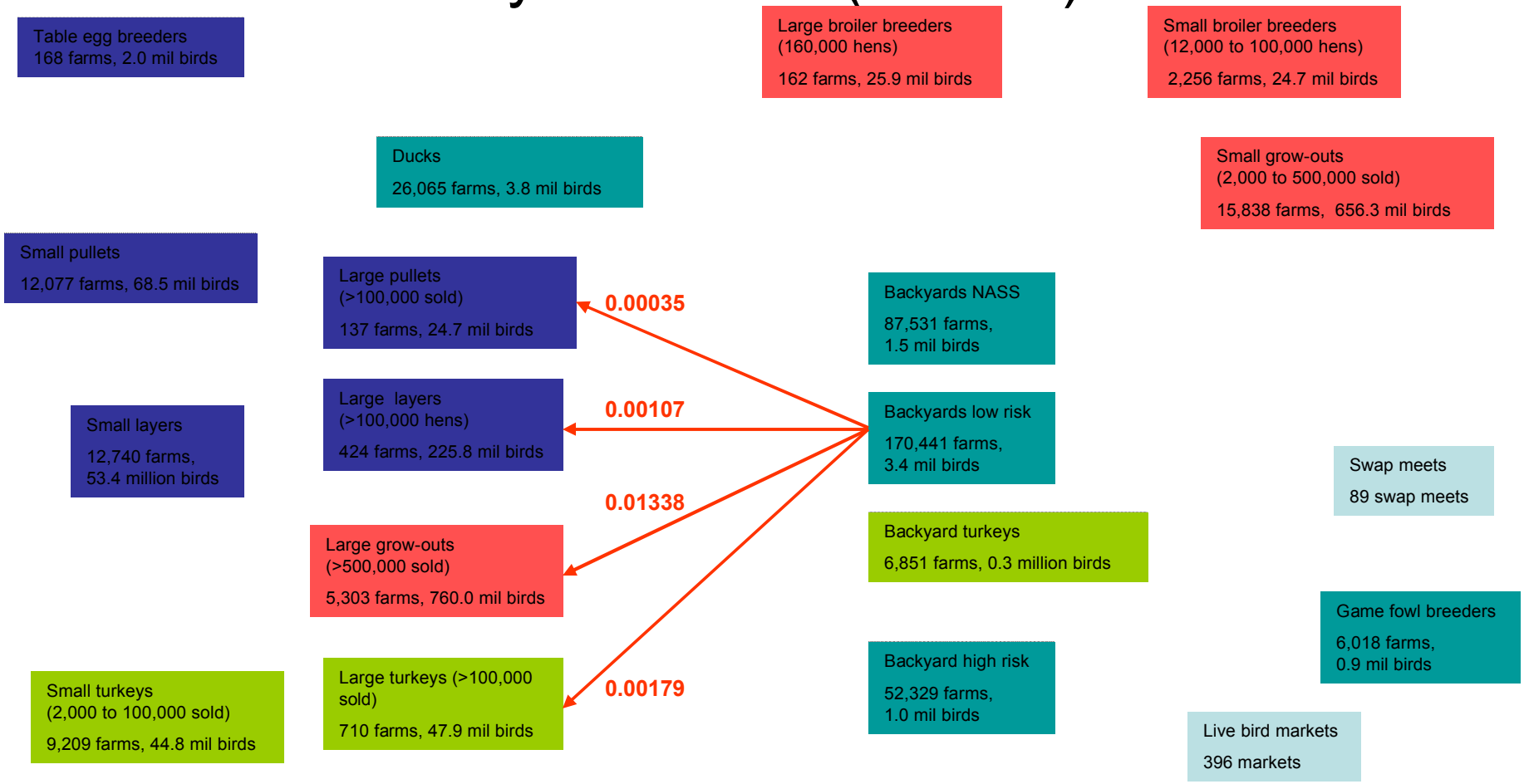
Note: Probability of backyard contact on a given facility on a given day = 1-0.96^3 = 0.115264. This is expressed as a contact rate of 0.6 per week for large commercial facilities to backyard flocks. Contact rates specific to each backyard type are calculated based on relative numbers of each type.

* Contact structure also applies to other large commercial facilities, i.e., breeders, layers, broiler grow-outs, and turkey facilities.

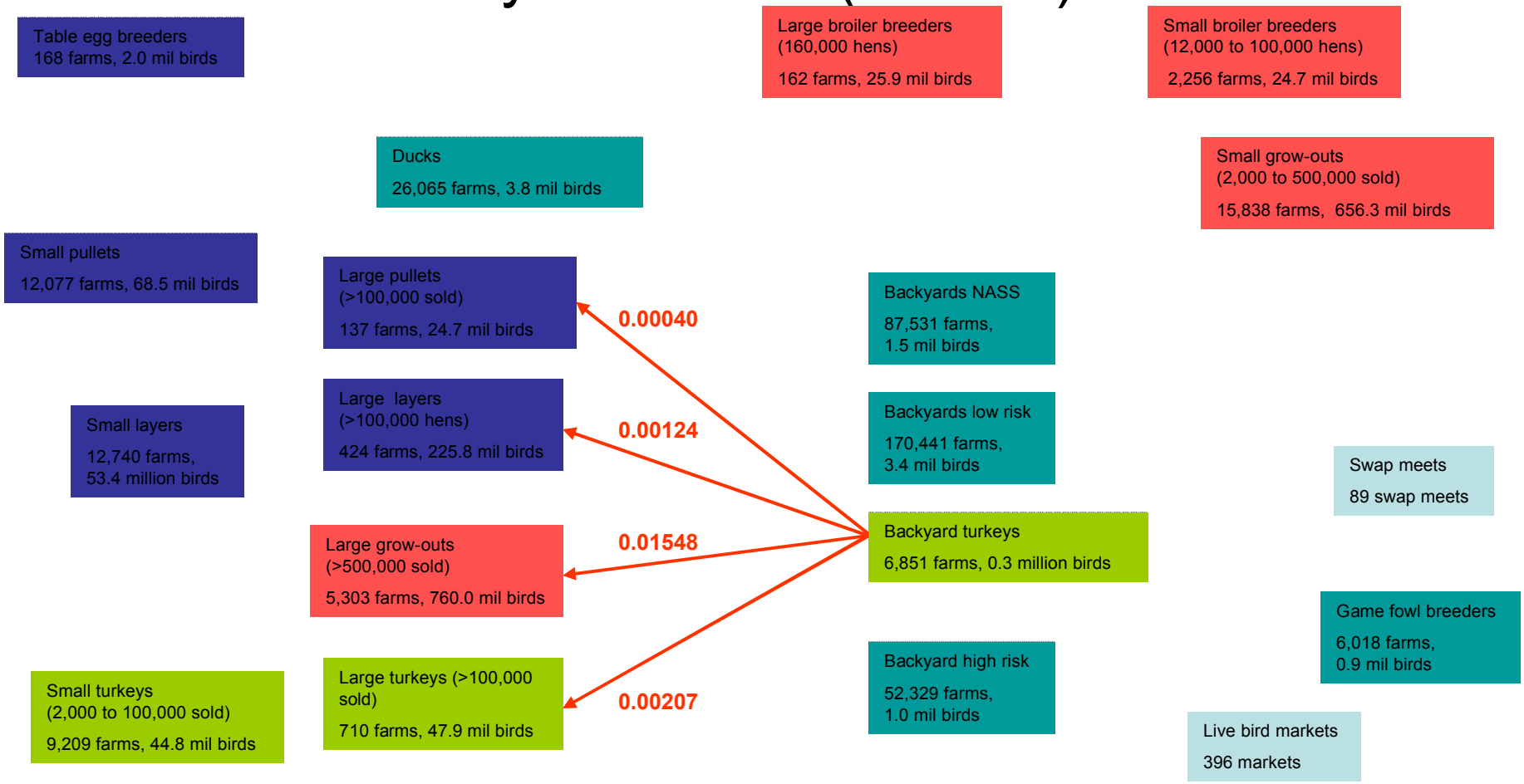
MESA contacts/wk “indirect due to workers with backyard flocks” (P=0.50)



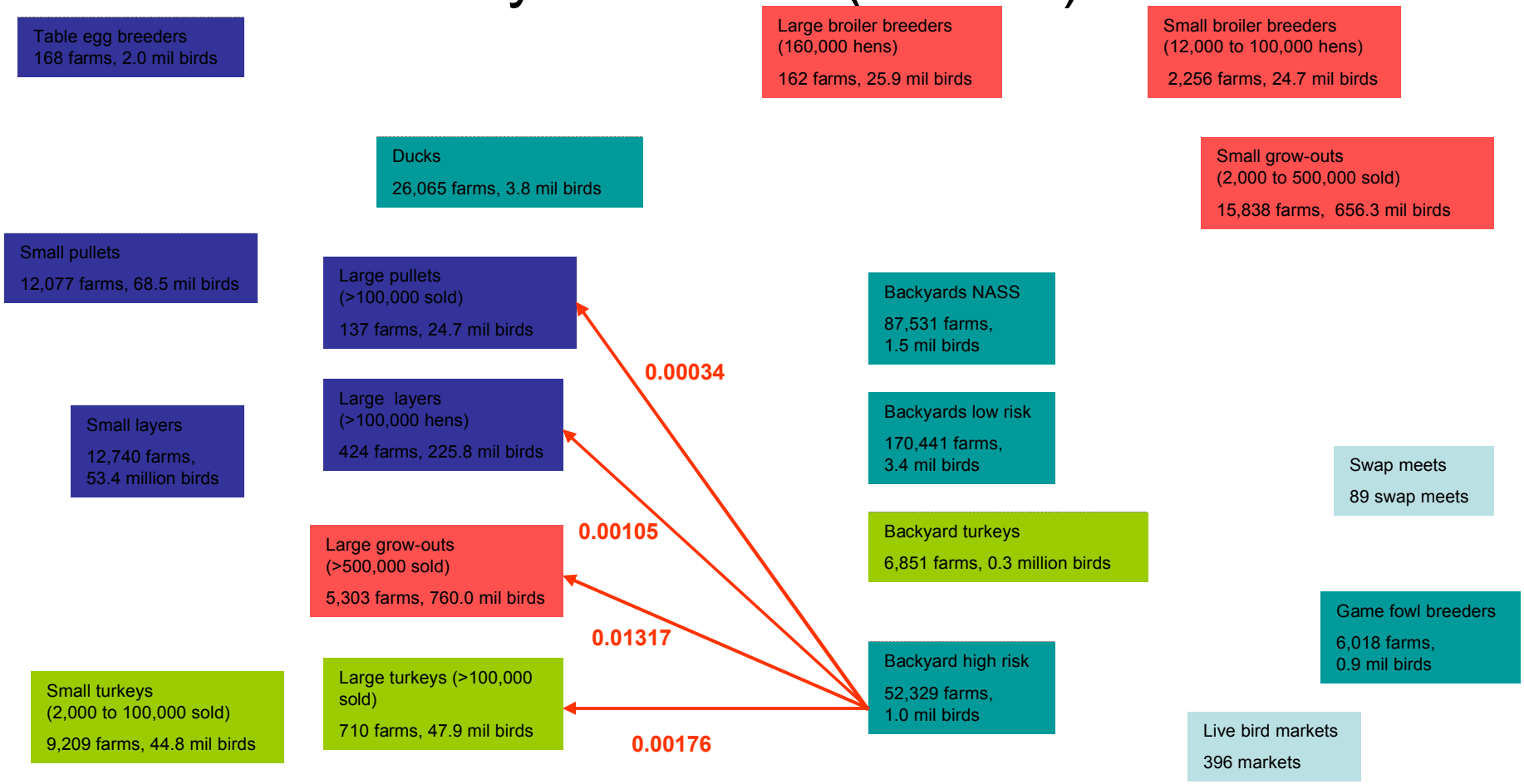
MESA contacts “indirect due to workers with backyard flocks” (P=0.50)



MESA contacts “indirect due to workers with backyard flocks” (P=0.50)

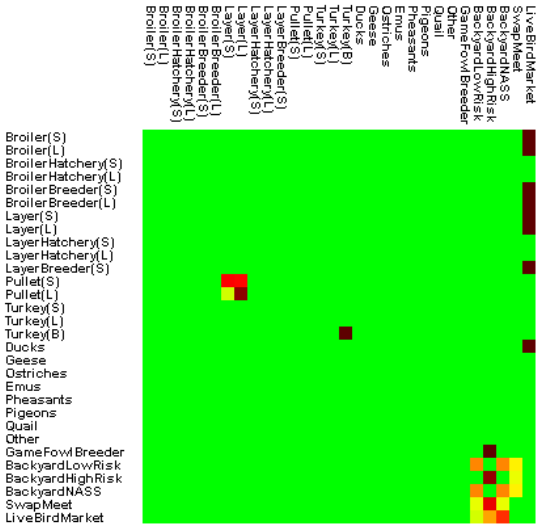


MESA contacts “indirect due to workers with backyard flocks” (P=0.50)

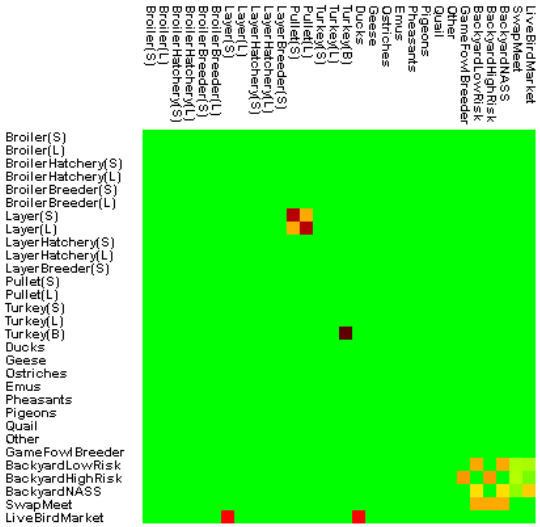


Contact Interactions

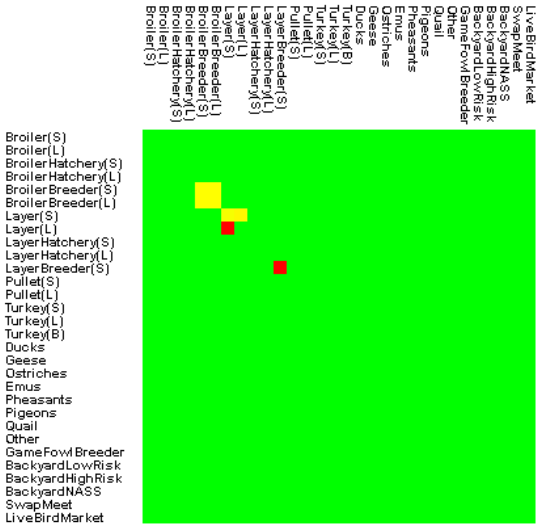
MESA interaction parameters for DirectLocal



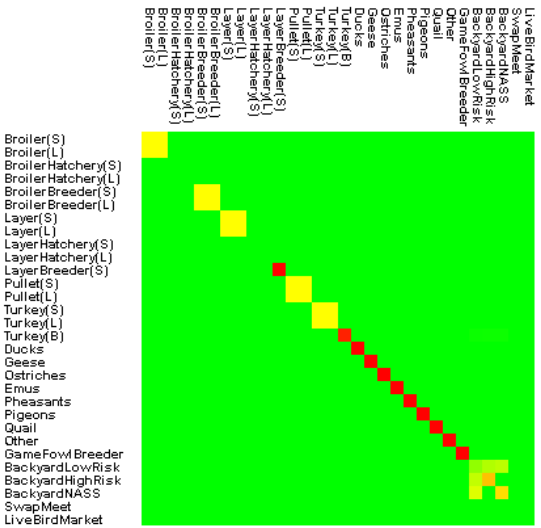
MESA interaction parameters for IndirectDueDirect



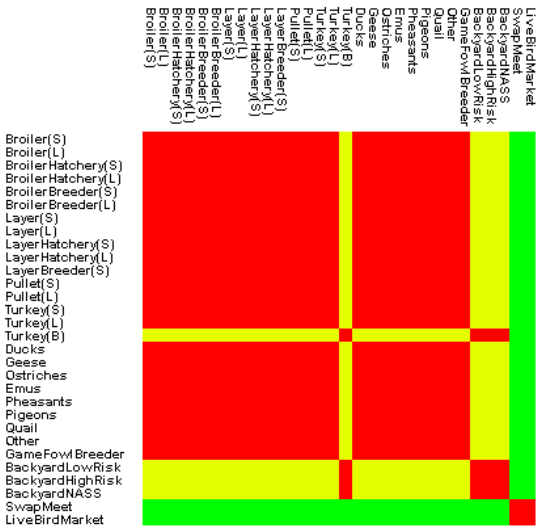
MESA interaction parameters for IndirectEggs



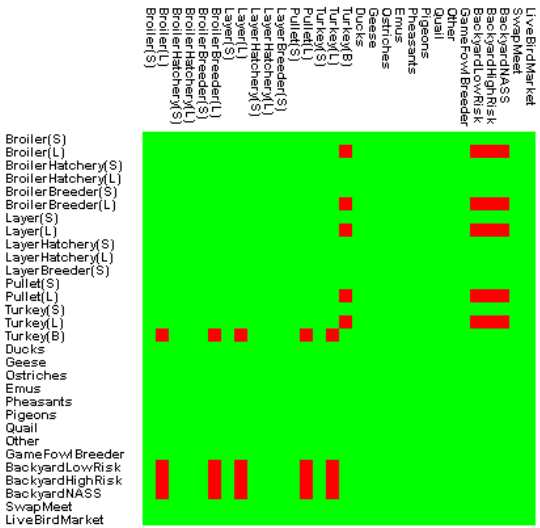
MESA interaction parameters for IndirectHighRisk



MESA interaction parameters for IndirectLowRisk

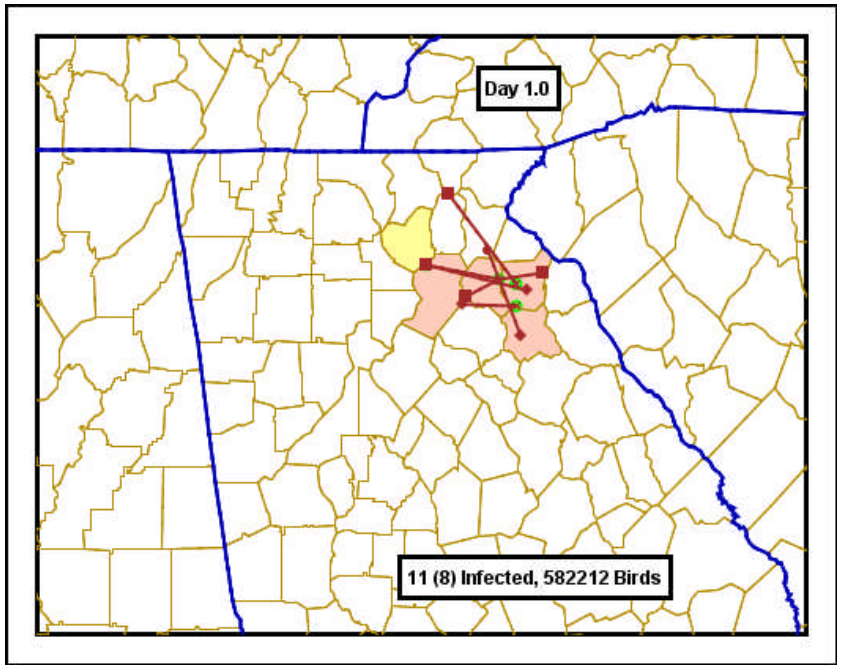


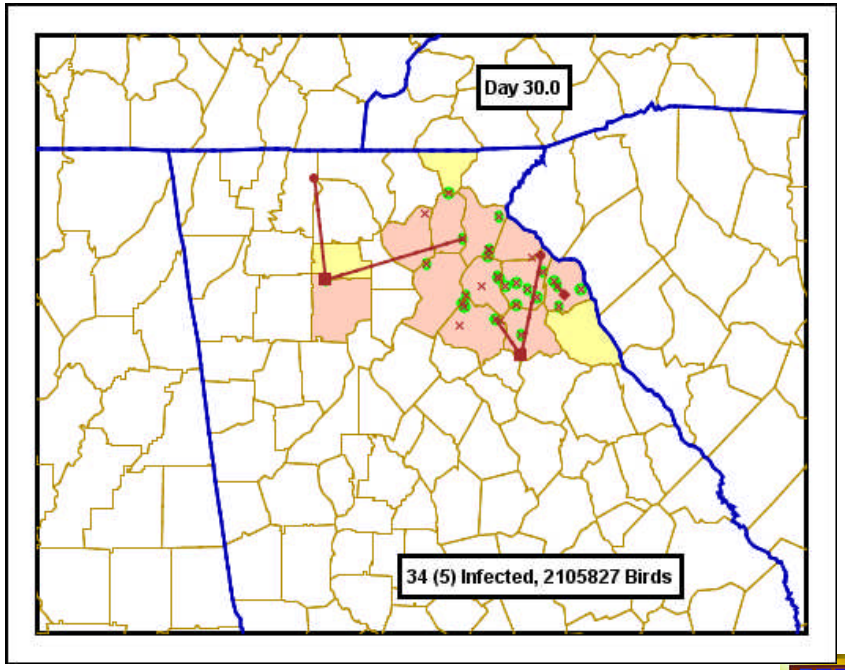
MESA interaction parameters for IndirectWorkers



Baseline response and controls

- **IZ 5km (using 5km vs. 3km due to uniform random distribution of facilities)**
- **BSZ = county and neighboring county if within 5km**
- **Awareness increases post confirmation**





Contact reductions post-confirmation

Type of Contact	Subtype	Infected Zone	BSZ
Direct	Industry	.95	.95
	Backyard (Low Risk)	.8	.8
	Backyard (High Risk)	.5	.5
Indirect - high risk		.5	.5
Indirect - low risk		.5	.5

Four scenarios with and without vaccination were investigated

CS1: Multiple (3) index farms in multiple counties in California

Counties: Fresno, San Joaquin, and Stanislaus, CA

Industry: Broilers and layers

CS2: Multiple (3) index farms in Minnesota, Pennsylvania, and Virginia

Counties: Stearns, MN, Lancaster, PA, and Rockingham, VA

Industry: Broilers, layers, and turkeys

CS3: Multiple (2) index farms in Arkansas

Counties: Benton, AR

Industry: Broilers and backyard

CS4: Single index farm in Iowa

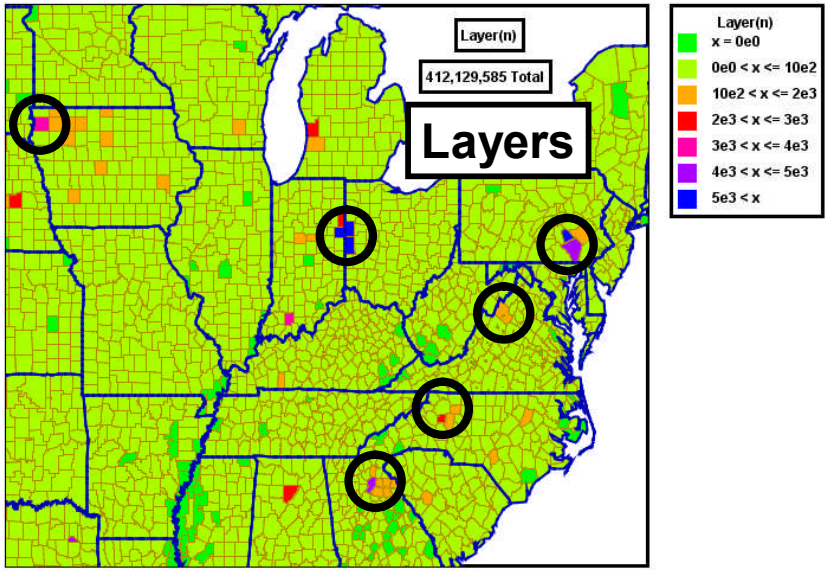
Counties: Guthrie, IA

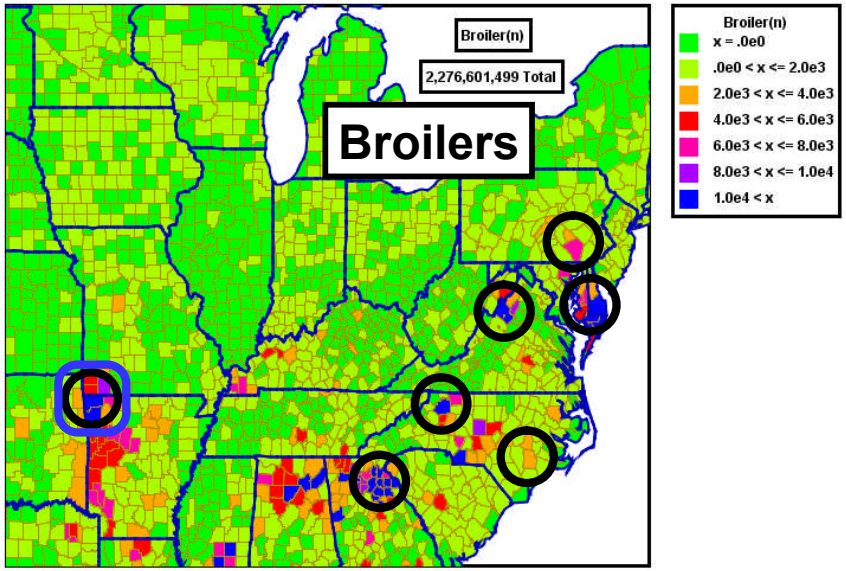
Industry: Layers

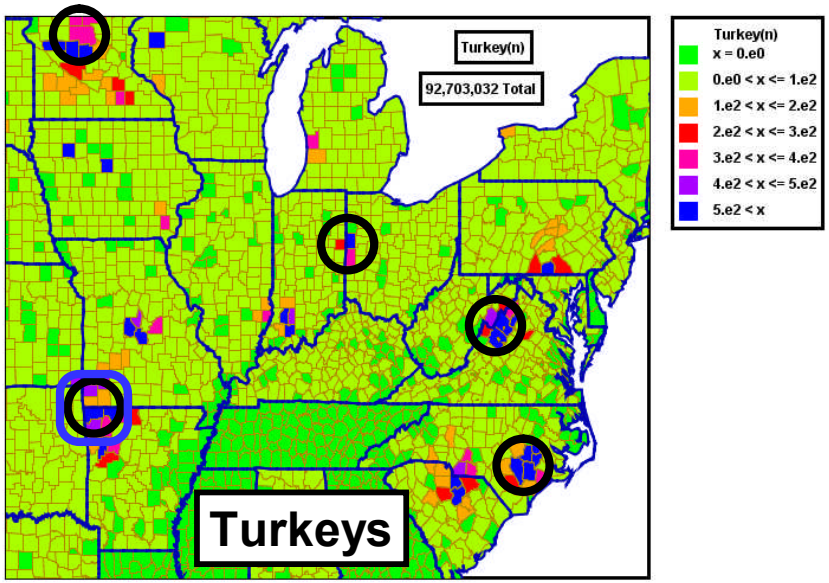
Various high-density poultry regions of the country were also investigated

11 high-density counties in the country with varying industry compositions were investigated

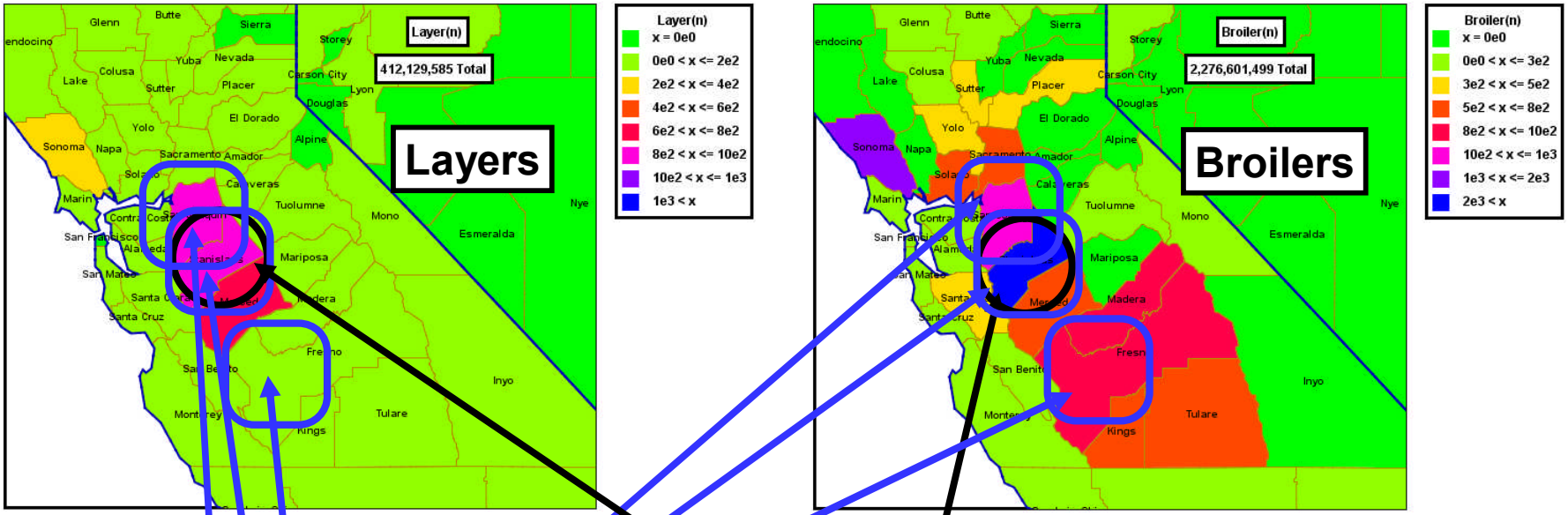
Benton, AR; Stanislaus, CA; Sussex, DE; Banks, GA; Sioux, IA; Stearns, MN; Wilkes, NC; Duplin, NC; Mercer, OH; Lancaster, PA, Rockingham, VA







Index Farms in California

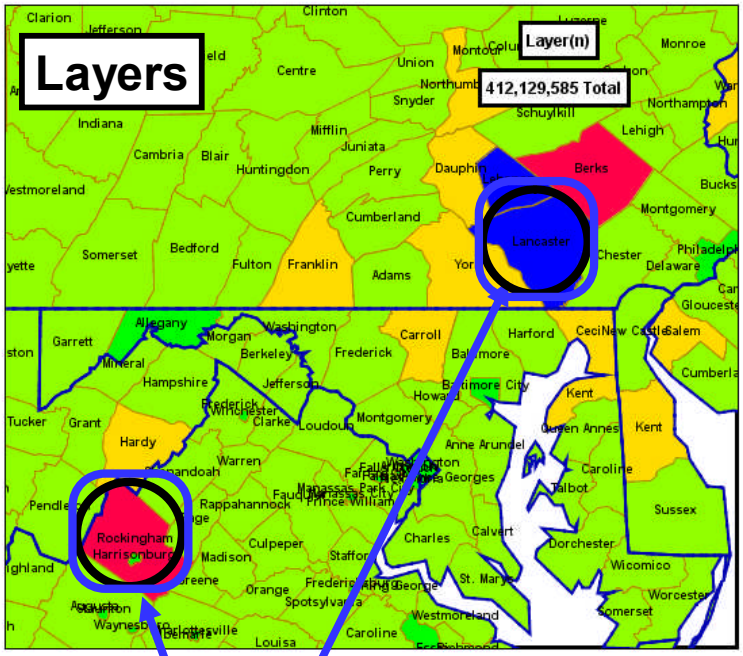


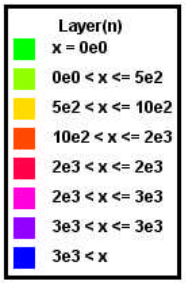
Scenario CS1

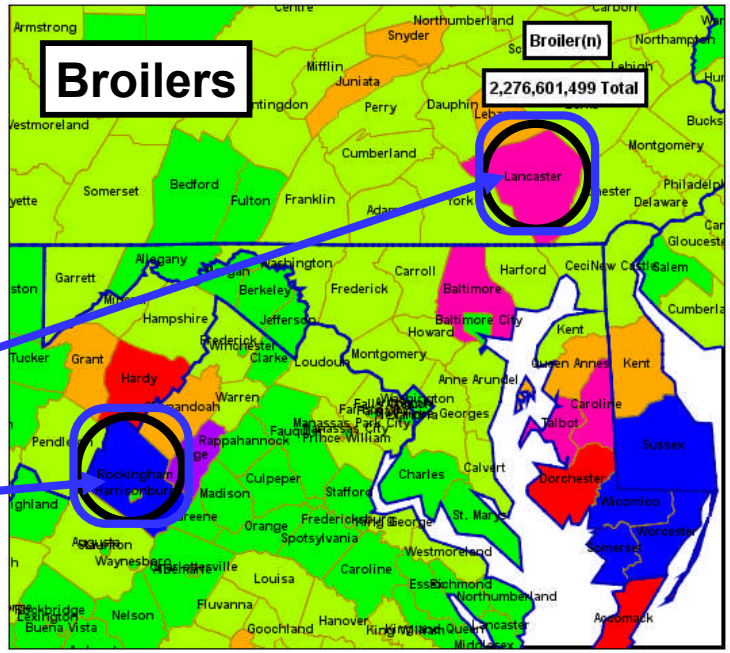
Fresno, San Joaquin, and Stanislaus

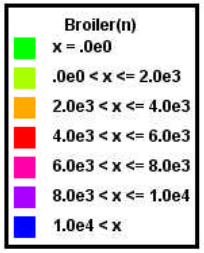
Single index farm in Stanislaus

Index Farms in Mideast









Scenario CS2

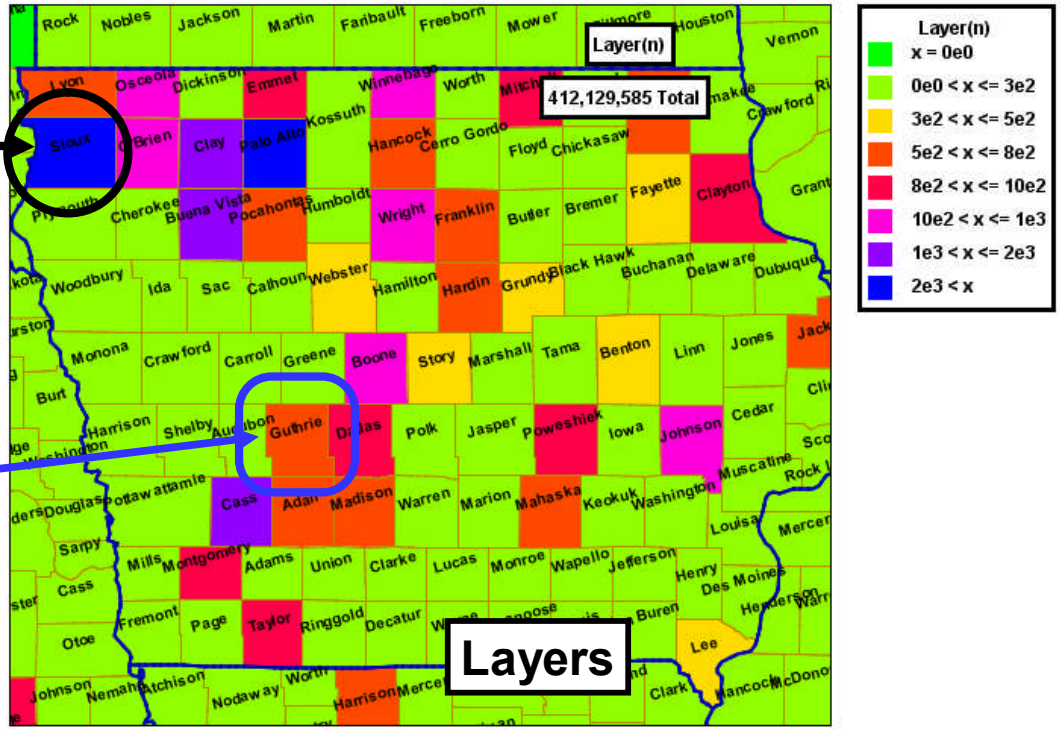
Lancaster, PA, Rockingham, VA, plus Stearns, MN

Index Farm in Iowa

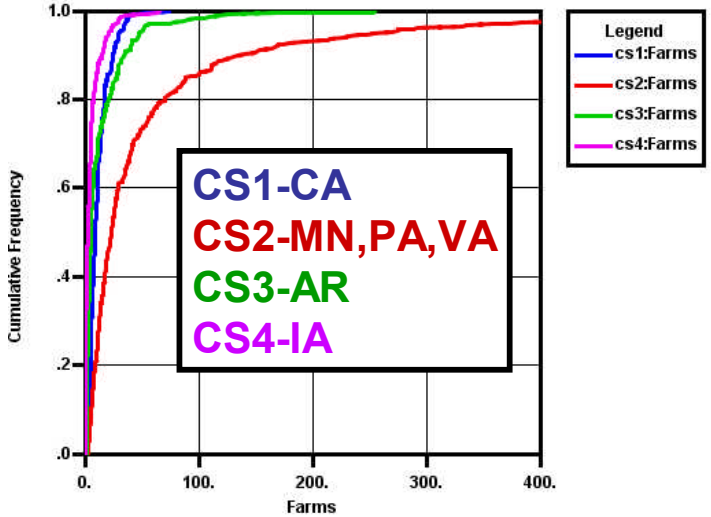
Single index farm in Sioux

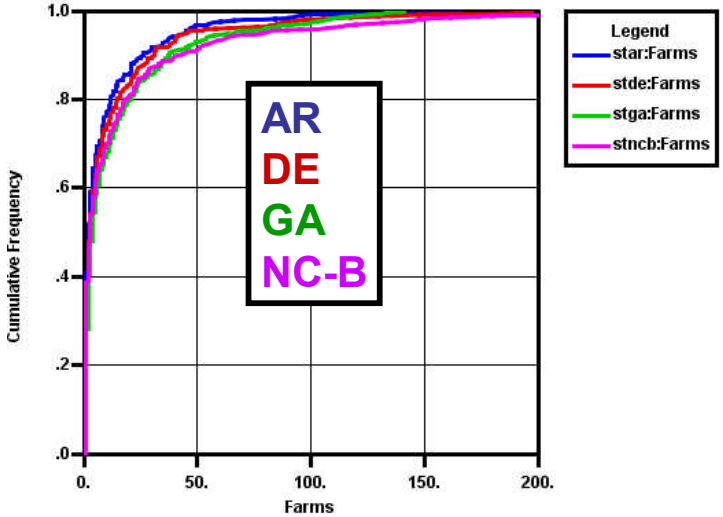
Scenario CS4

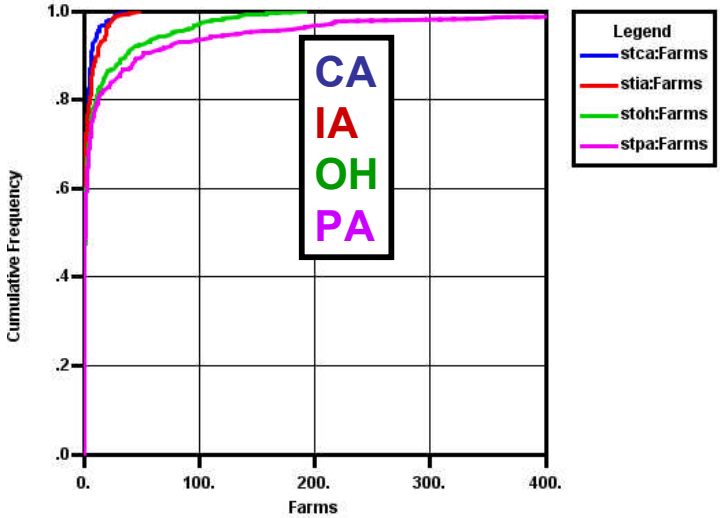
Guthrie, IA

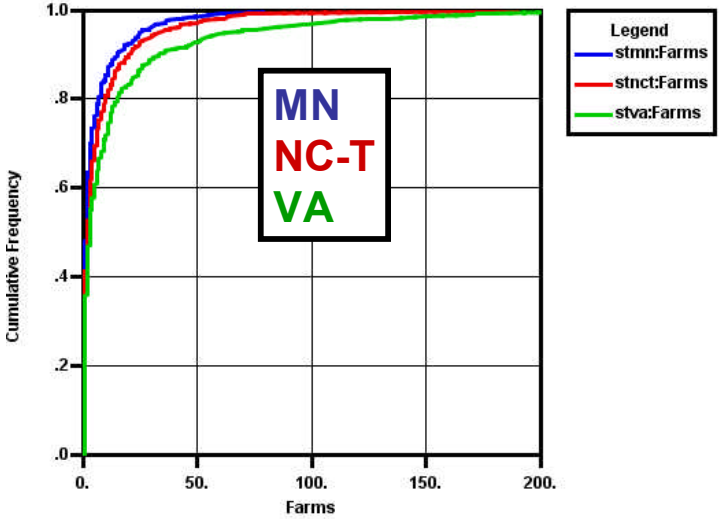


Comparisons: Farms

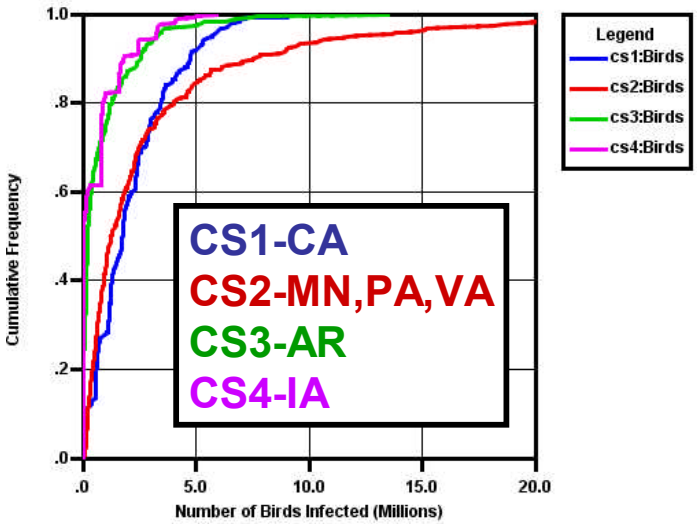


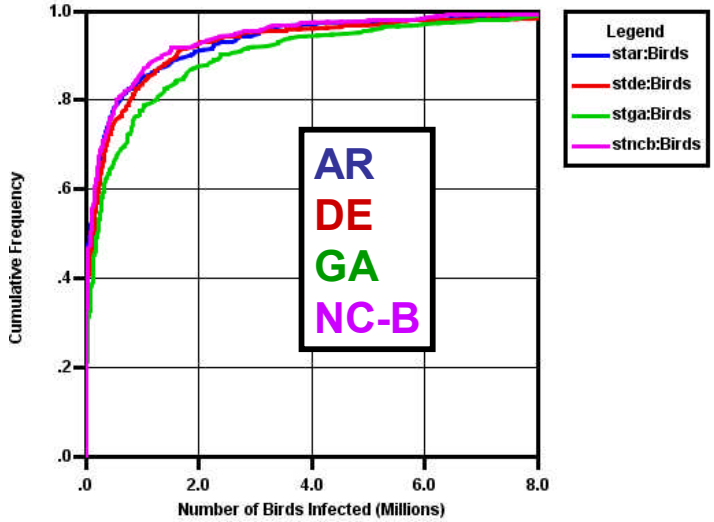


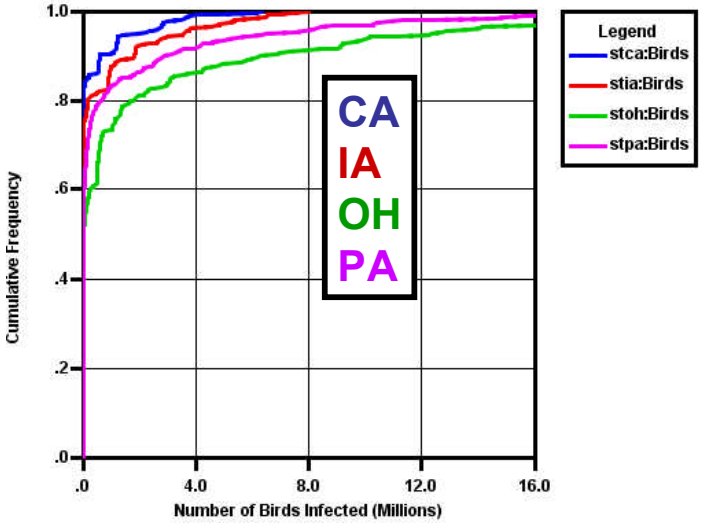


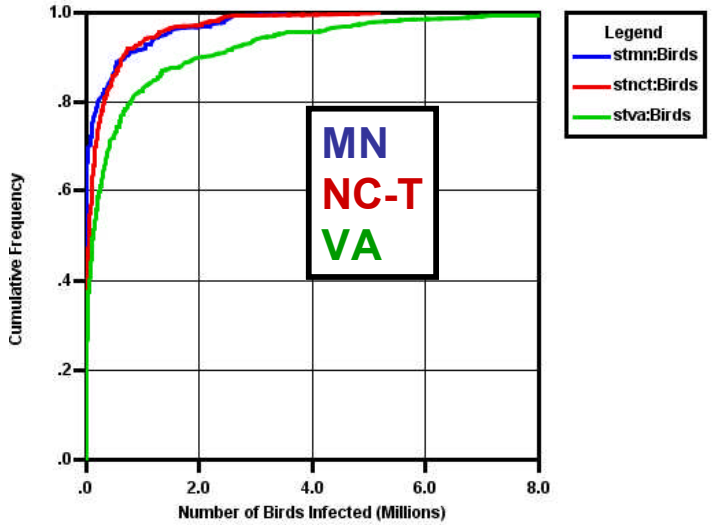


Comparisons: Birds

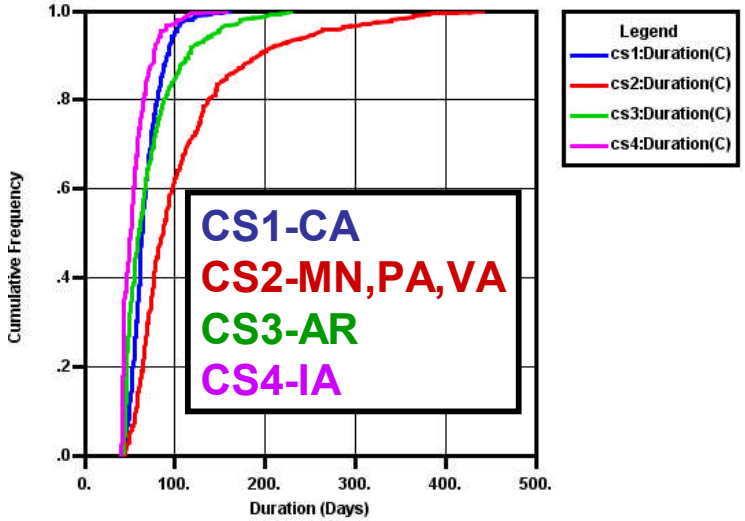


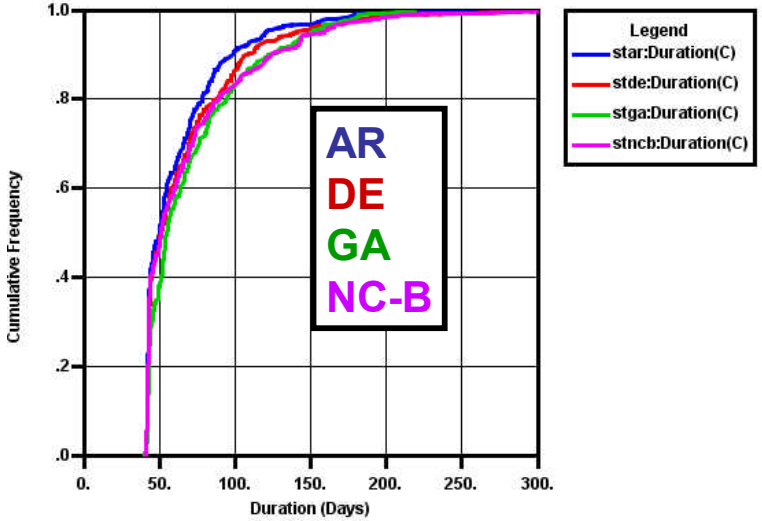


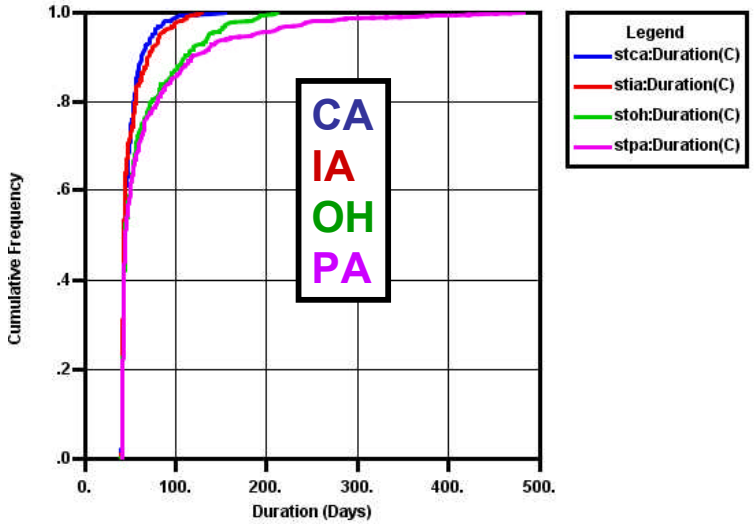


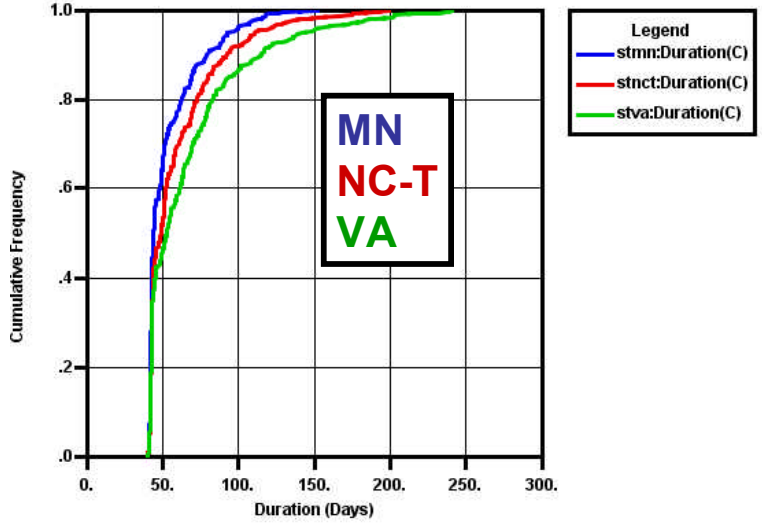


Comparisons: Duration

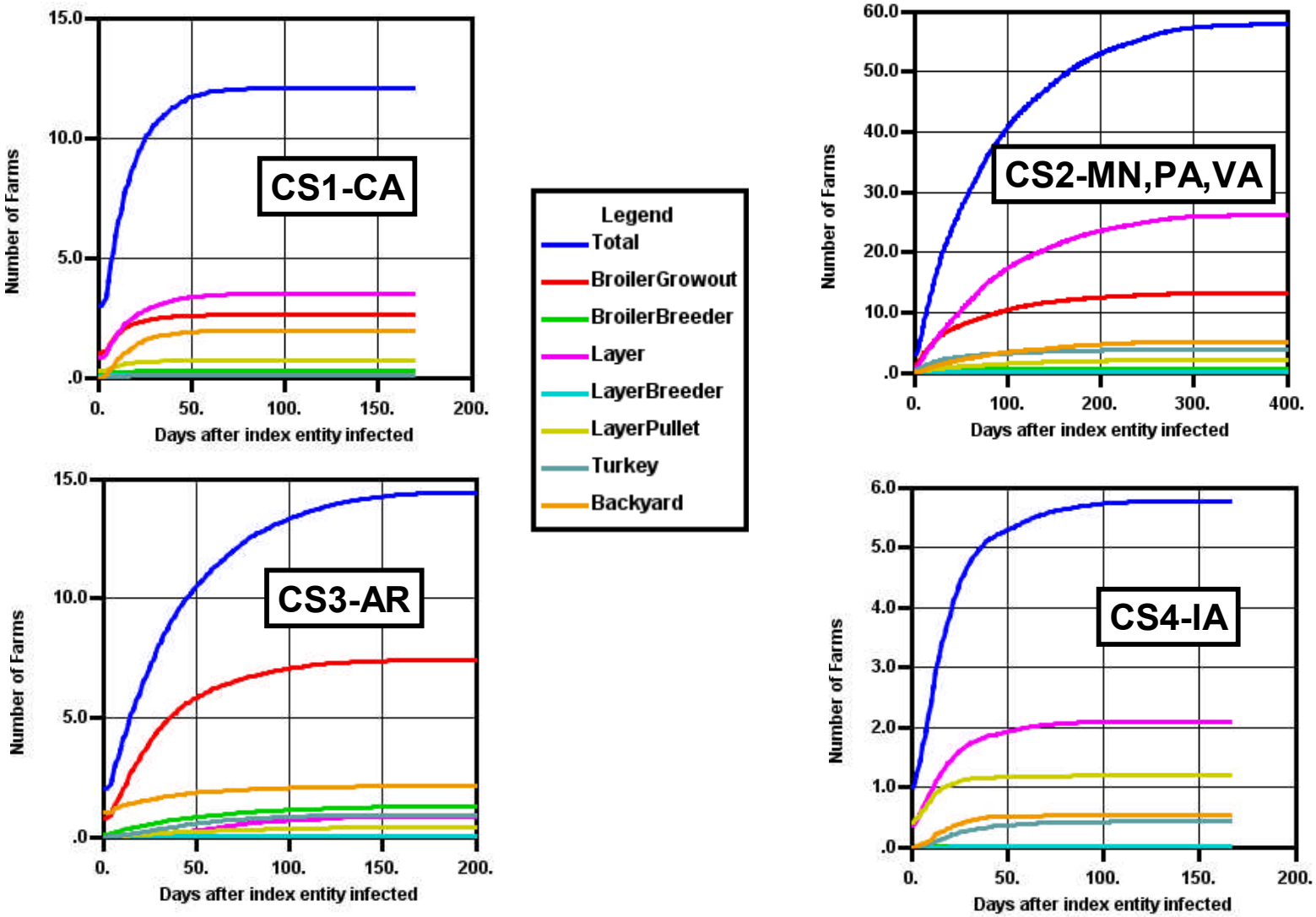




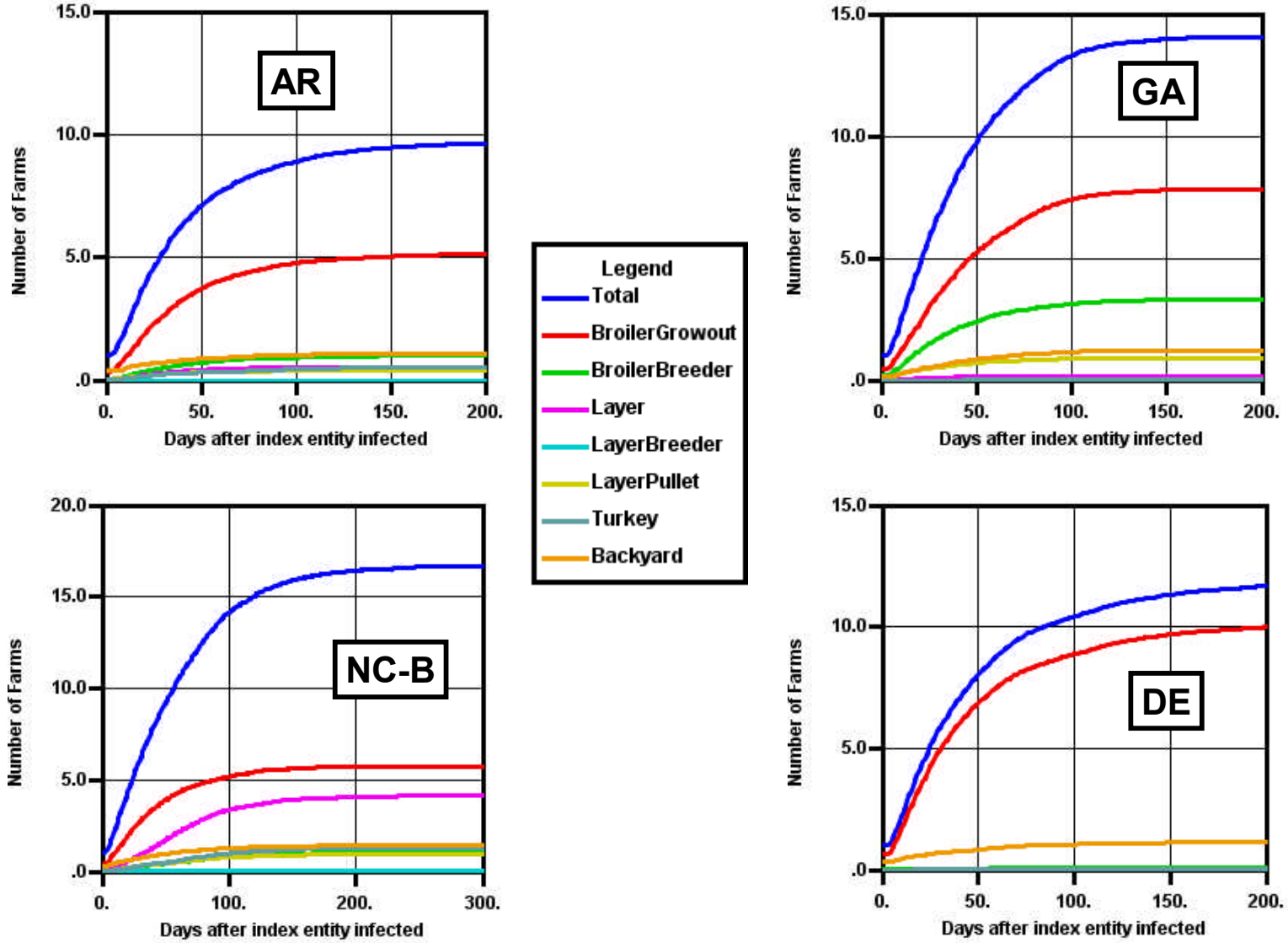




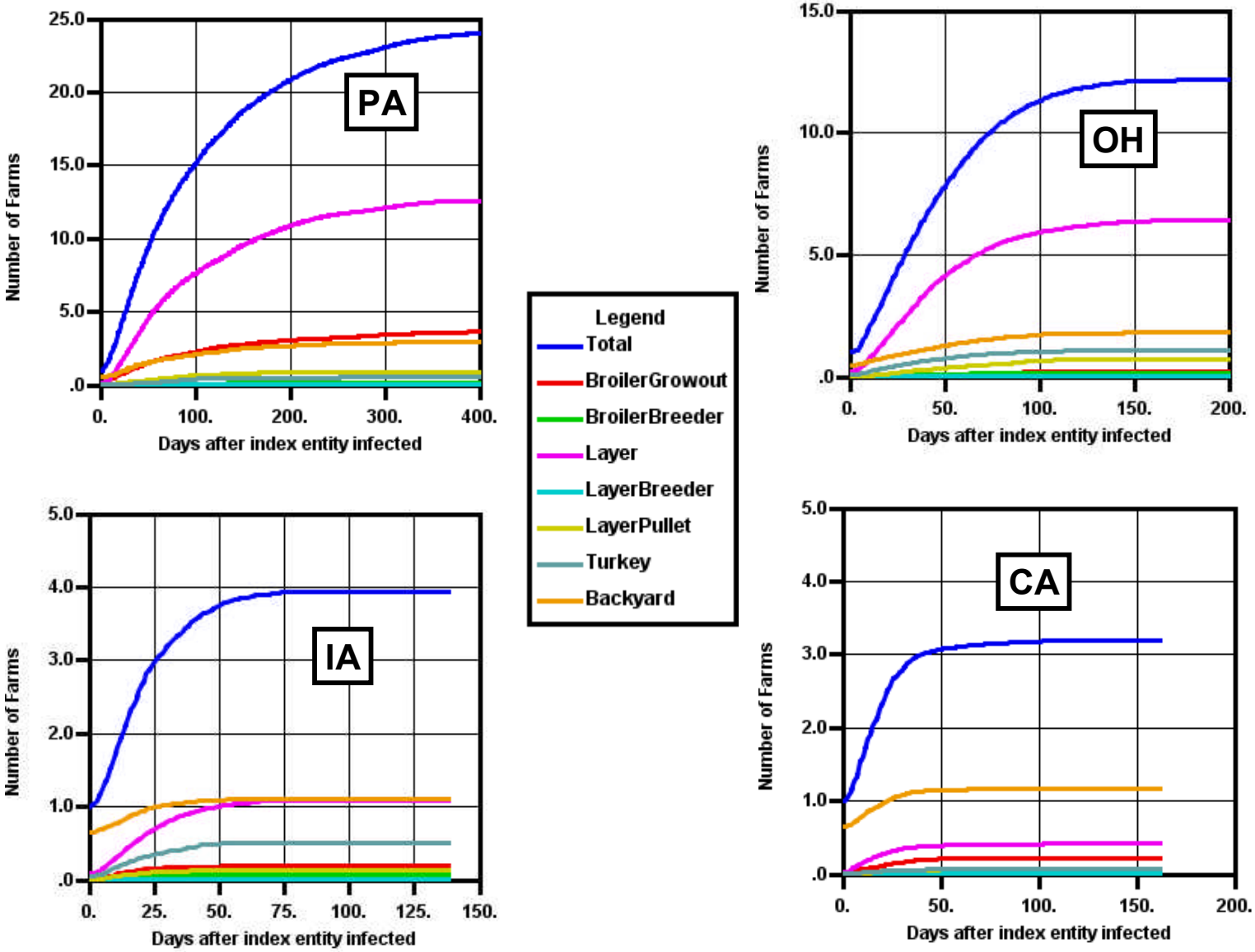
Industry types becoming infected - Scenarios



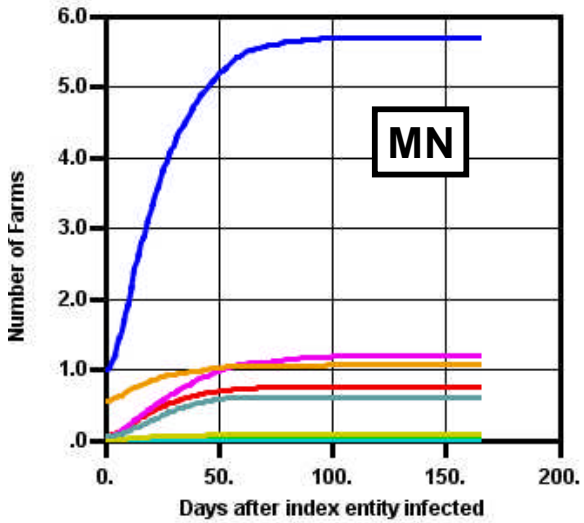
Industry types becoming infected - Broilers

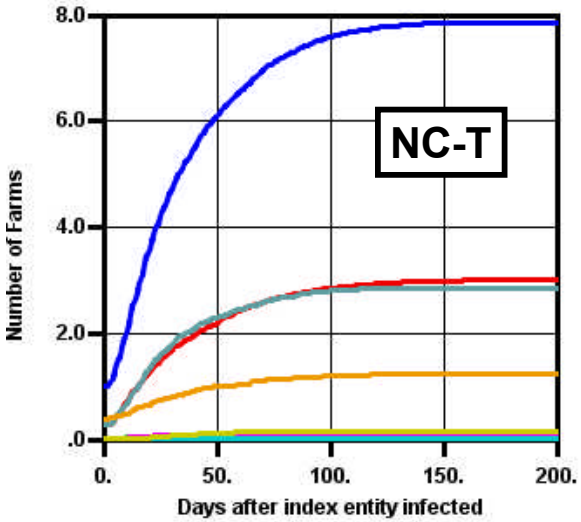


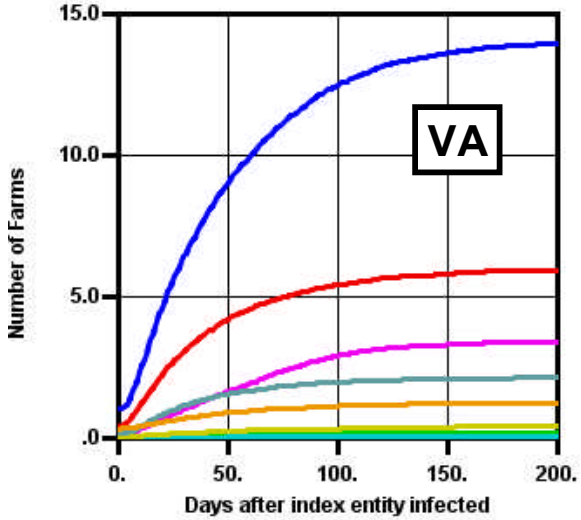
Industry types becoming infected - Layers



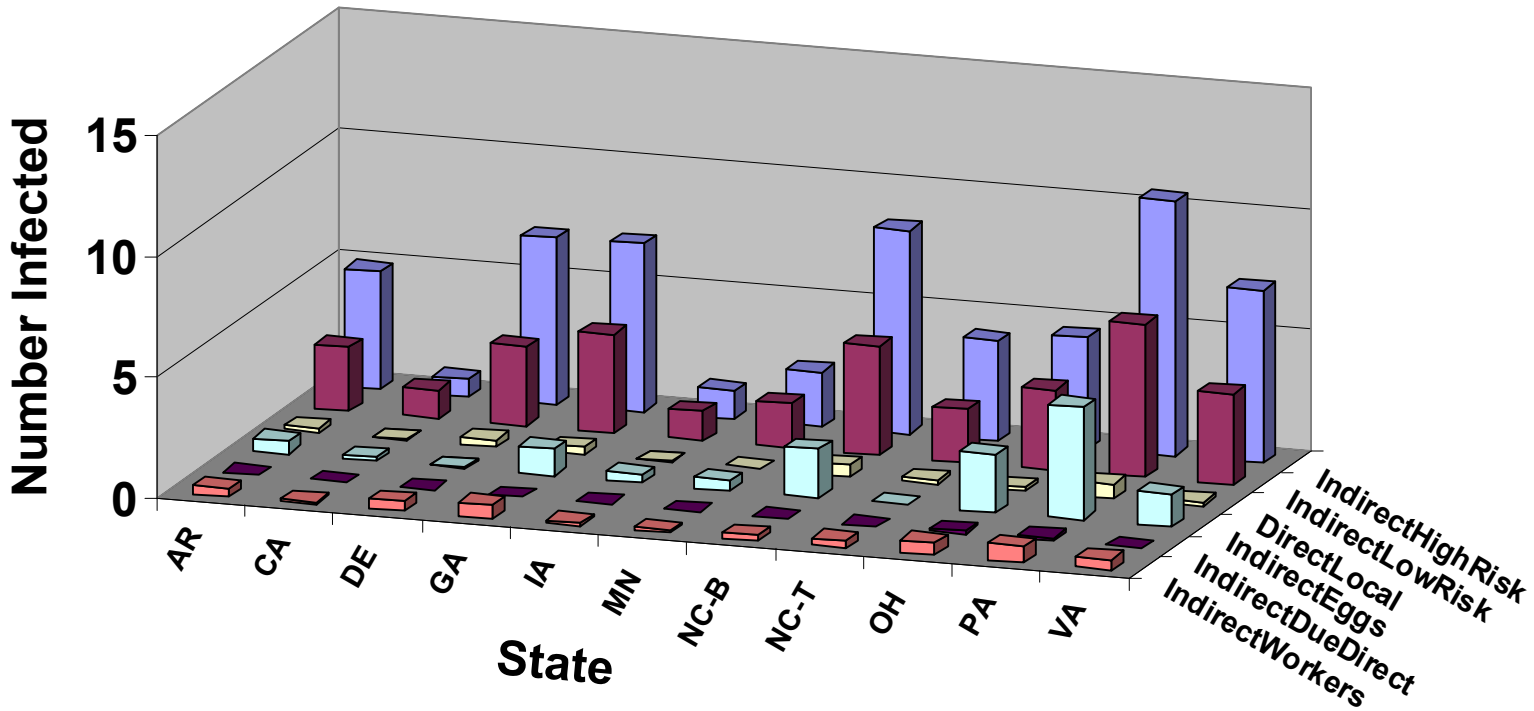
Industry types becoming infected – Turkeys, Mixed



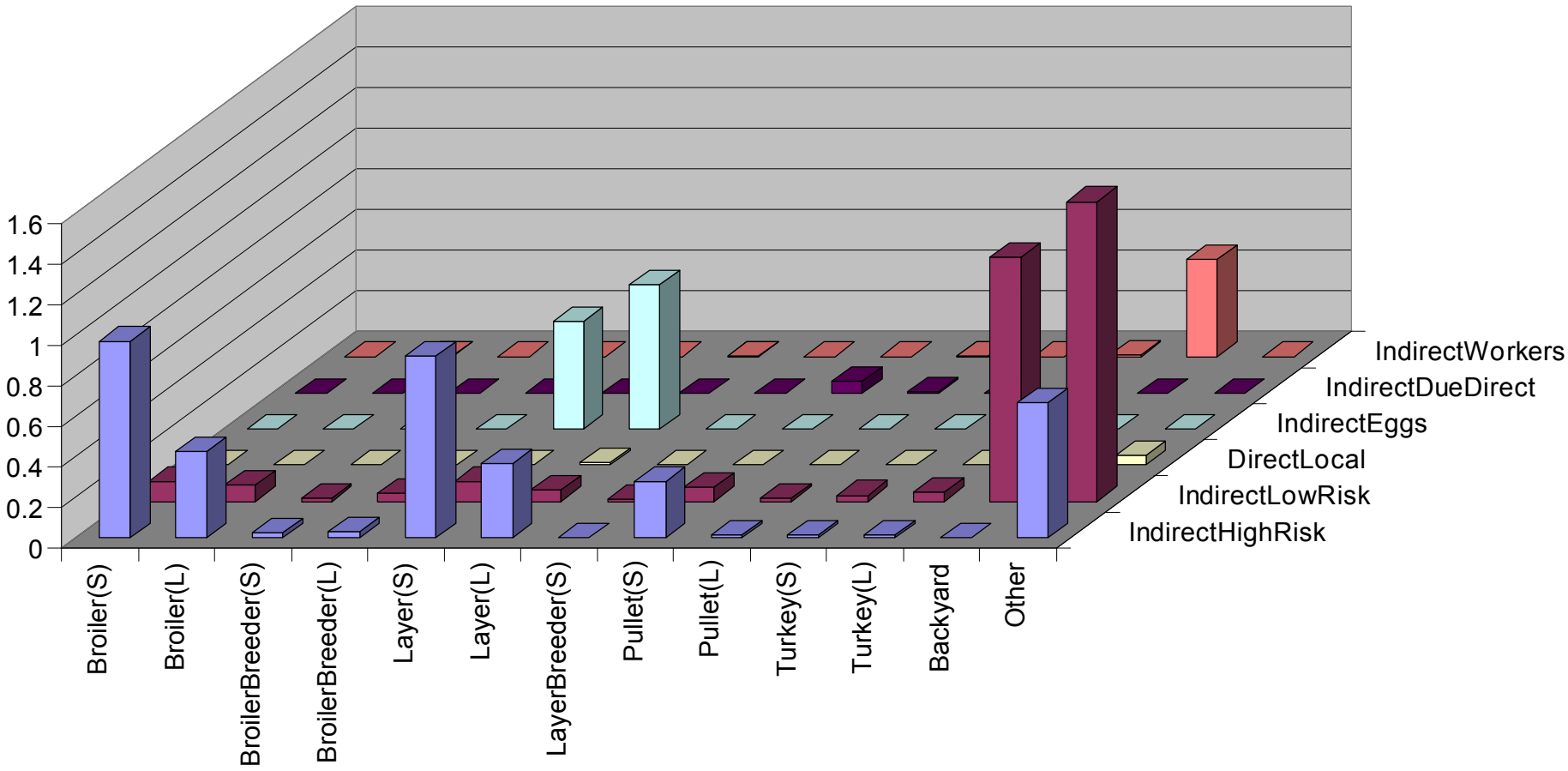




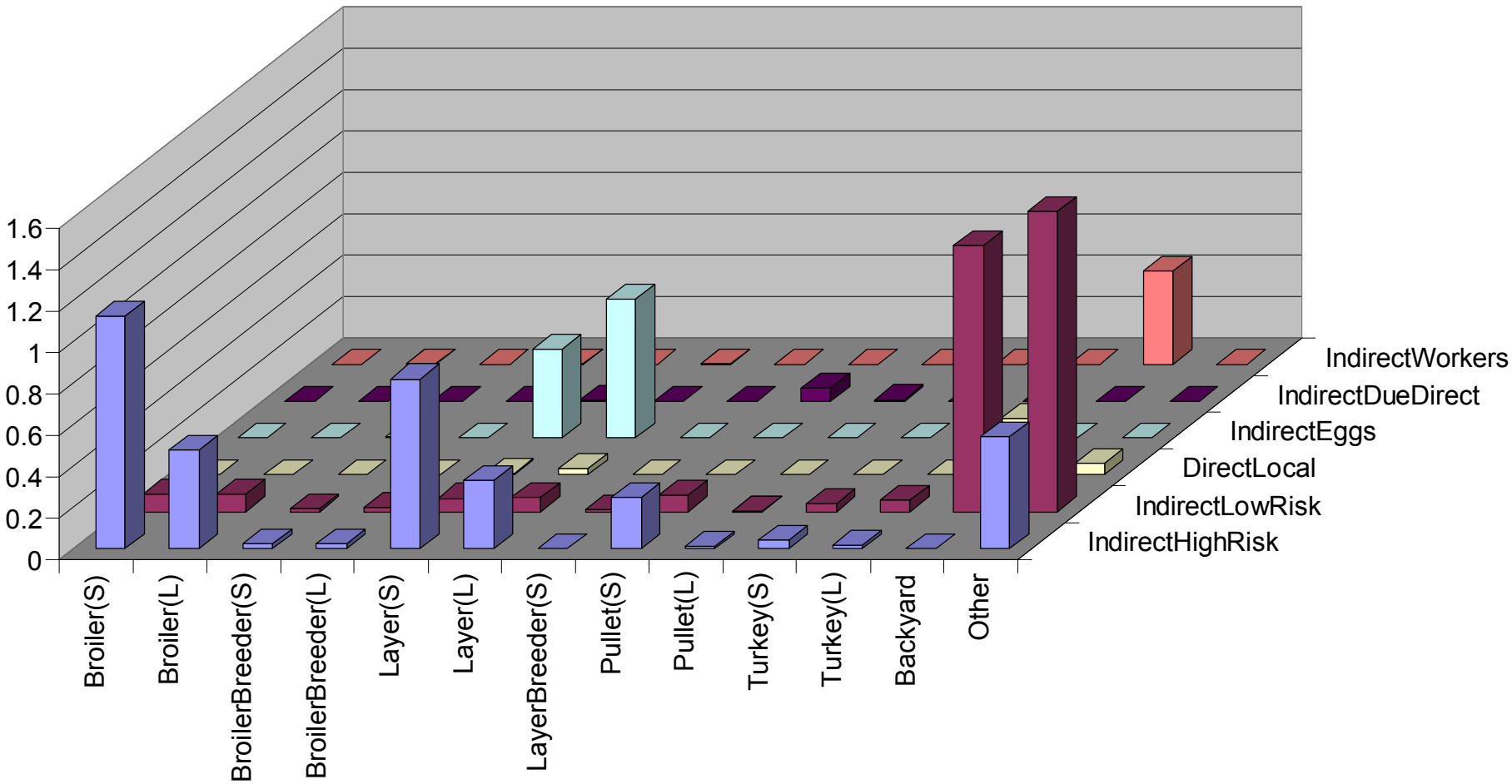
Infection by spread method varies by state



Average number of flocks infected with HPAI following introduction into one commercial broiler or layer facility in each of Fresno, San Joaquin, and Stanislaus Counties, CA (Scenario 1)



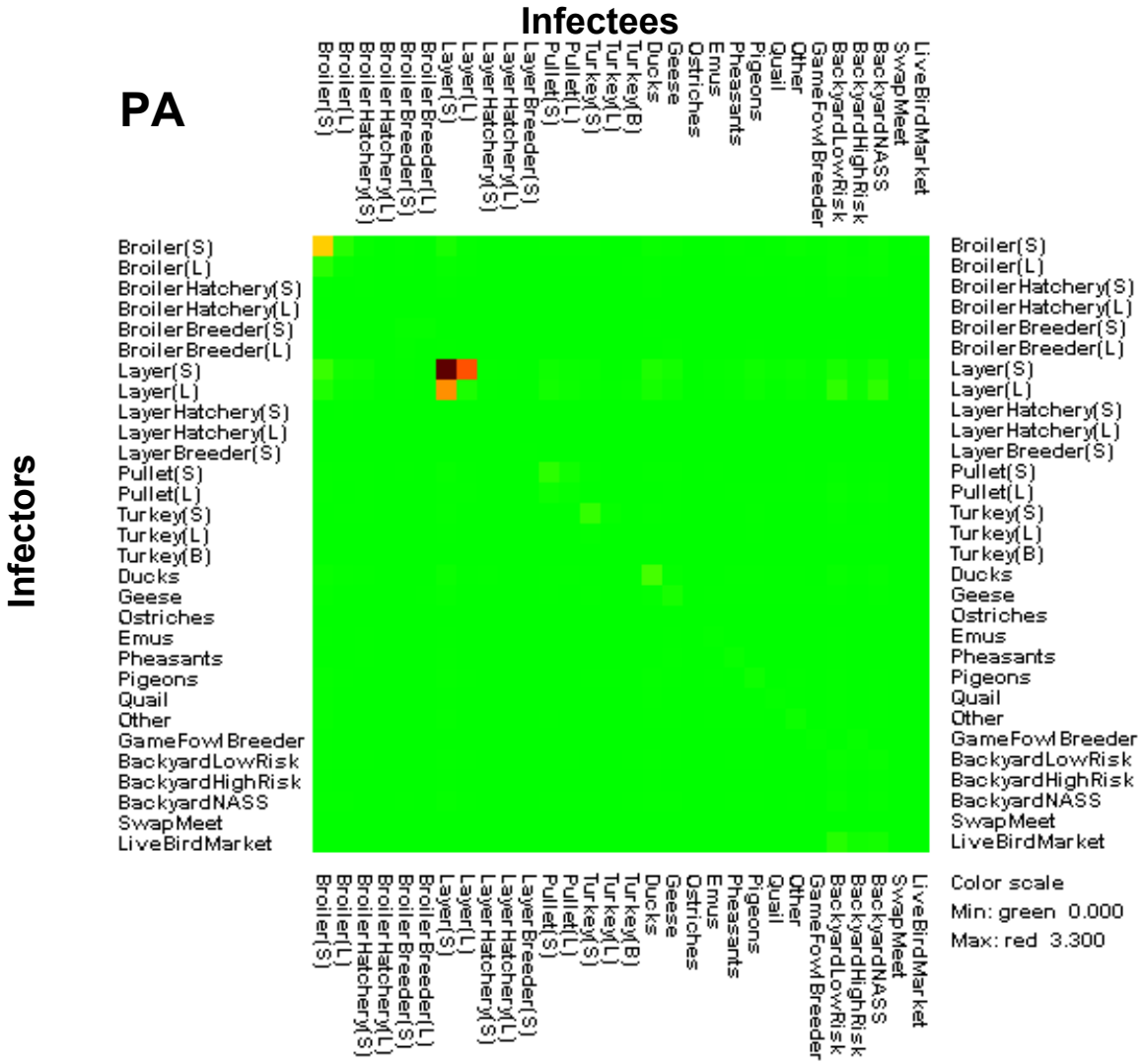
Average number of flocks infected with HPAI for Scenario 1 with vaccination on triggers (Scenario V-1)



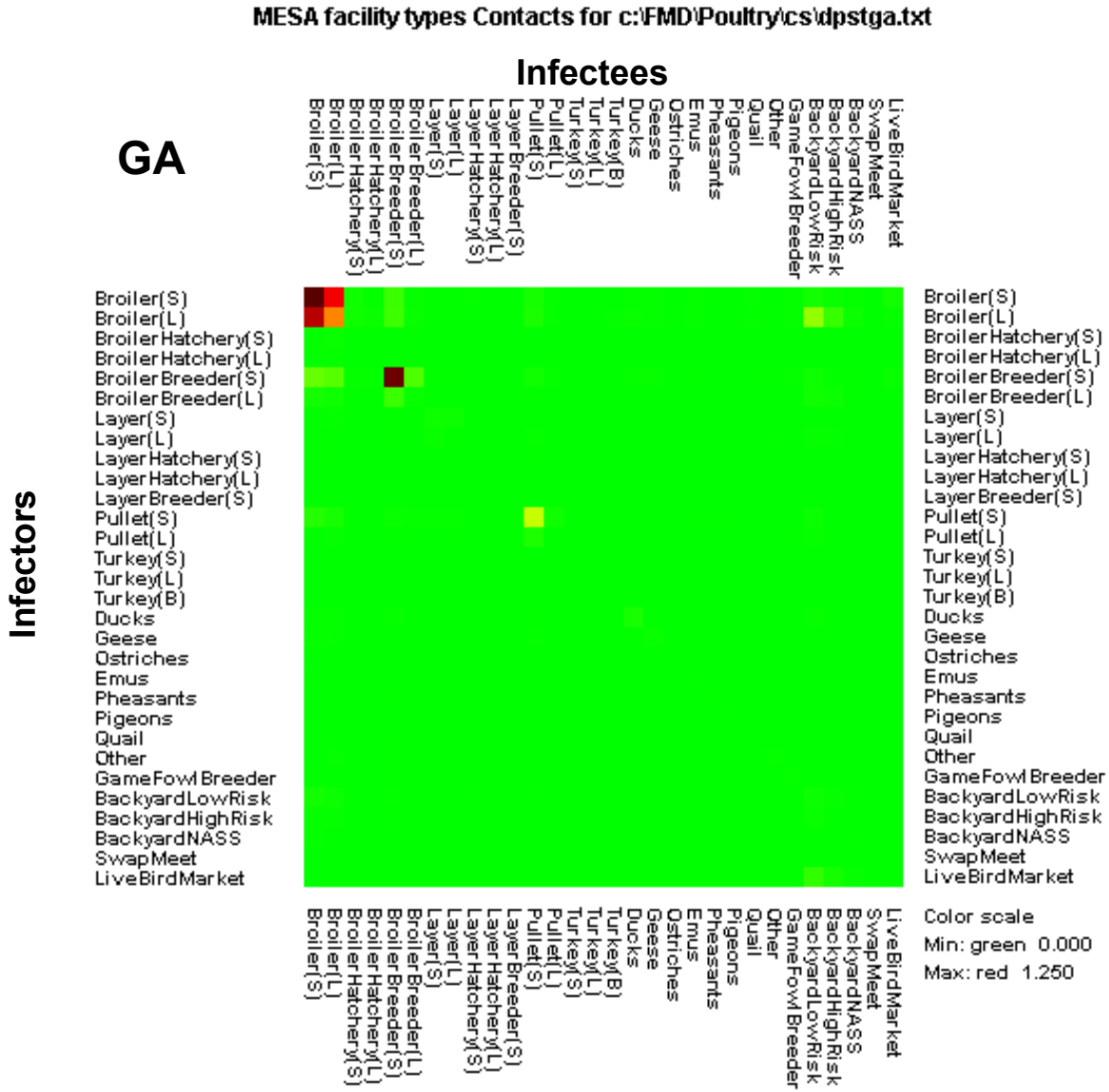
Who infected whom: Pennsylvania

MESA facility types Contacts for c:\FMD\Poultry\cs\dpstpa.txt

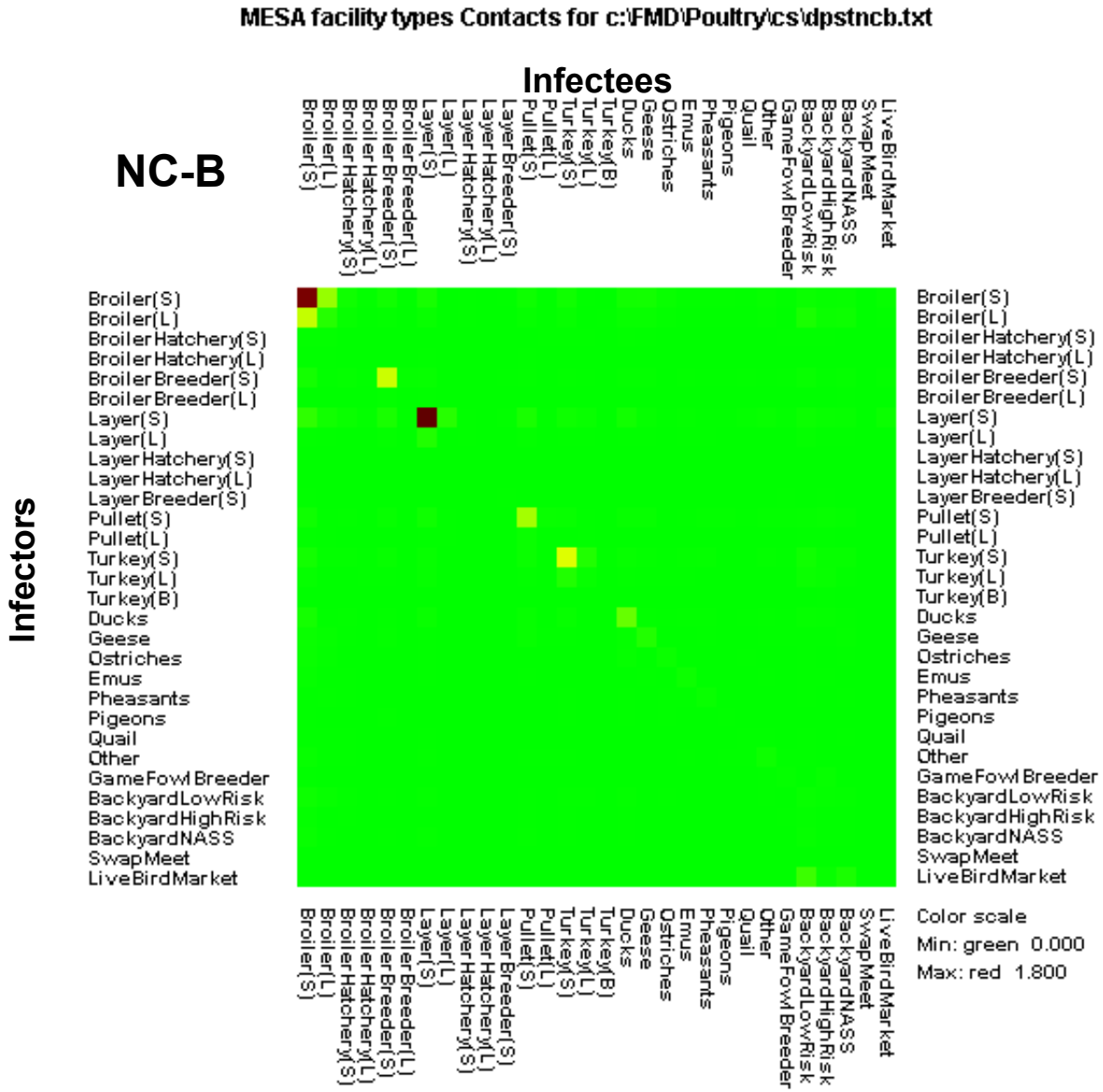
PA



Who infected whom: Georgia



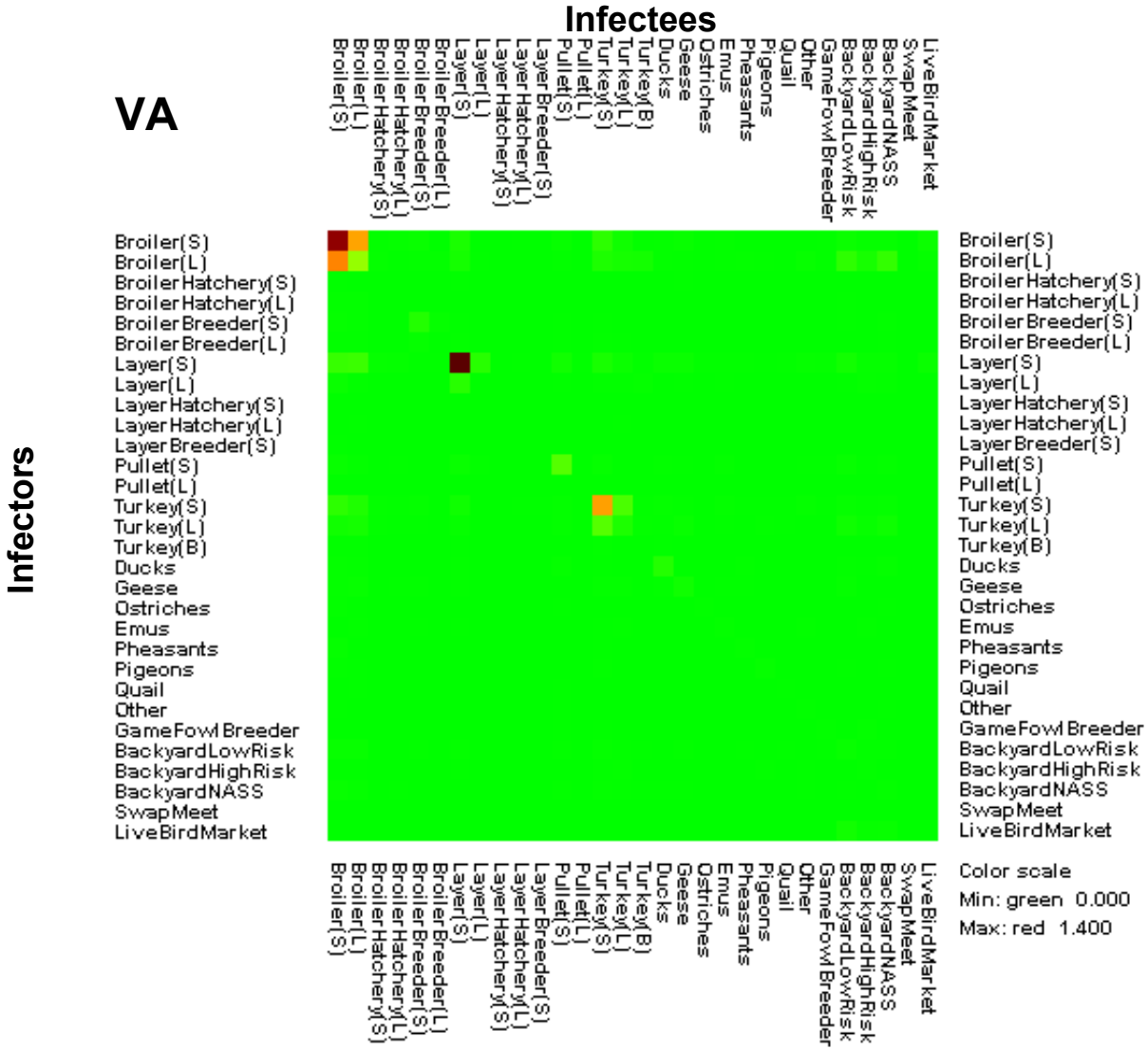
Who infected whom: North Carolina Broilers



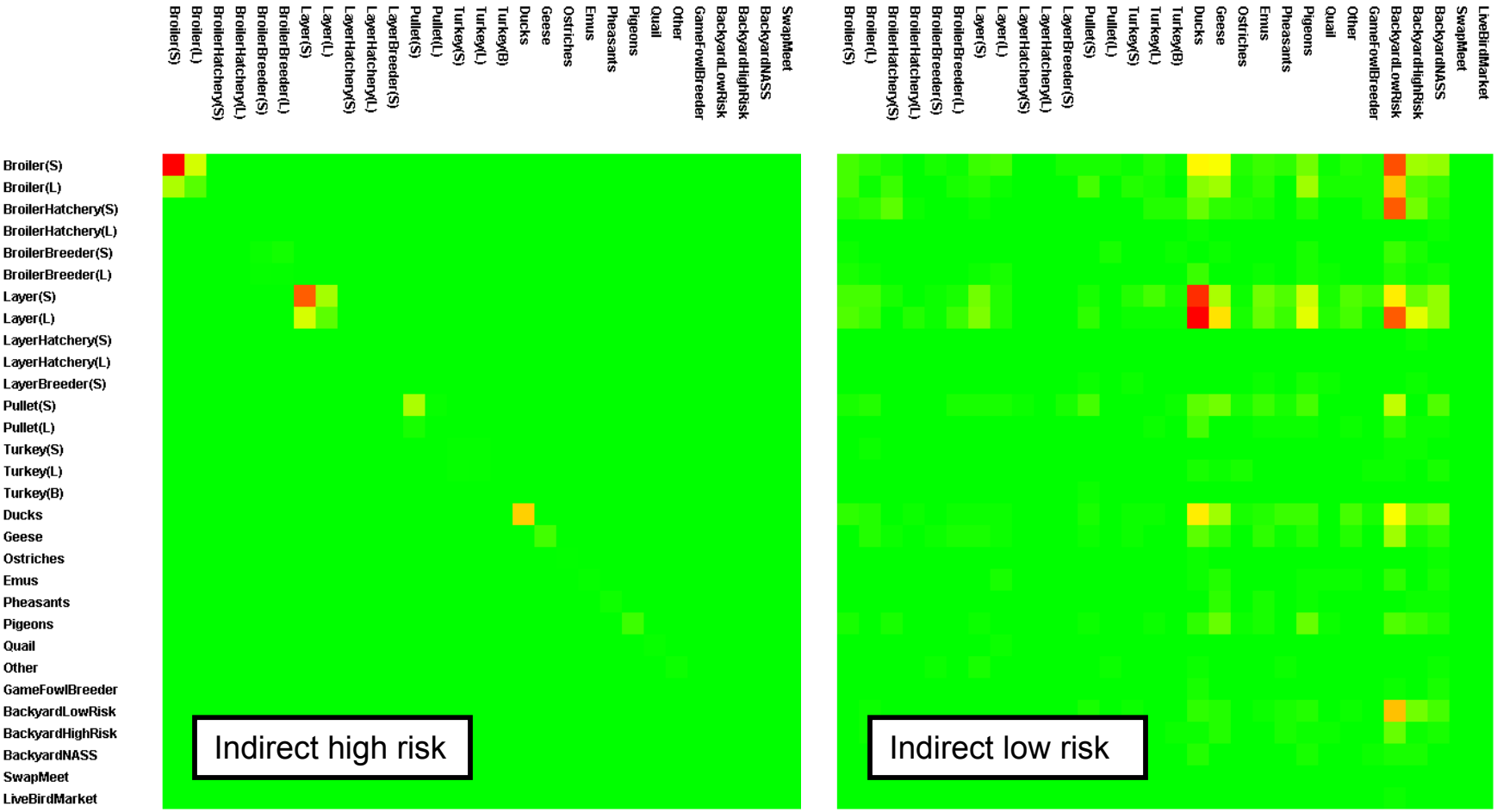
Who infected whom: Virginia

MESA facility types Contacts for c:\FMD\Poultry\cs\dpstva.txt

VA



Average effective contacts for Scenario 1



MESA triggers and delays for vaccination events

1. Decide	Time for decision trigger to occur in a simulation run. 1) 3 premises infected in 2 days; or 2) at least two different facility types infected.
2. Implement	Vaccine will be delivered to all producers in infected and neighboring counties. Time to deliver vaccine can be random for each premises, from a probability distribution that is specific to each facility type. E.g., Triangular 1-3 days for layer hatcheries; Triangular 17-21 days for broiler and layer parent stock, and commercial layers; Bi-modal for pullets.
3. Administer	Time to administer vaccine can be random for each premises, from a probability distribution that is specific to each facility type.
4. Protect	E.g., 95 percent flock immunity is reached at 7 days for all flocks.

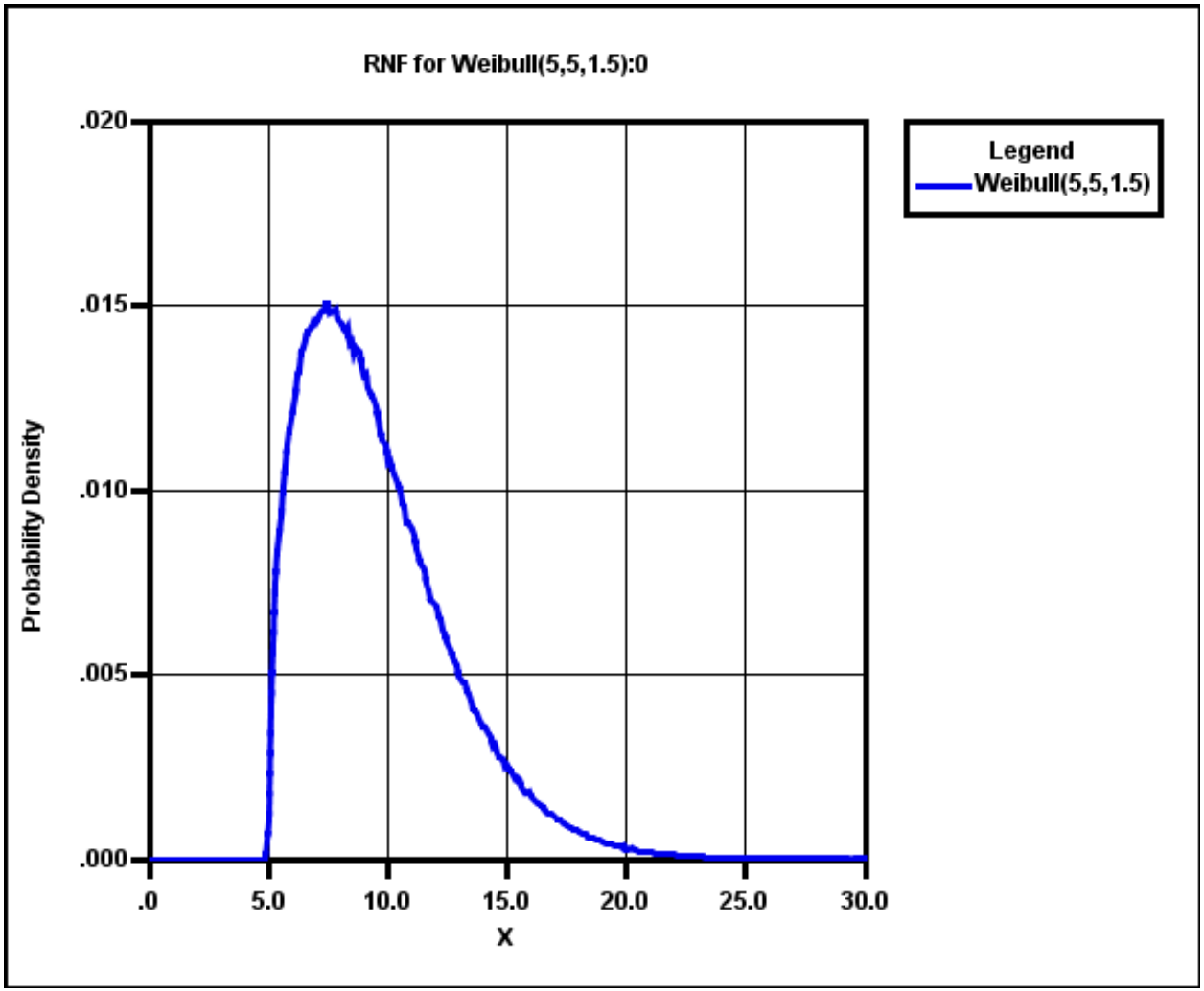
Table shows trigger and delay parameters for vaccination in the MESA model

Parameter	Pox-vectored	Killed	Half pox-vectored and half killed
Trigger	Vaccine will be delivered to all premises in infected and surrounding counties upon a trigger. Use: 1)3 premises confirmed in 2 days; **or** 2)At least two different facility types confirmed (operation type definition used here).		
Facilities receiving each vaccine type	Layer hatcheries	Broiler Breeders, Layers, Layer Breeders	Pullets
Days to implement trigger (set up vaccination zones)	0		
Days to deliver vaccines to producers*	1-3 (triangular)	1-3 used# (17-21 real value) (triangular)	1-3 (triangular)
Days for producers to administer vaccine to flocks*	1-14 (uniform)	15-28 used# (1-14 real value) (uniform)	1-28 (uniform)
Days to onset of immunity*(see below)	Weibull (5,5,1.5)	Weibull (5,5,1.5)	Weibull (5,5,1.5)
Efficacy*	95 percent	95 percent	95 percent

*A different pdf can be specified for each facility type. Default parameters will be the same.

The extra days needed to deliver the killed vaccine needed to be accounted for in the "days to administer" as they could not (due to limits in the model) be accounted for across multi regions/facility types in the "days to deliver category".

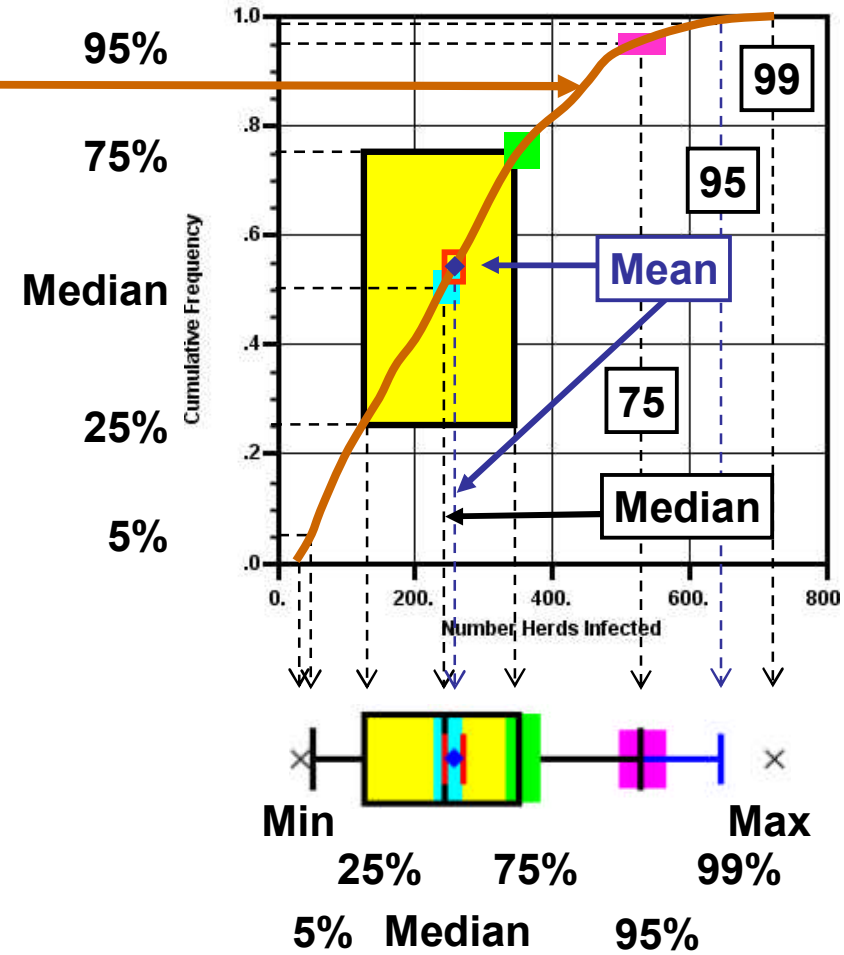
Weibull (5,5,1.5) pdf used to model time to onset of immunity. 5 days to onset, max at ~7 days and decay to 21 days.



Cumulative distribution functions can be represented by box-whisker plots

Mapping of CDF to box-whisker plot

Cumulative distribution function (CDF) representing how often an outbreak remains less than a given size



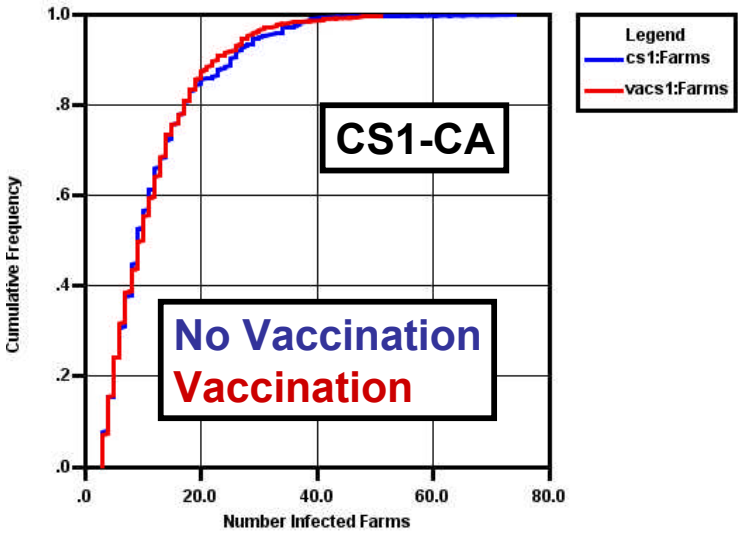
Confidence intervals for
- **Median**
- **75%**
- **95%**

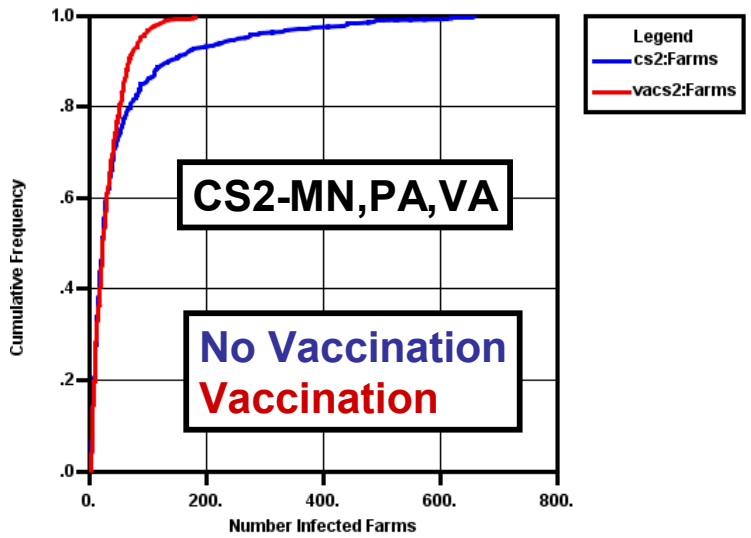
are defined by $1.96\,(N\ p\,(1-p))^{1/2}$, where N is the number of Monte Carlo runs and p is the percentile fraction

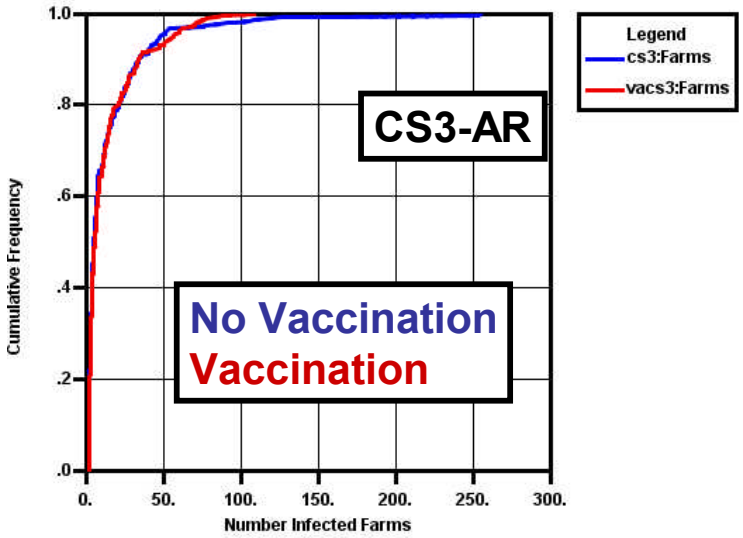
Enhanced Box-whisker plot with additional 99% whisker and uncertain ranges

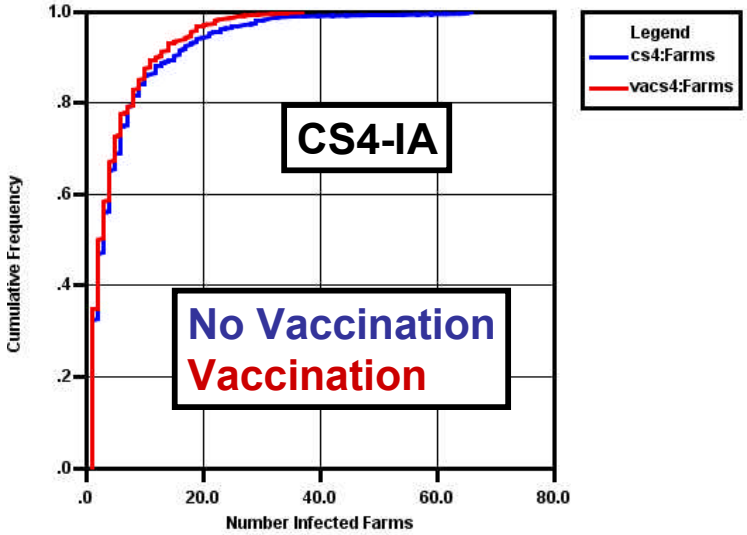
| | bars represent confidence interval for the mean ♦

Vaccination: Scenarios Farms

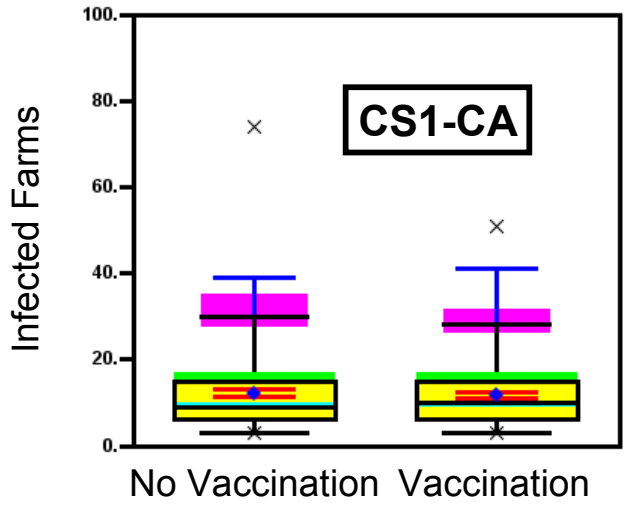


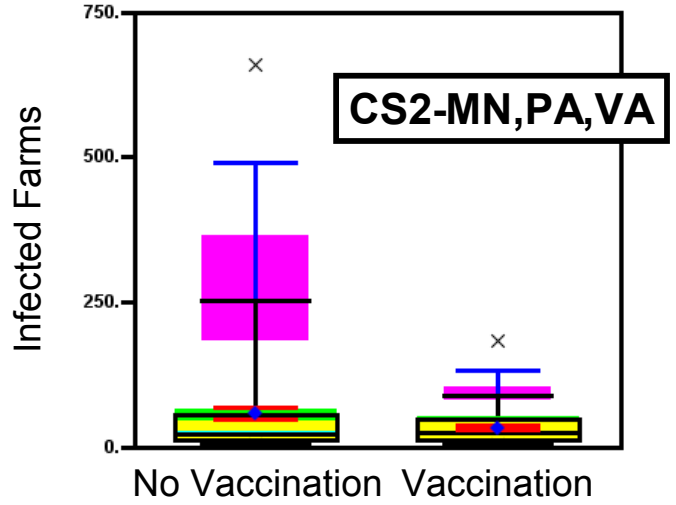


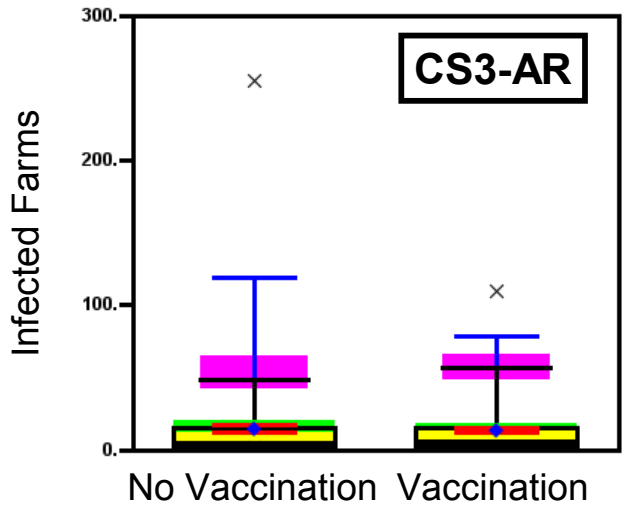


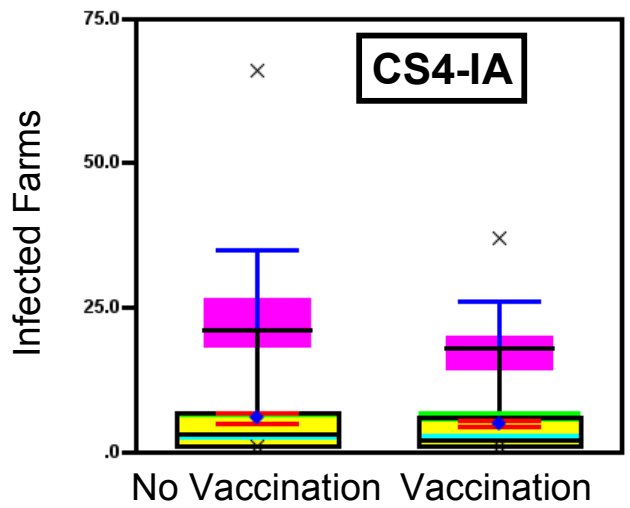


Vaccination: Scenarios Farms

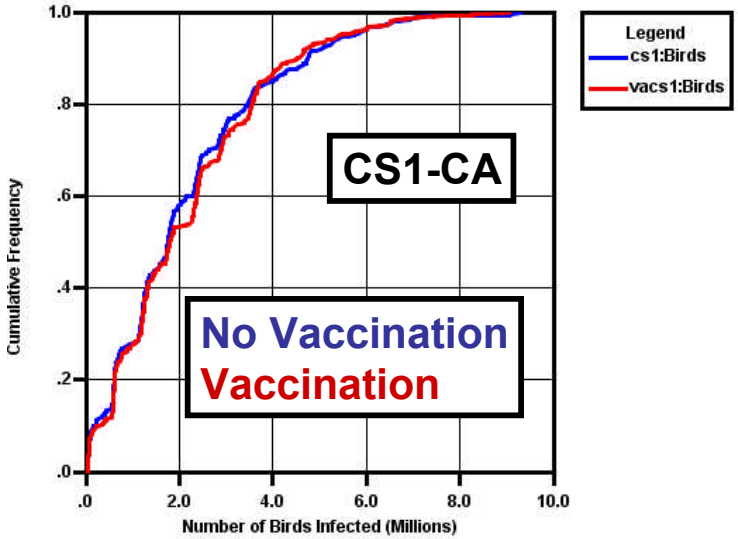


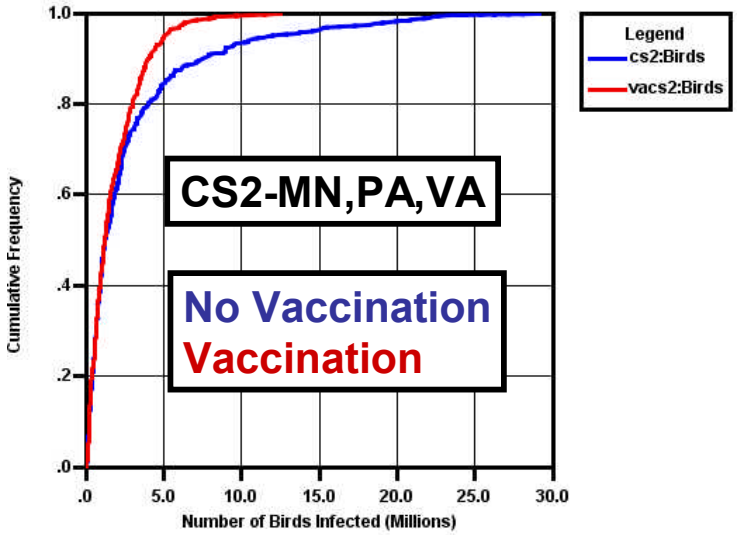


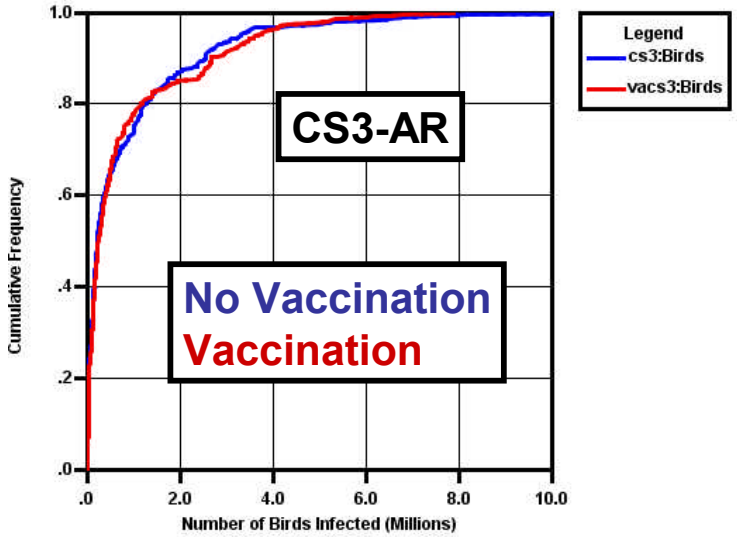


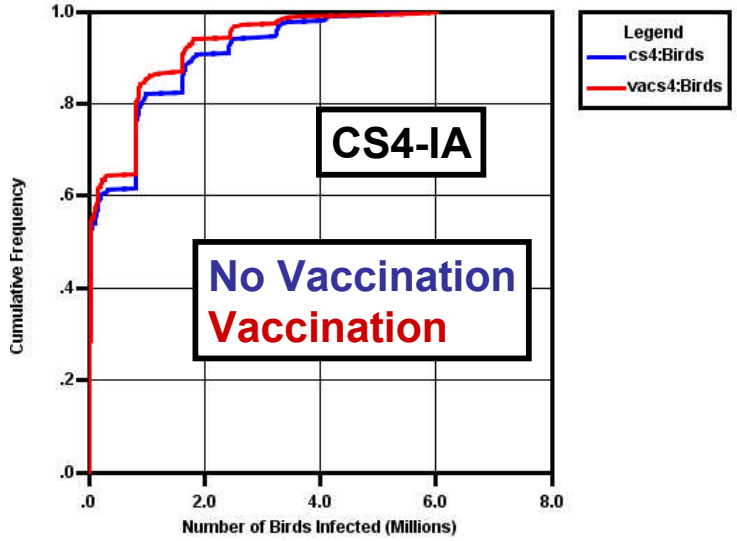


Vaccination: Scenarios Birds

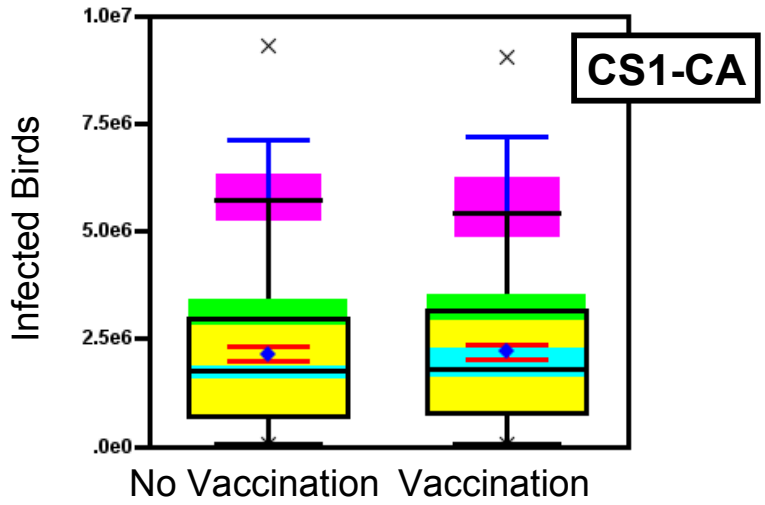


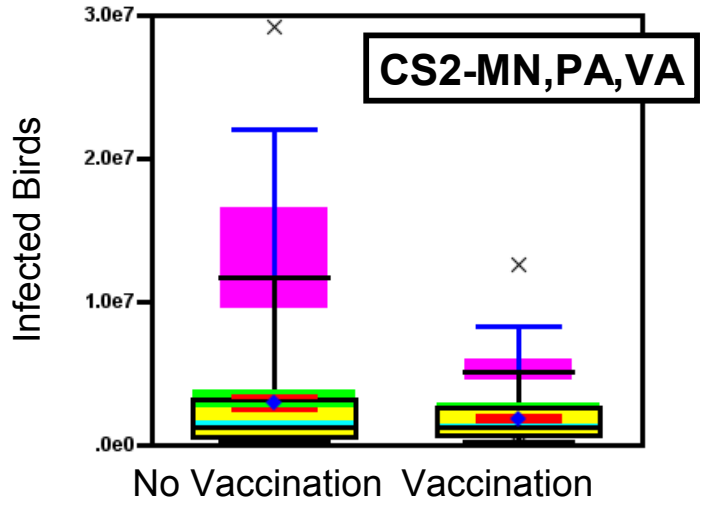


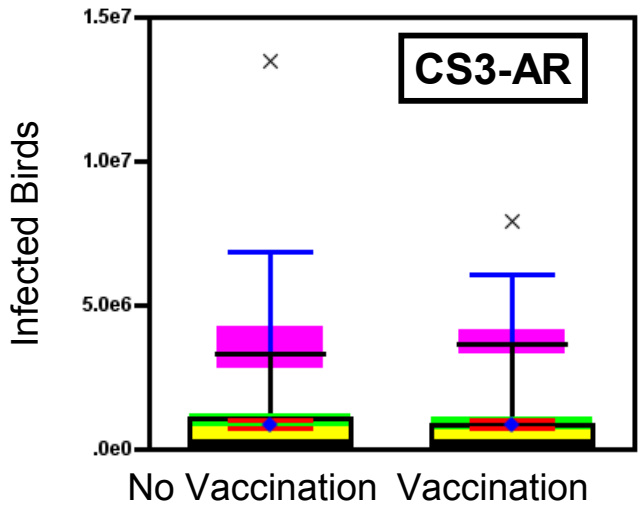


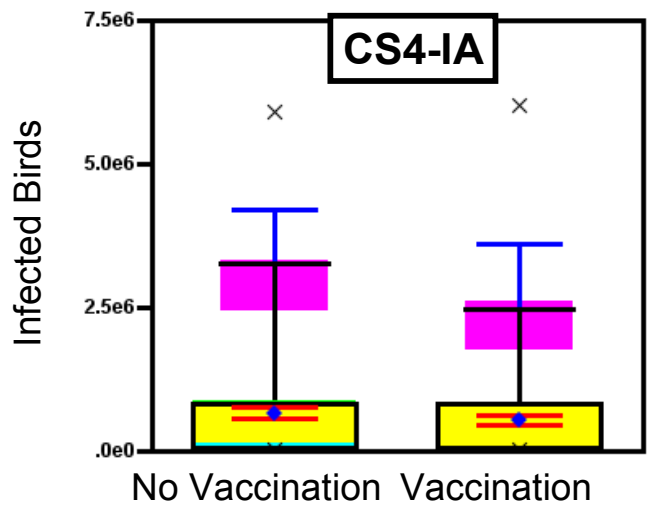


Vaccination: Scenarios Birds

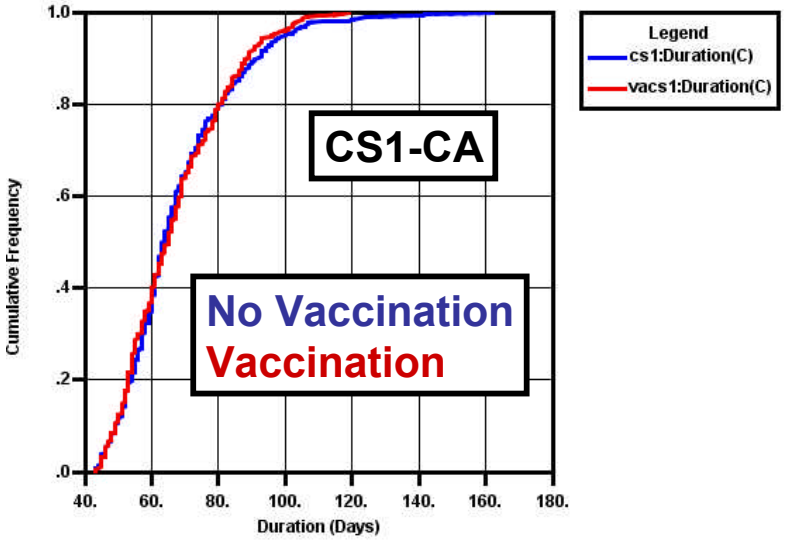


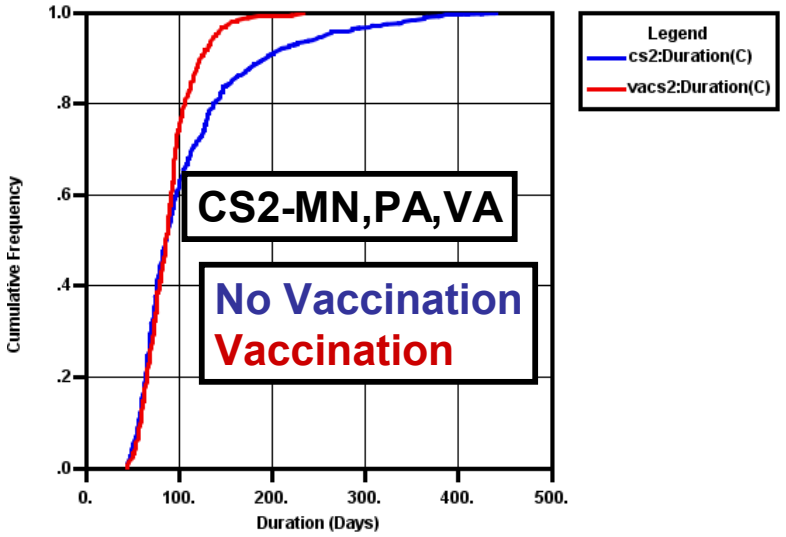


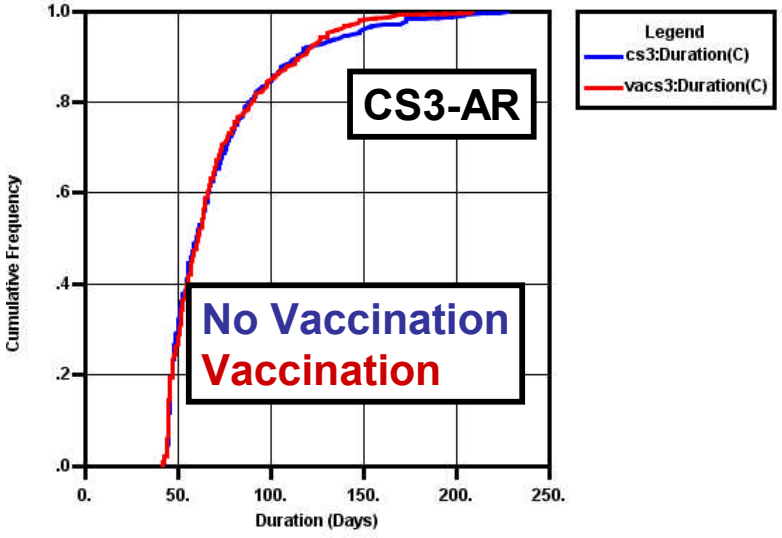


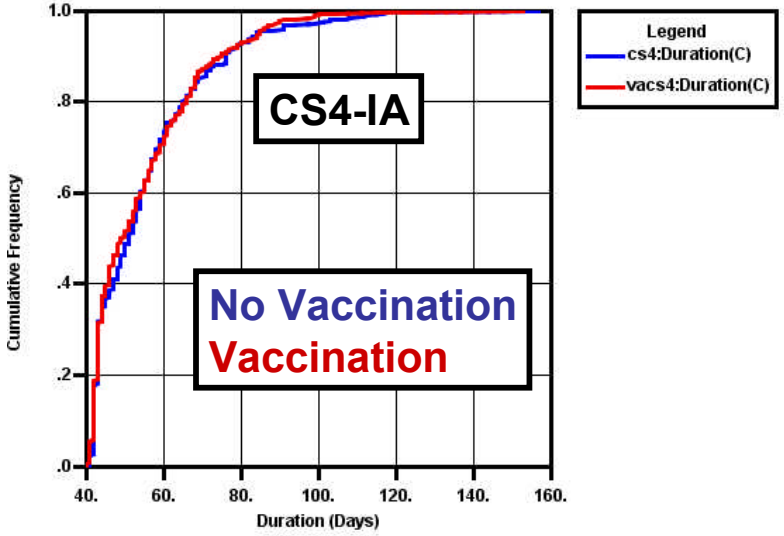


Vaccination: Scenarios Duration

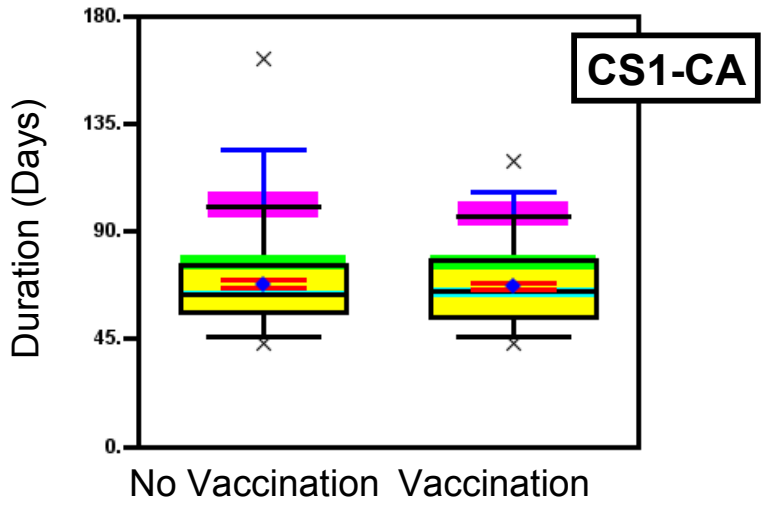


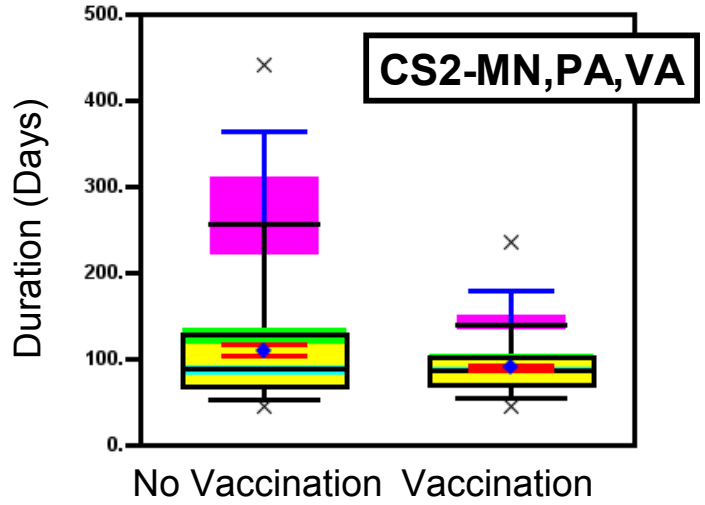


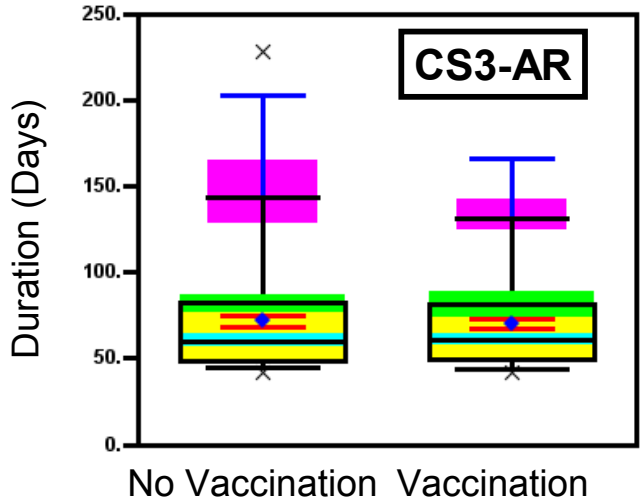


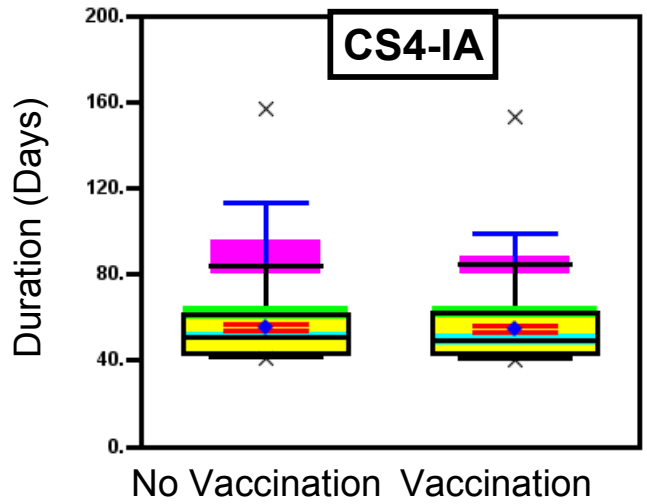


Vaccination: Scenarios Duration









Surveillance Diagnostic Calculations

- Convert model premises data to number of commercial and non-commercial premises
- Number of diagnostics calculated for the buffer surveillance zone (BSZ).
- Commercial premises -- Weekly surveillance
  - 2 pooled samples (pools of 5, 1 OP, 1 CL) per house.
  - 60,000 birds / house for layers, 10,000 birds / house for others
- Non-commercial premises -- Freedom from disease
  - Number of premises calculated at 95% confidence of detection at 0.5% prevalence.
  - 14 samples (7 pools of 5, 1 OP, 1 CL) / premise

Facility types for MESA

Table egg breeders
168 farms, 2.0 million birds

Large broiler breeders
(160,000 hens)

162 farms, 25.9 mil birds

Small broiler breeders
(12,000 to 100,000 hens)

2,256 farms, 24.7 mil birds

Large hatcheries
(>900,000 hatched)

11 farms, 22.6 mil birds

Small hatcheries

931 farms,
15.0 mil birds

Large hatcheries
(<900,000 hatched)

321 farms, 666.1 mil birds

Small hatcheries

5,004 farms,
143.1 mil birds

Large pullets
(>100,000 sold)

137 farms, 24.7 mil birds

Small pullets

12,077 farms,
68.5 mil birds

Large grow-outs
(>500,000 sold)

5,303 farms, 760.0 mil birds

Small grow-outs
(2,000 to 500,000 sold)

15,838 farms,
656.3 mil birds

Large layers
(>100,000 hens)

424 farms, 225.8 mil birds

Small layers
(50 to 100,000 hens)

12,740 farms, 53.4 mil birds

Game fowl breeders

6,018 farms,
0.9 mil birds

"Poultry, other"
(show/exhibition??)

7,722 farms, 0.7 mil birds

Large turkeys
(>100,000 sold)

710 farms,
47.9 mil birds

Small turkeys
(2,000 to 100,000 sold)

9,209 farms,
44.8 mil birds

Backyard high risk

52,329 farms,
1.0 mil birds

Live bird markets

396 markets

Swap meets

89 swap meets

Backyard turkeys

6,851 farms,
0.3 million birds

Backyards low risk

257,972 farms,
4.9 mil birds

Backyards NASS

87,531 farms,
1.5 mil birds

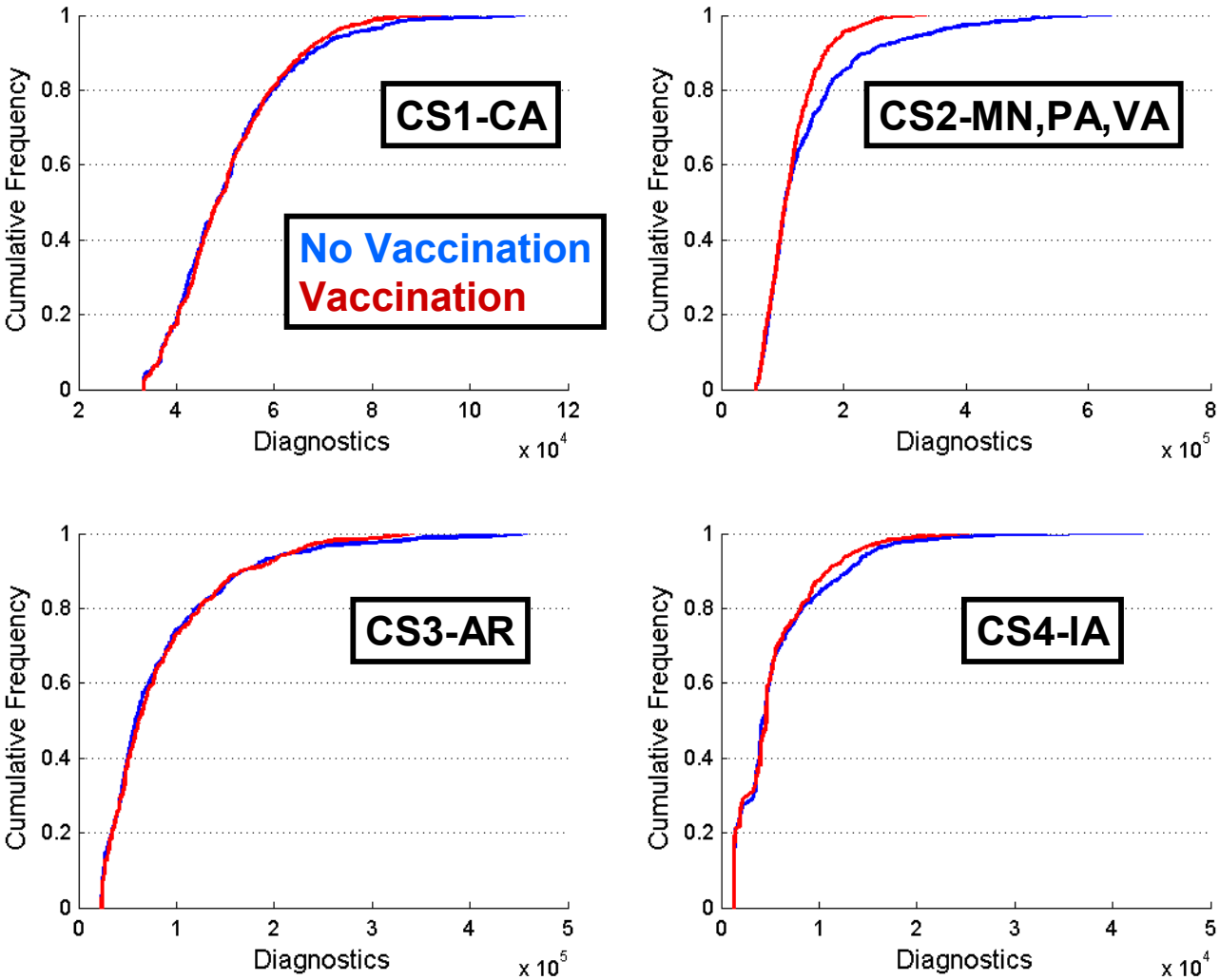
Ducks

26,065 farms,
3.8 mil birds

Geese, pheasants,
pigeons, quail, emus,
ostriches

37,027 farms,
7.8 mil birds

USDA Scenarios: Total Diagnostics



USDA Scenarios: Total Diagnostics

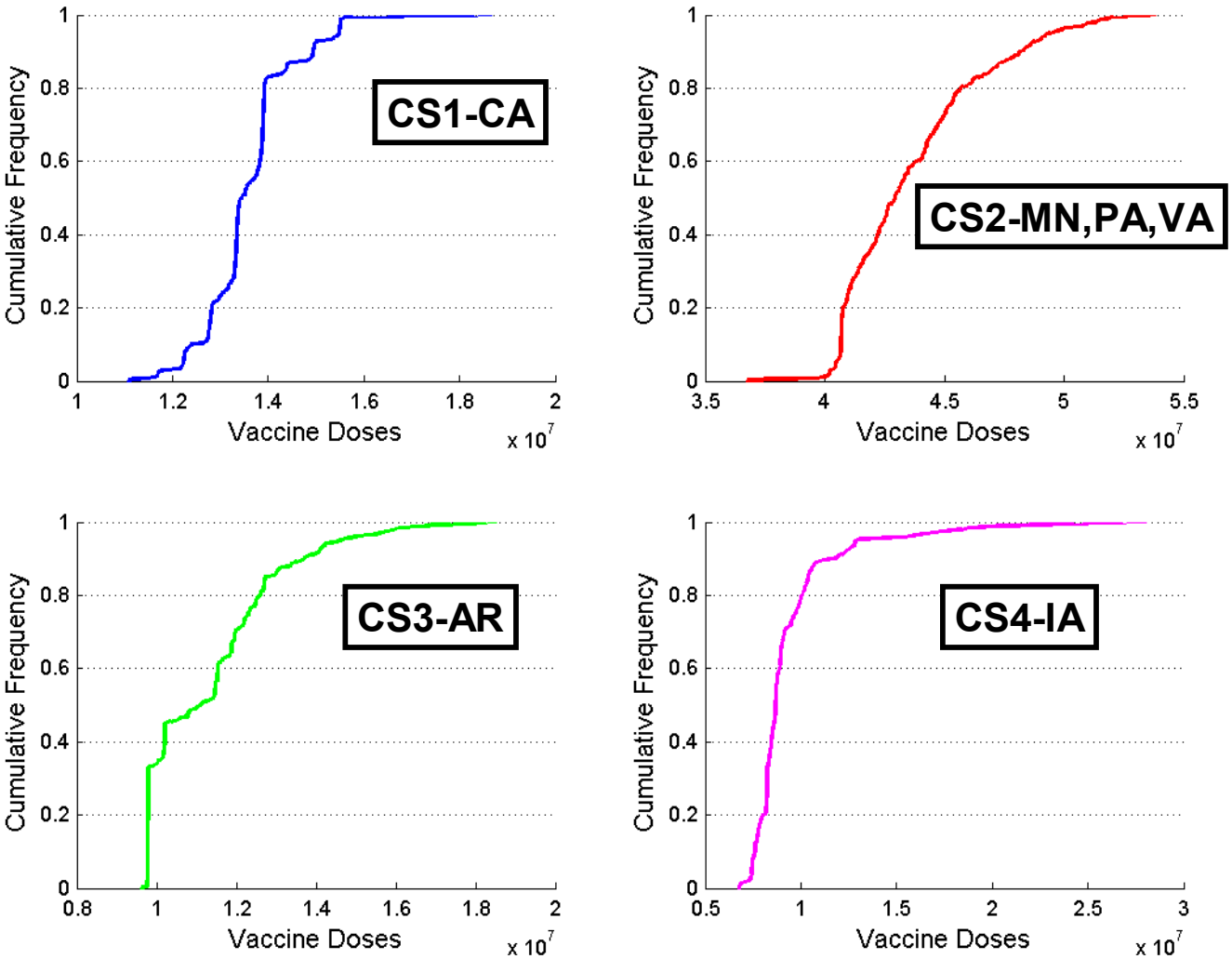
CS1-CA

CS2-MN,PA,VA

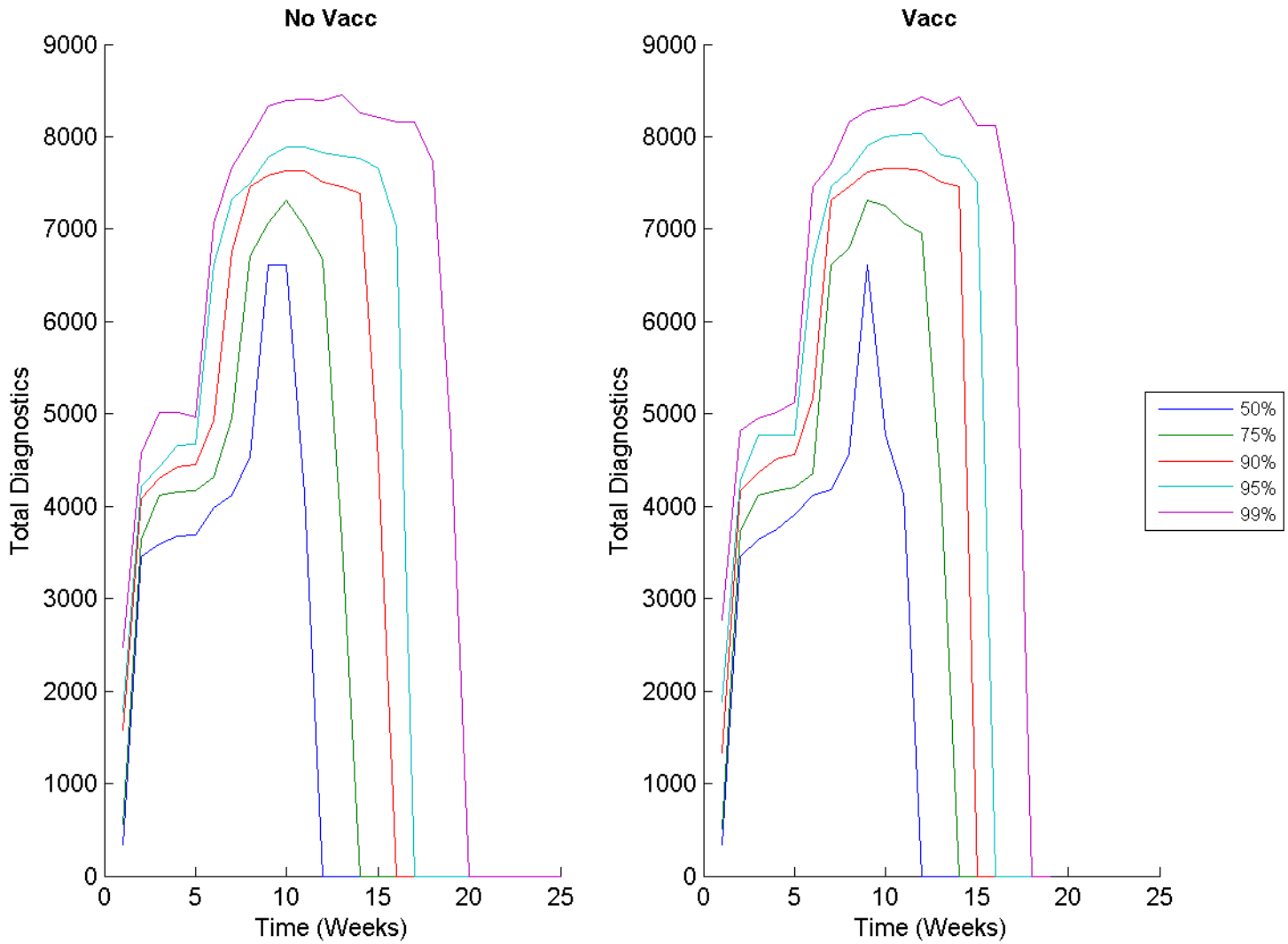
CS3-AR

CS4-IA

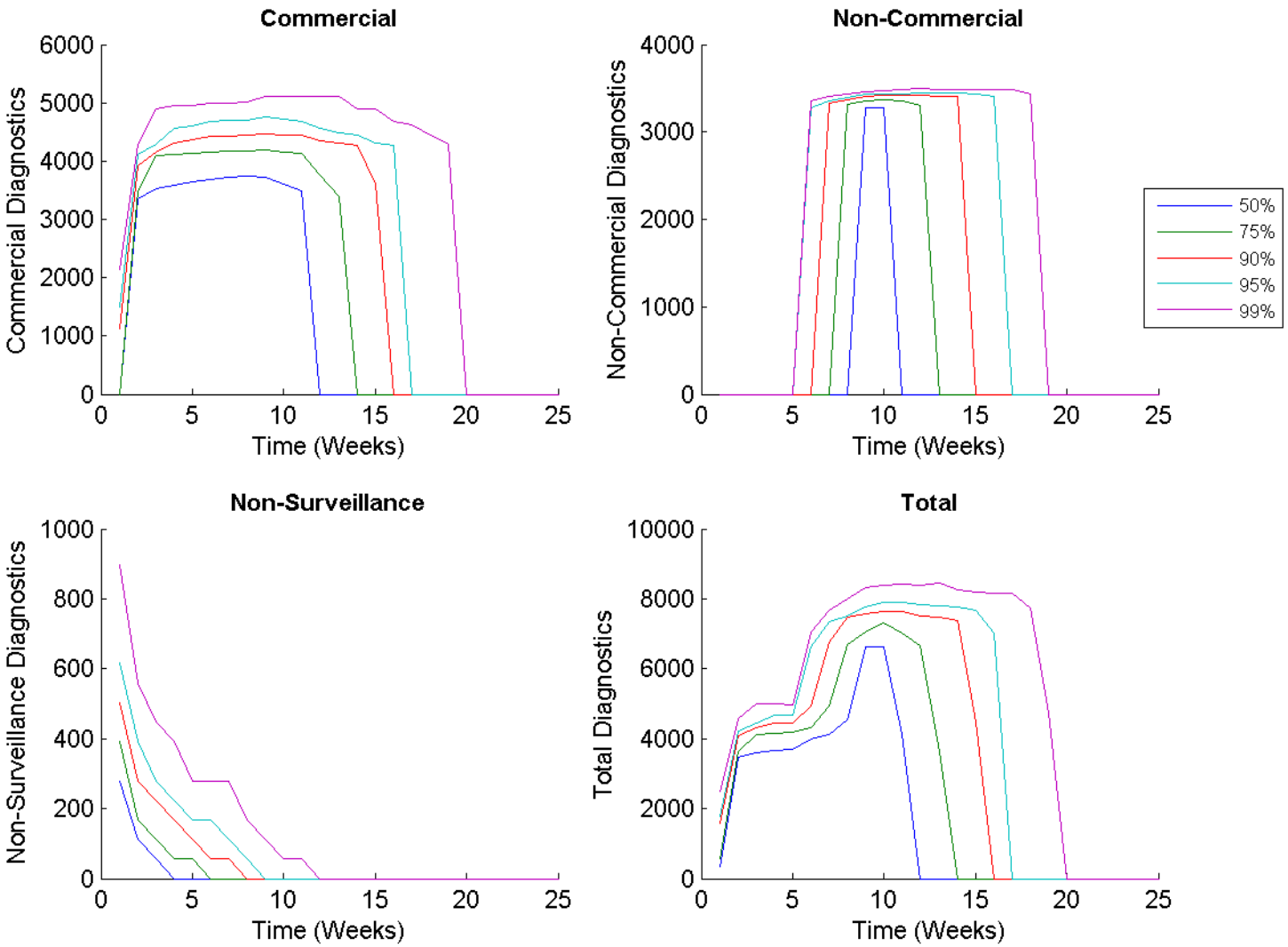
USDA Scenarios: Total Vaccines



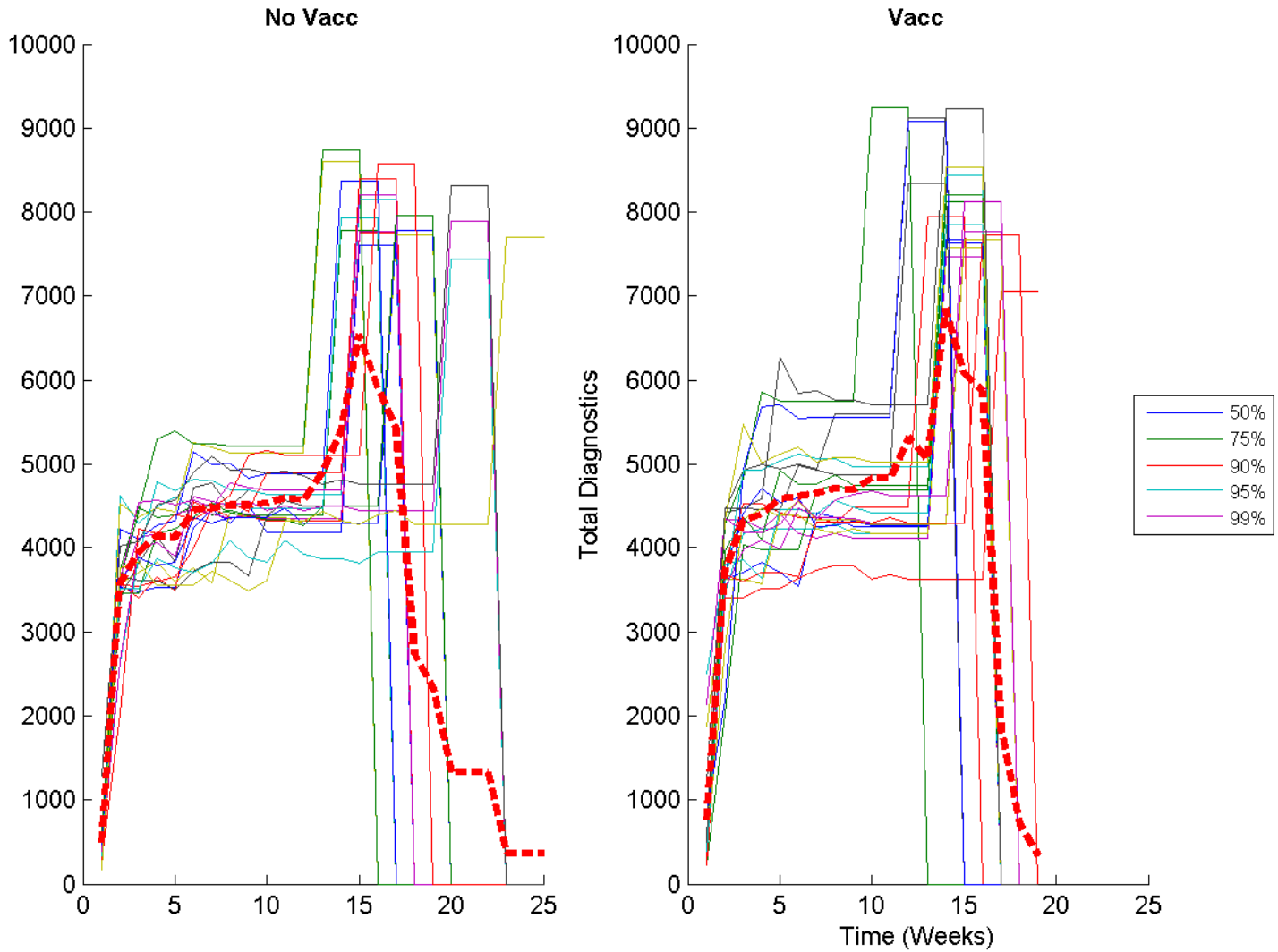
Scenario 1 (CA): Total Diagnostics



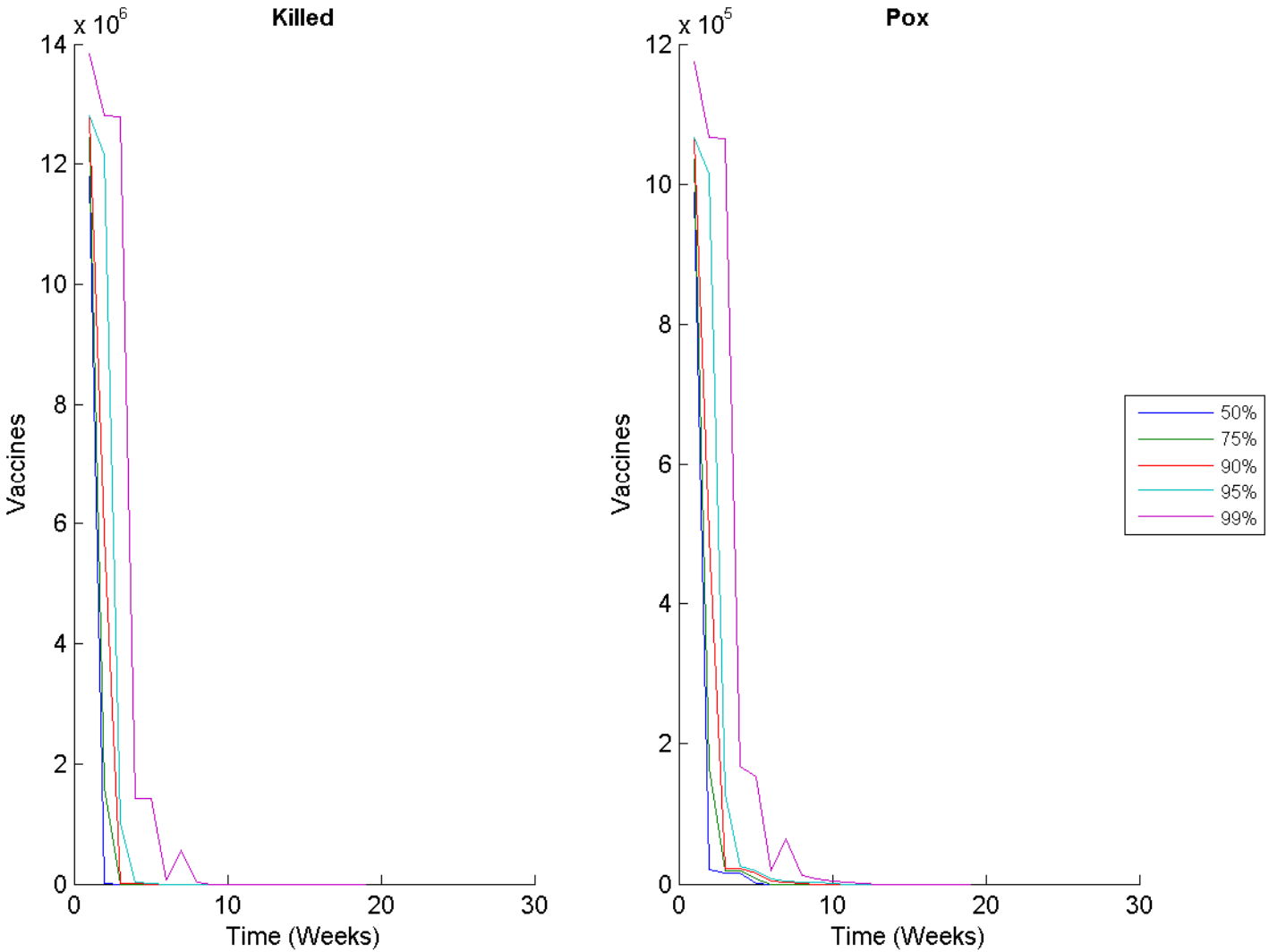
Scenario 1 (CA): Components vs. Total Diagnostics



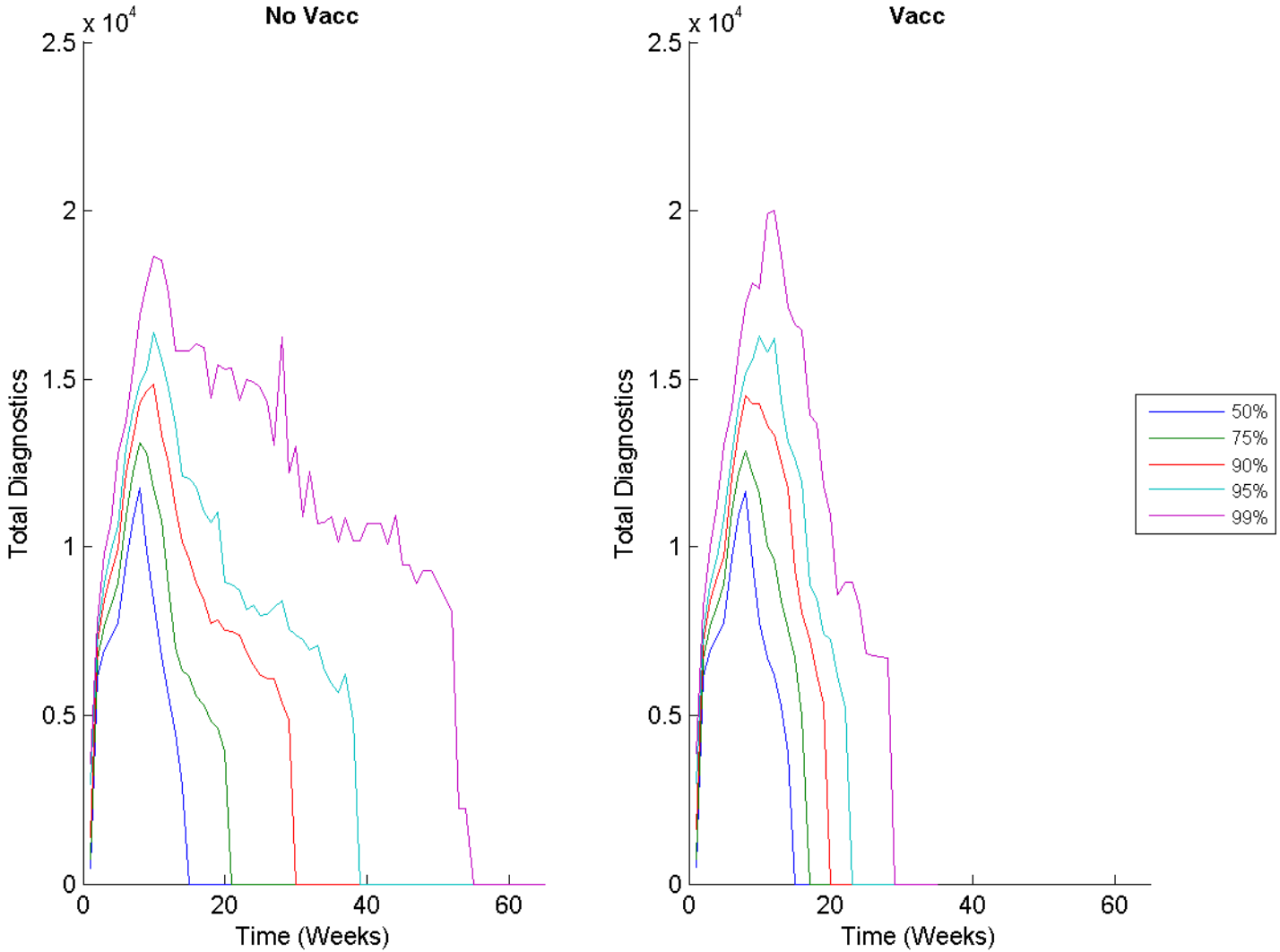
Scenario 1 (CA): Total Diagnostics over Time for the Largest 5% of Outbreaks



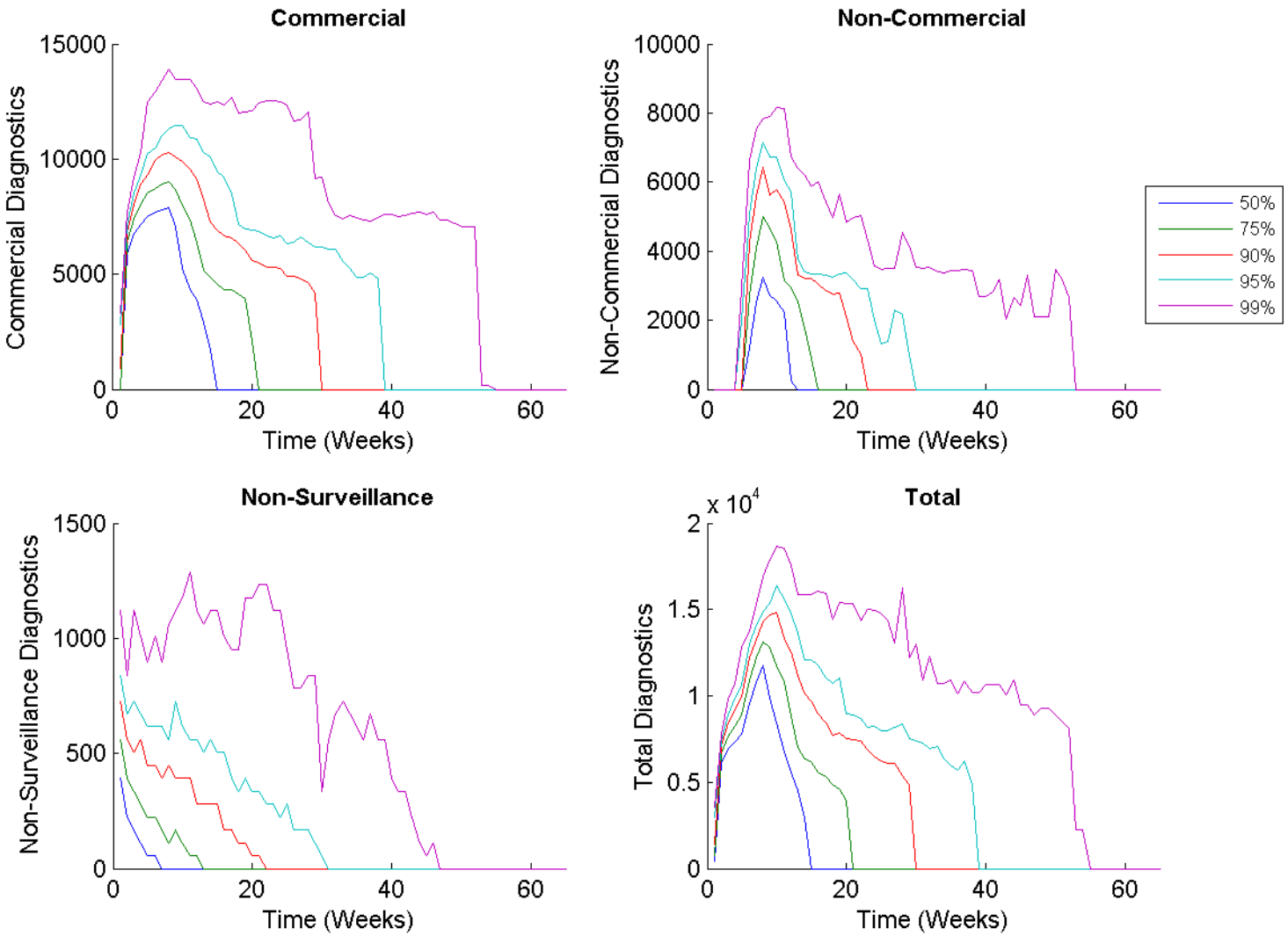
Scenario 1 (CA): Vaccinations



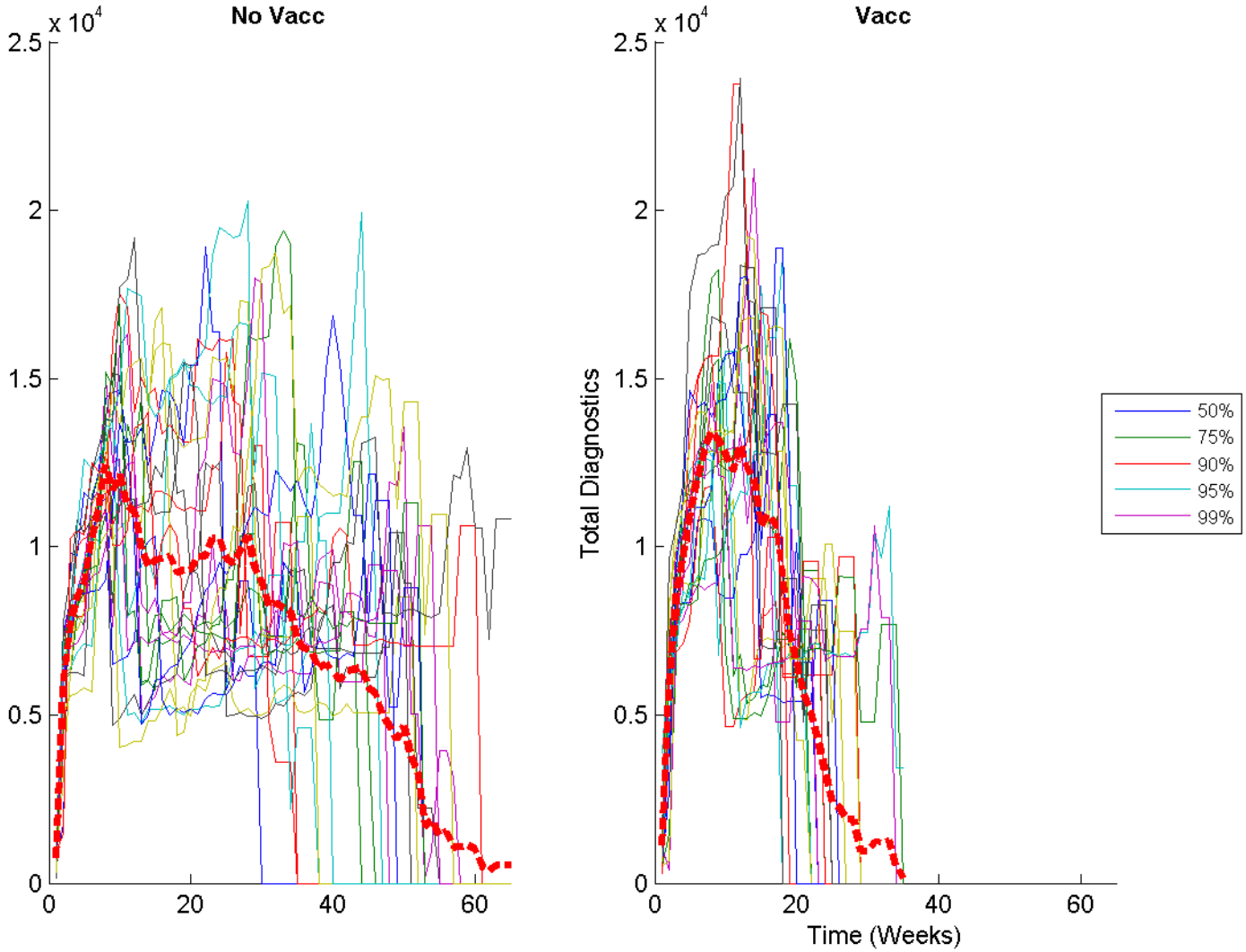
Scenario 2 (MN, PA, VA): Total Diagnostics



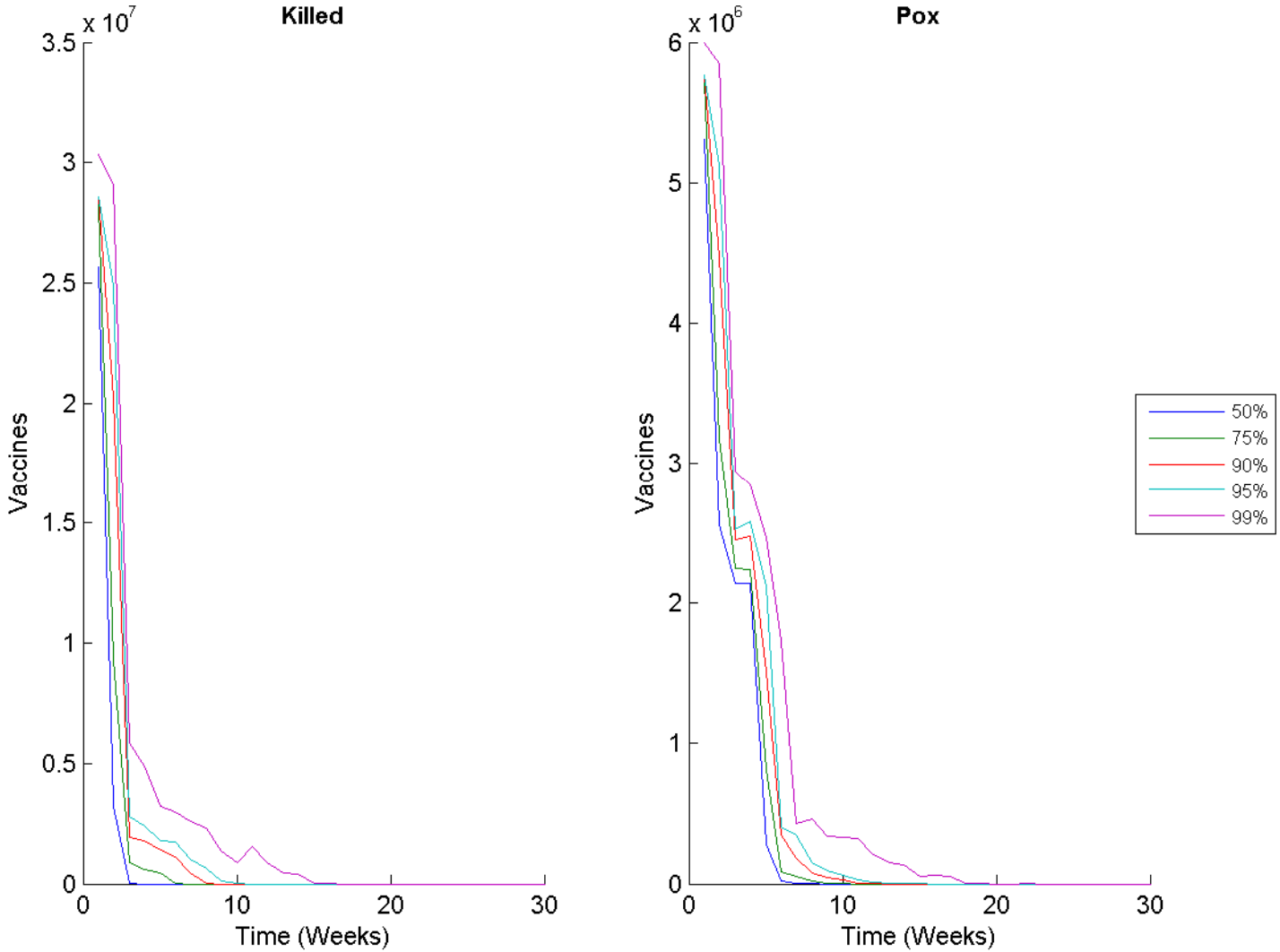
Scenario 2 (MN, PA, VA): Components vs. Total Diagnostics



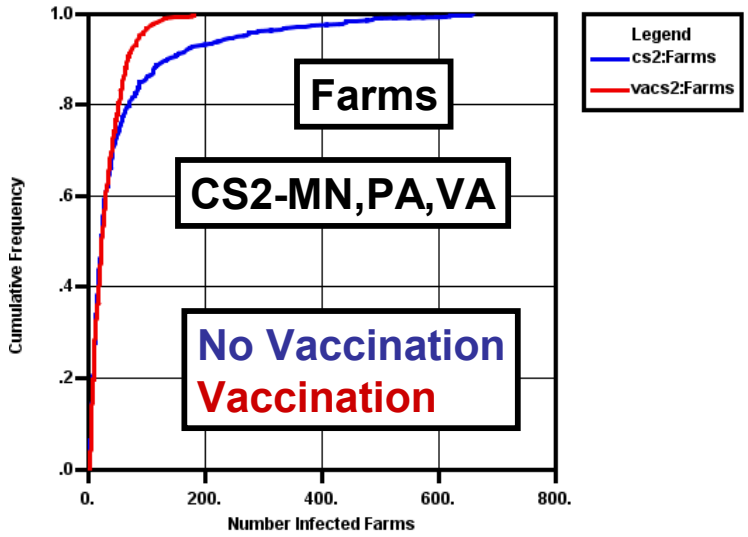
Scenario 2 (MN, PA, VA): Total Diagnostics over Time for the Largest 5% of Outbreaks

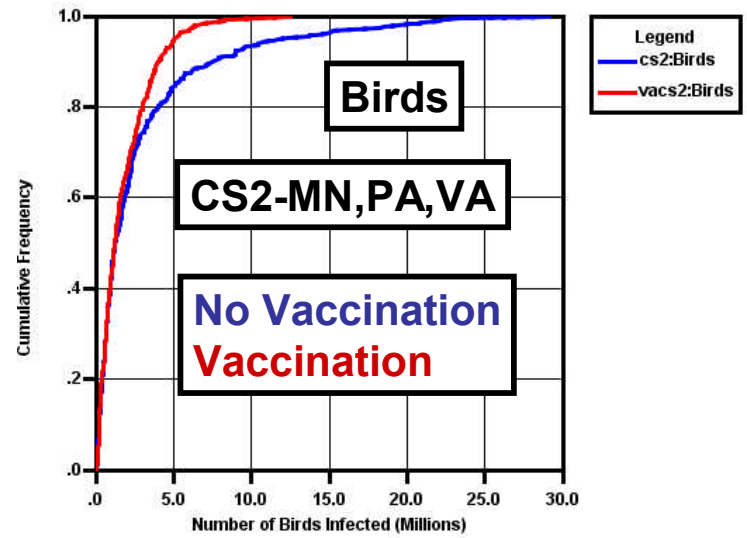


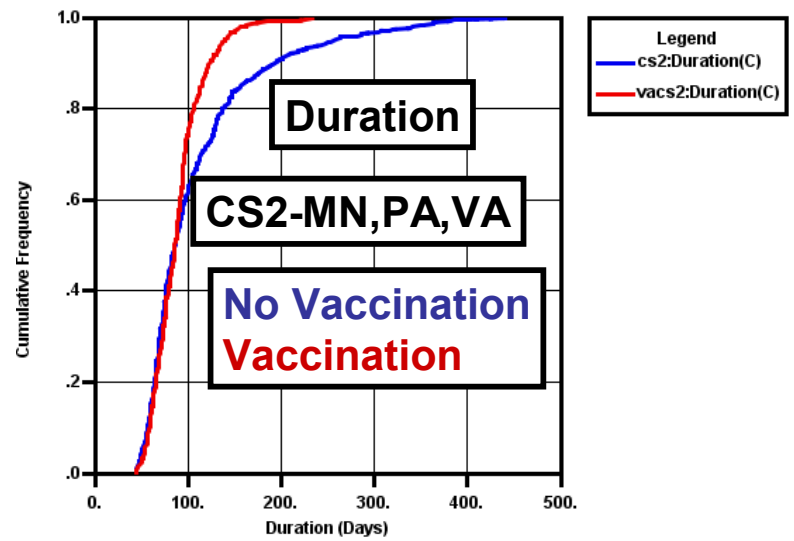
Scenario 2 (MN, PA, VA): Vaccinations



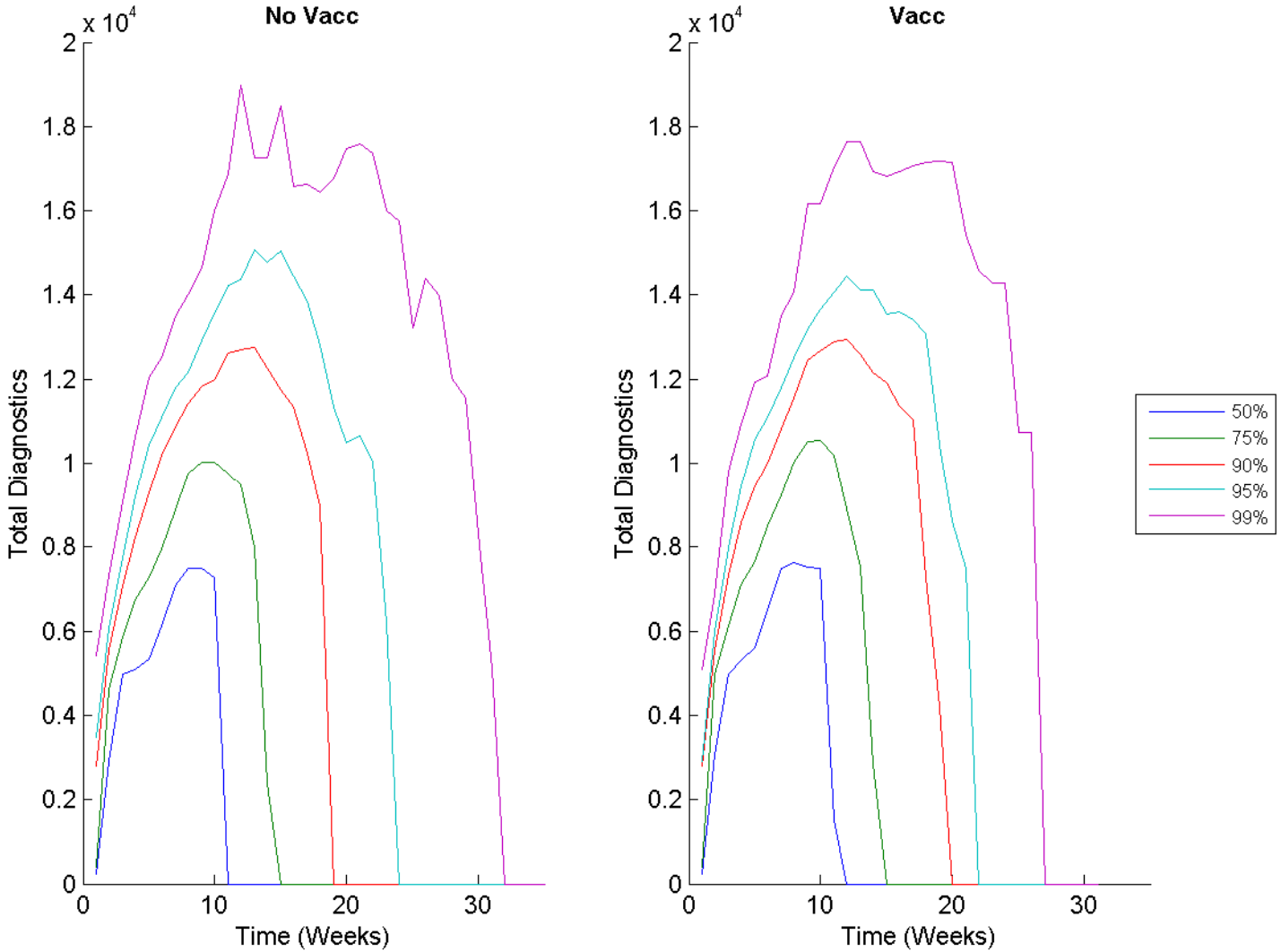
Only scenario CS2 showed significant change due to vaccination



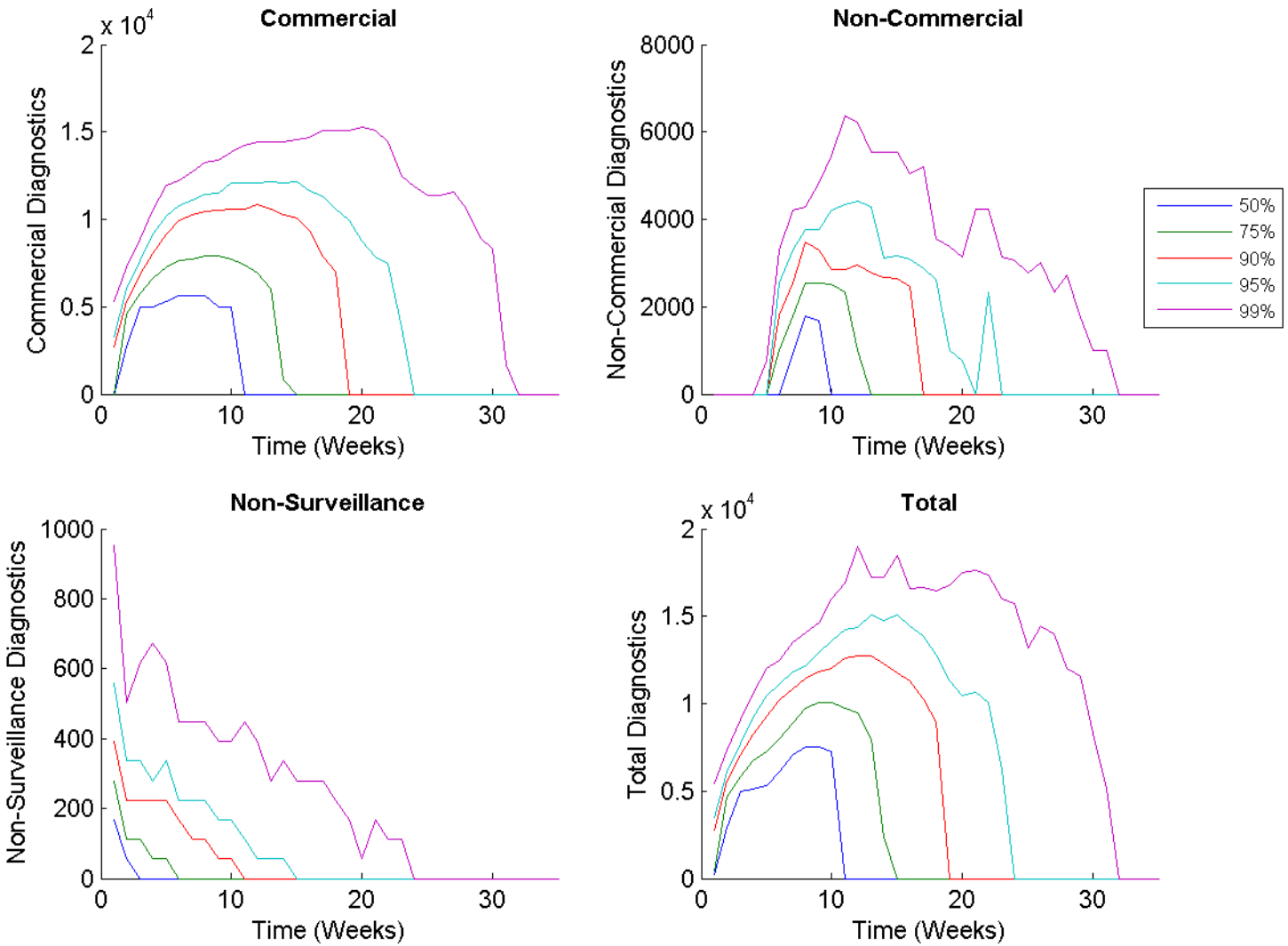




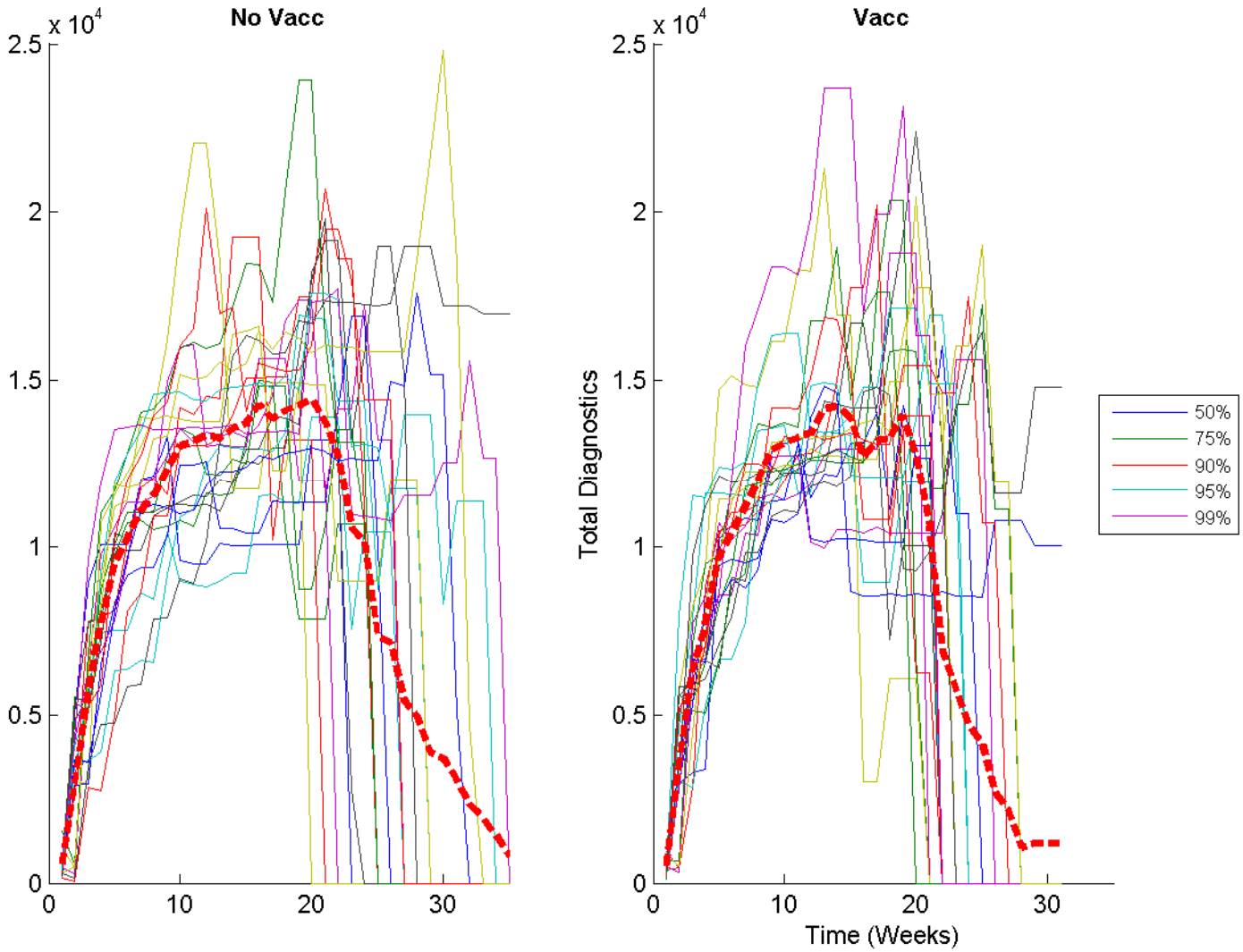
Scenario 3 (AR): Total Diagnostics



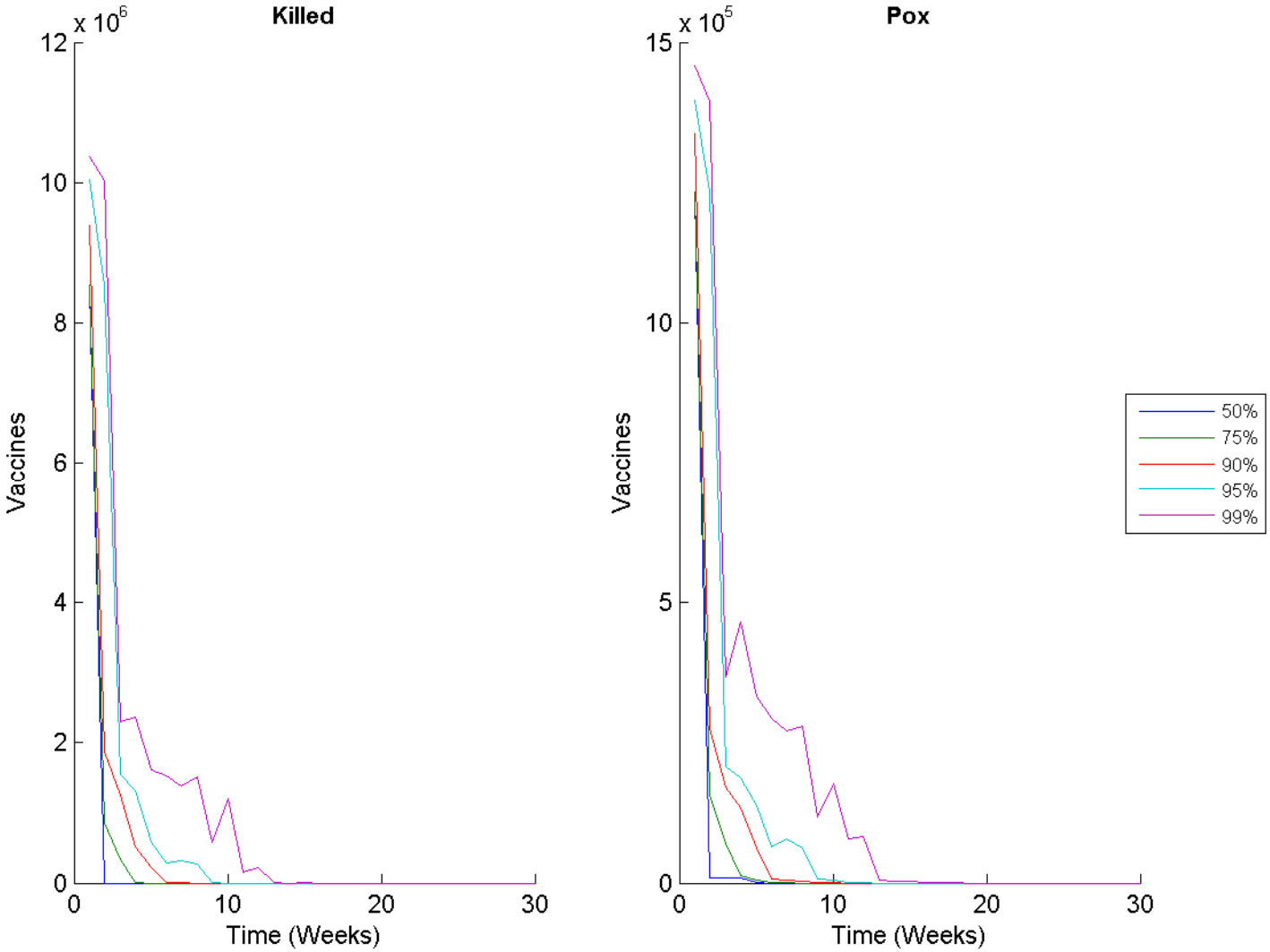
Scenario 3 (AR): Components vs. Total Diagnostics



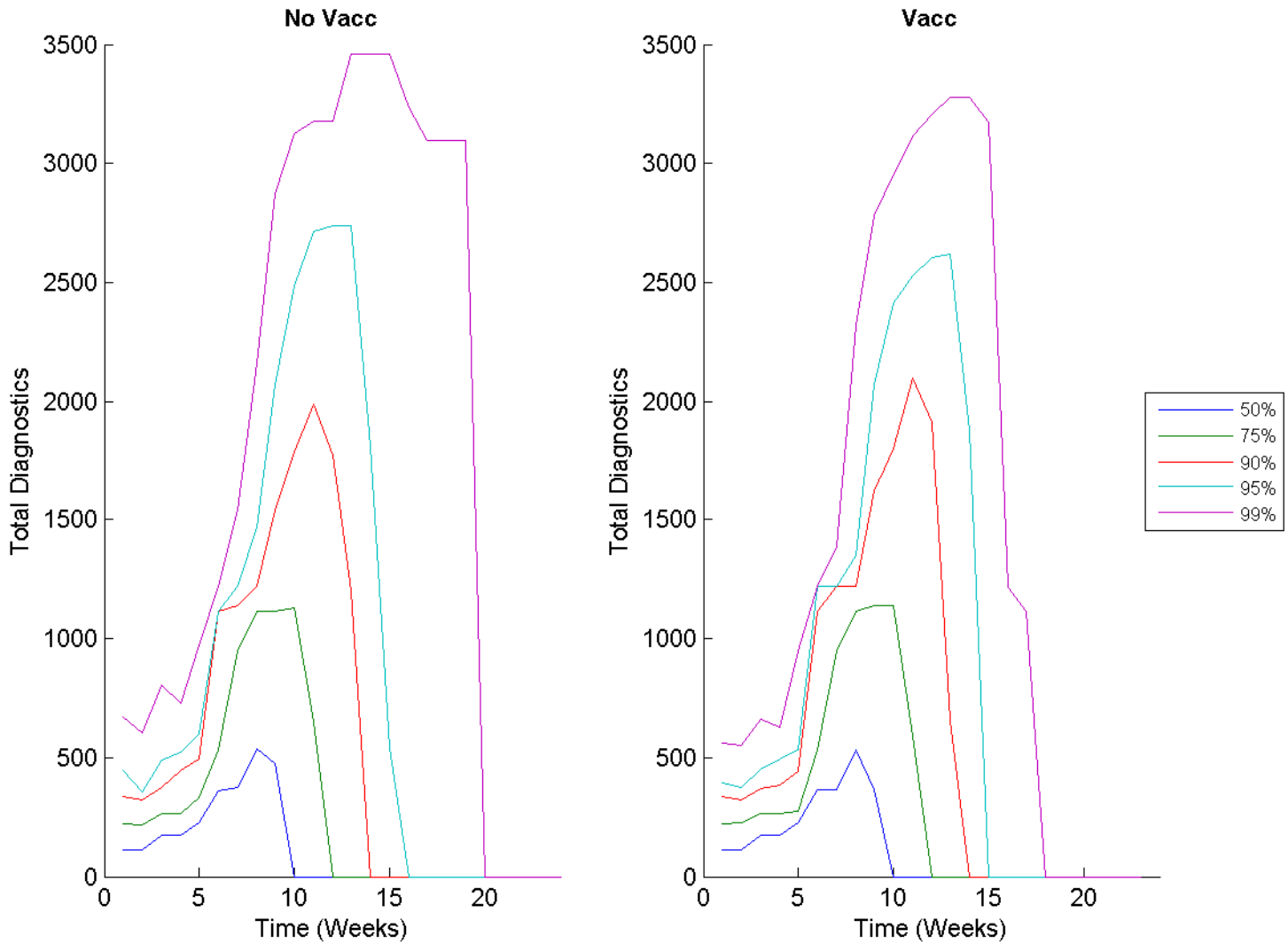
Scenario 3 (AR): Total Diagnostics over Time for the Largest 5% of Outbreaks



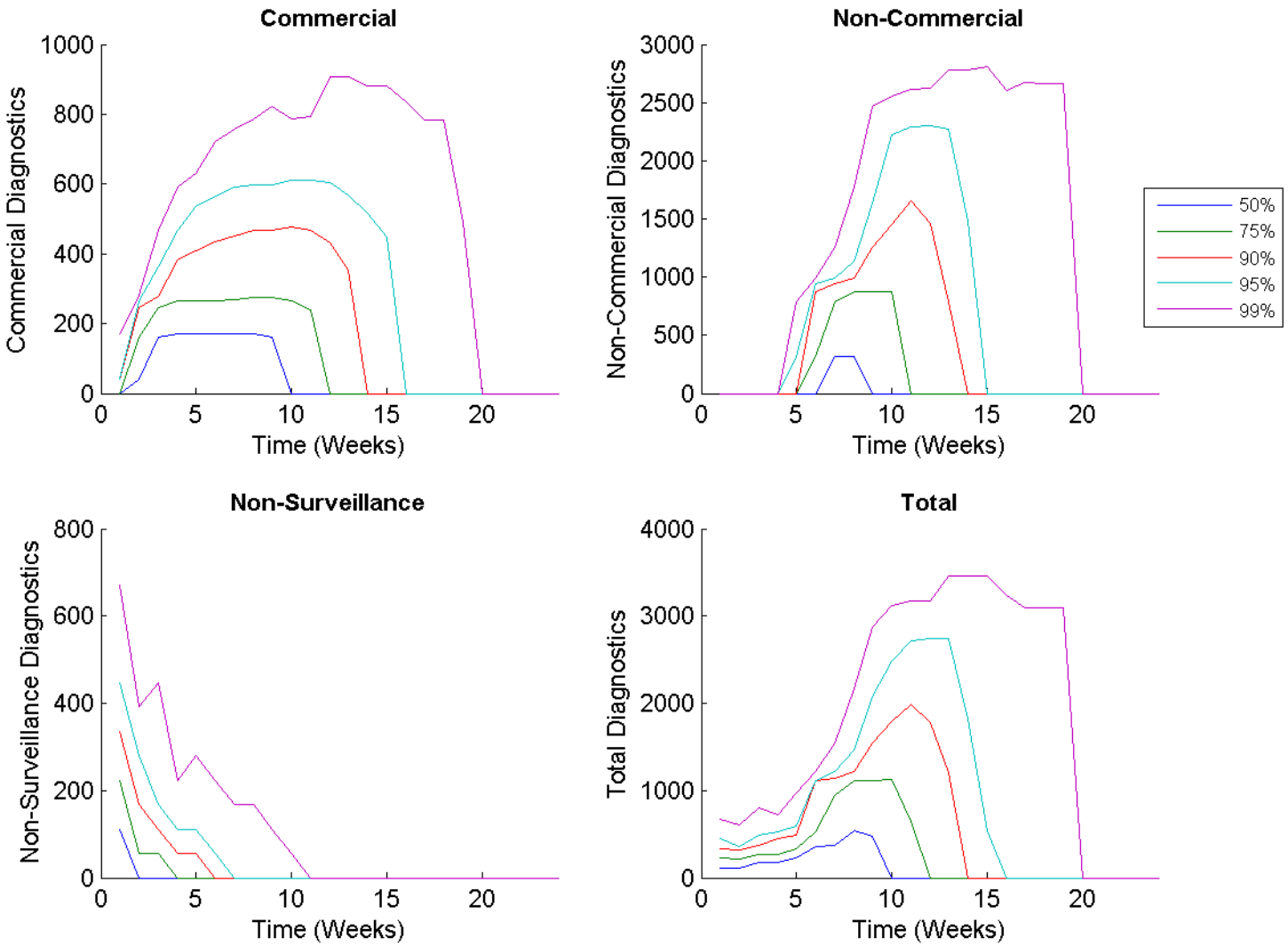
Scenario 3 (AR): Vaccinations



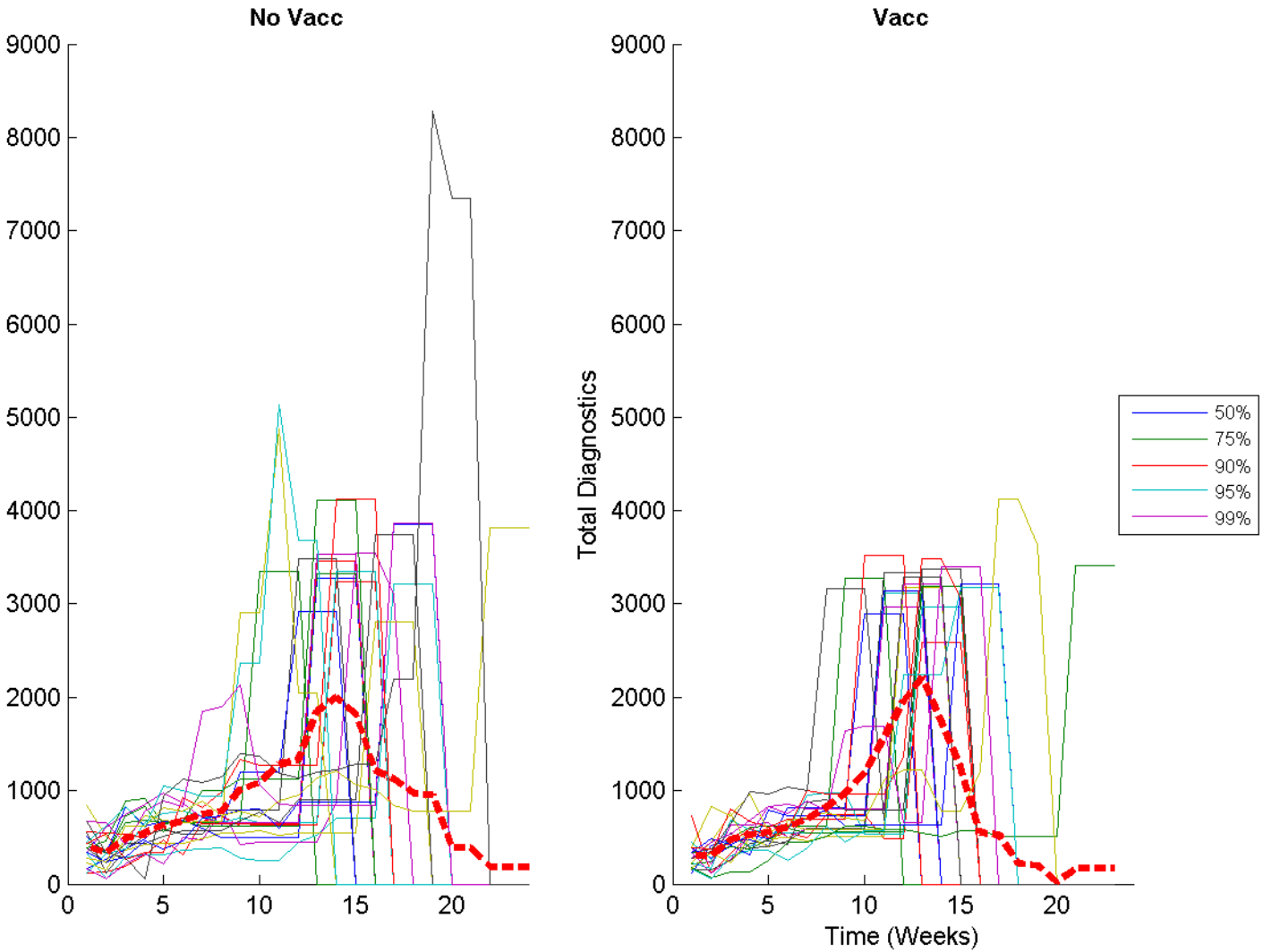
Scenario 4 (IA): Total Diagnostics



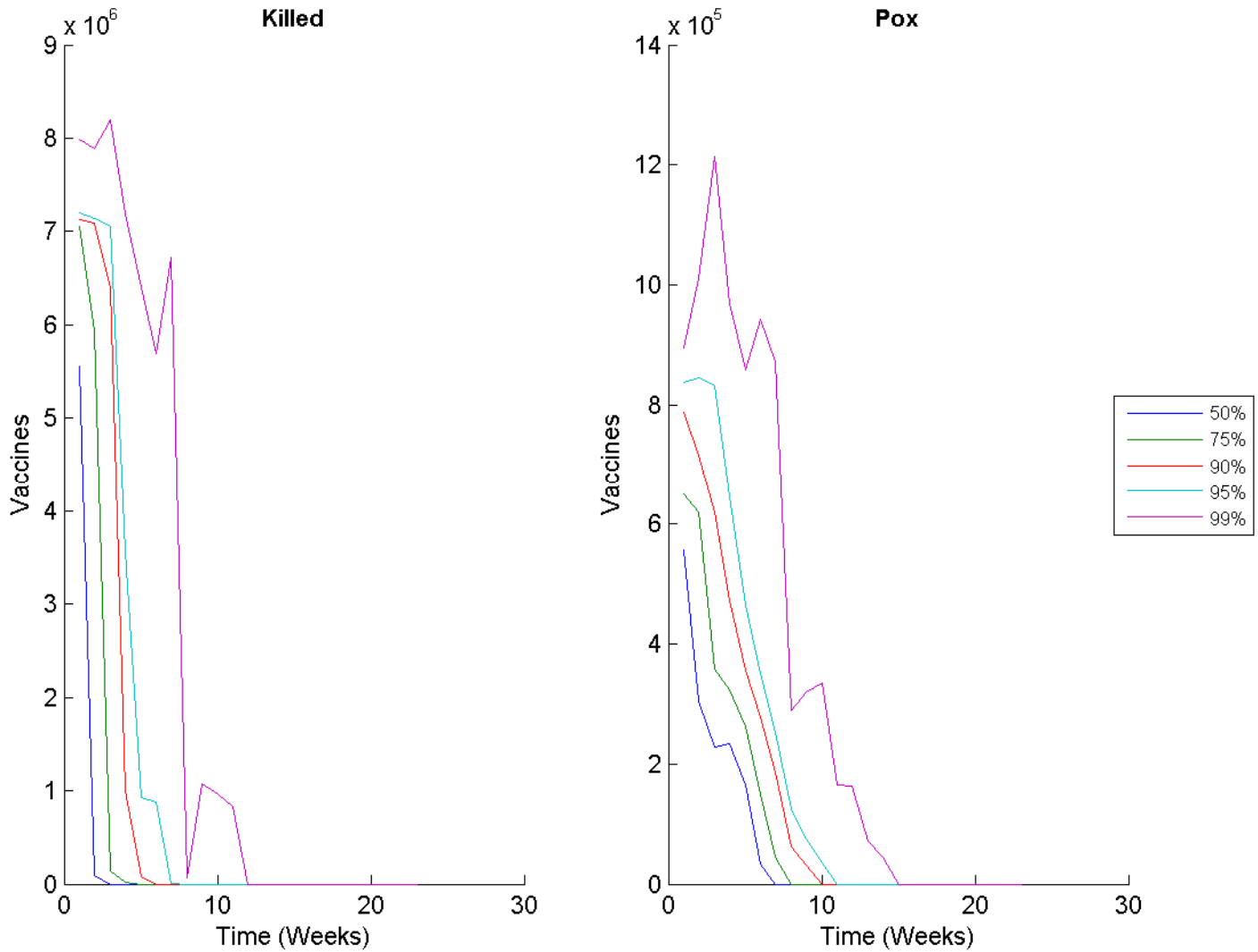
Scenario 4 (IA): Components vs. Total Diagnostics



Scenario 4 (IA): Total Diagnostics over Time for the Largest 5% of Outbreaks

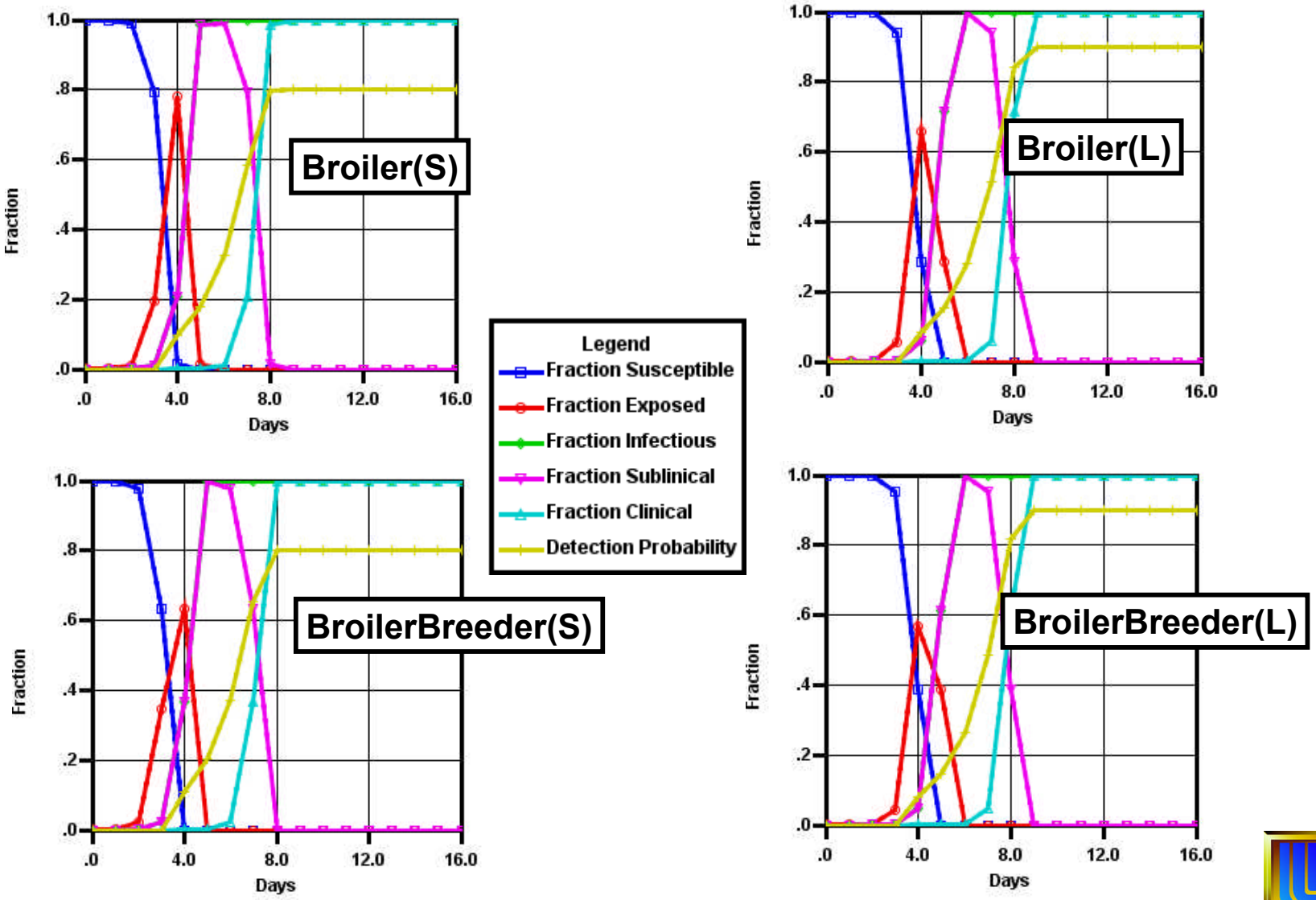


Scenario 4 (IA): Vaccinations

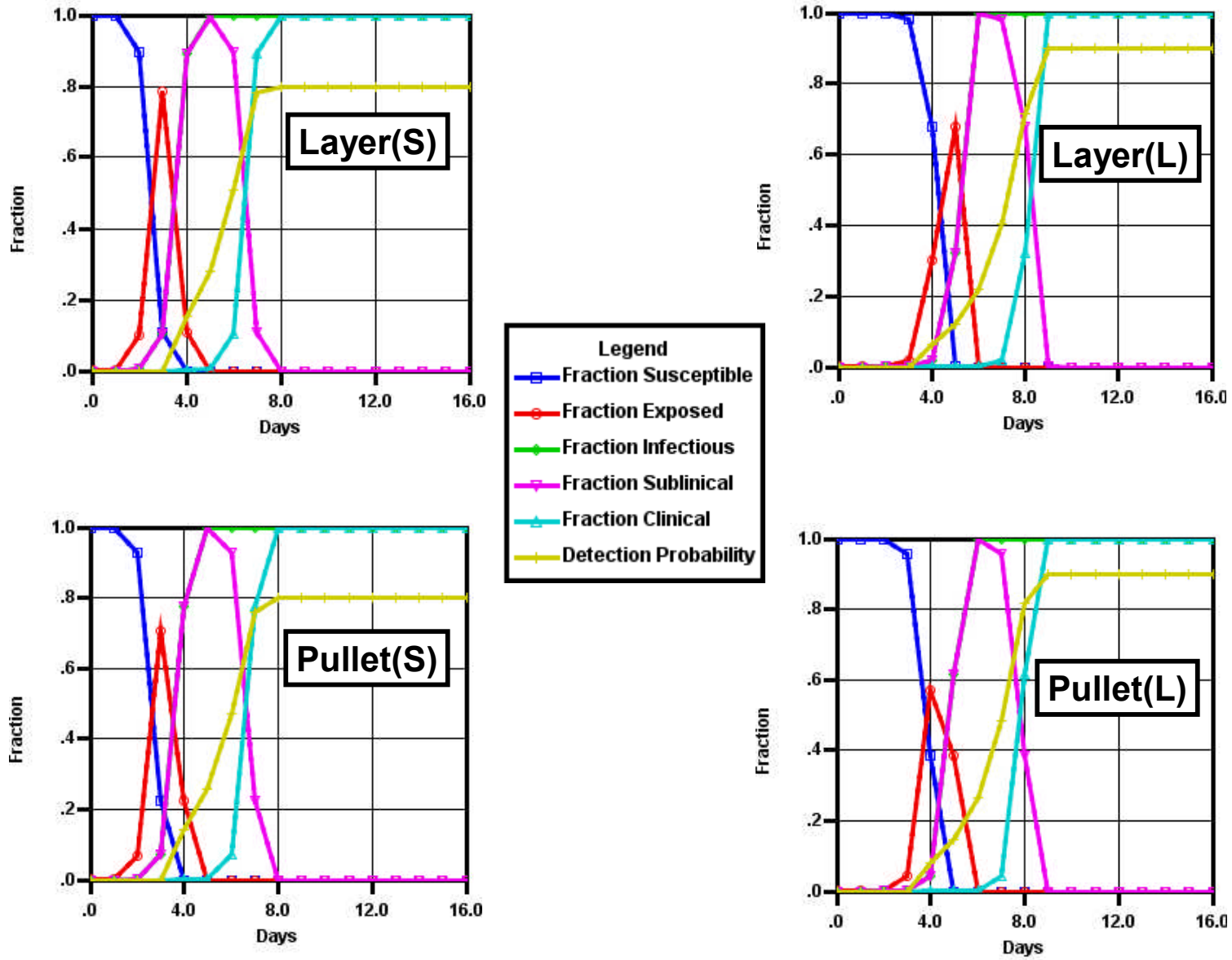


Supplementary data

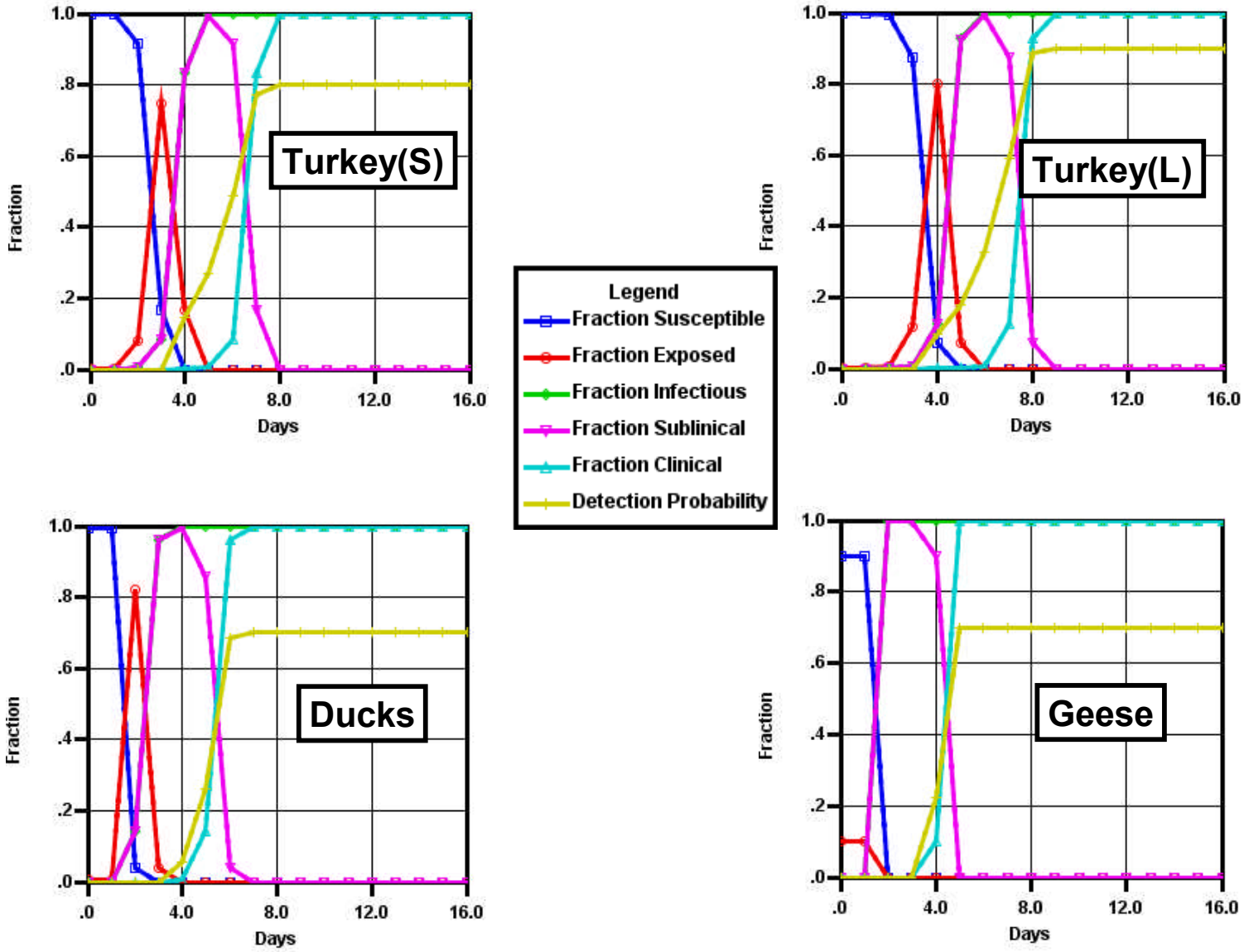
Intraherd Disease Spread



Intraherd Disease Spread



Intraherd Disease Spread



Intraherd Disease Spread

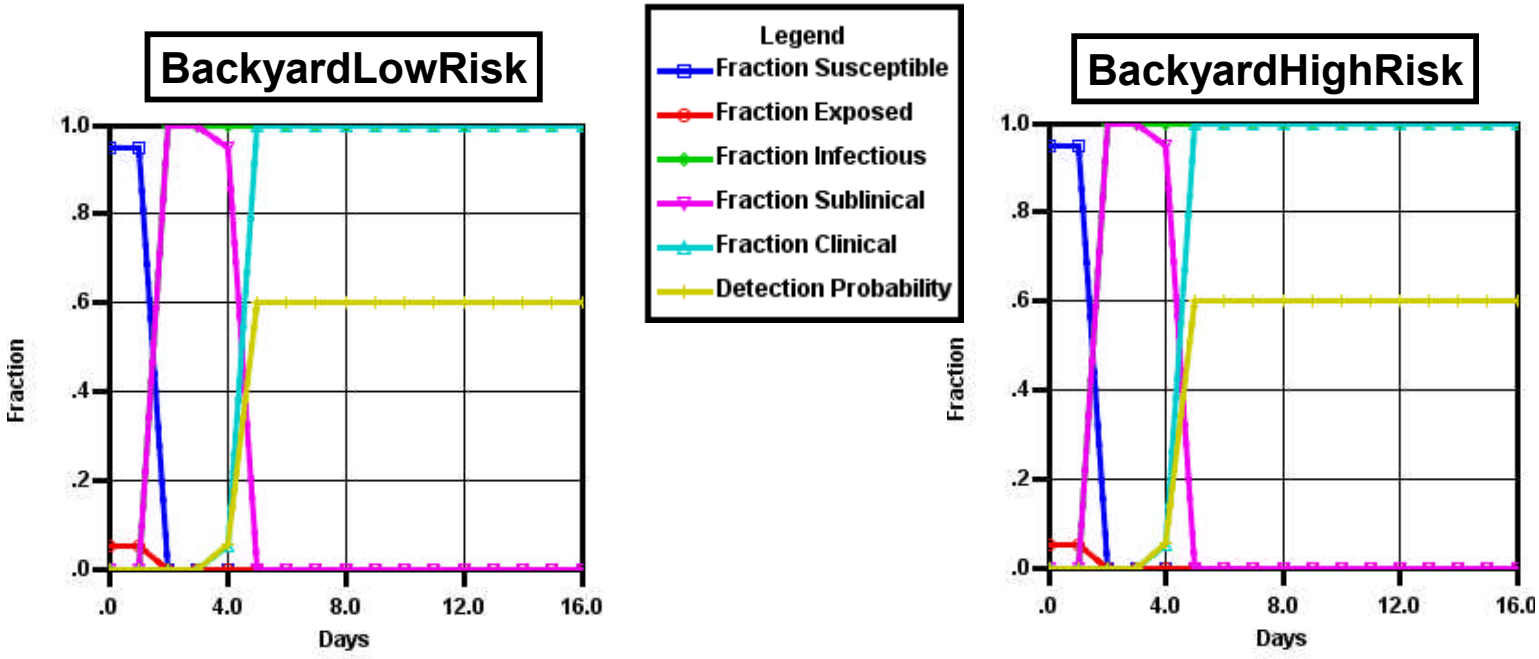


Figure 12. MESA heat map for indirect contacts due to workers with backyard flocks

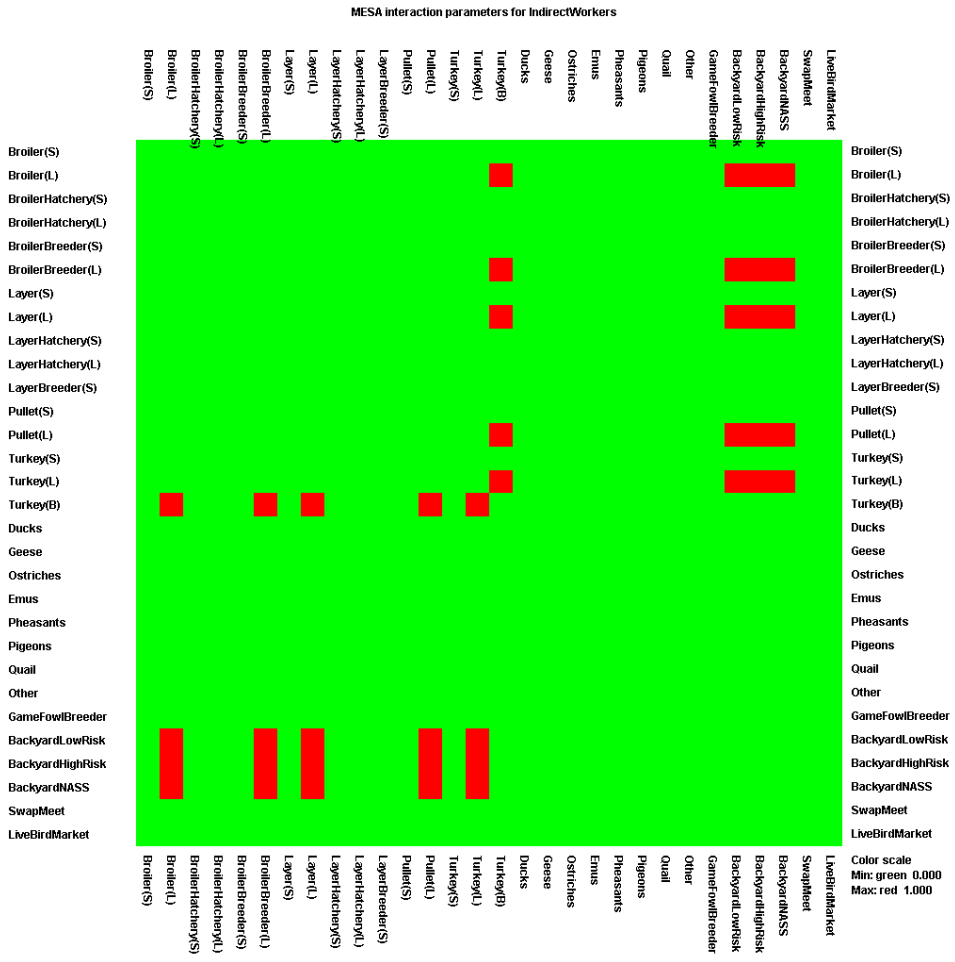
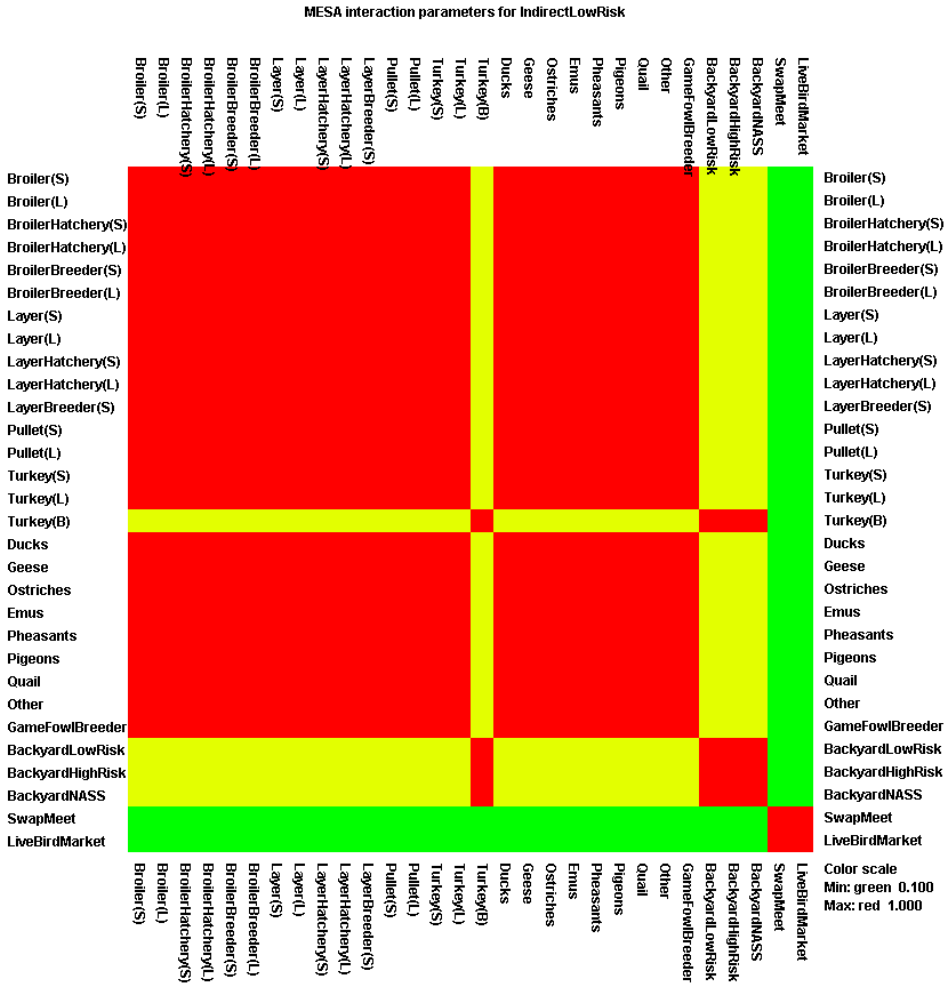
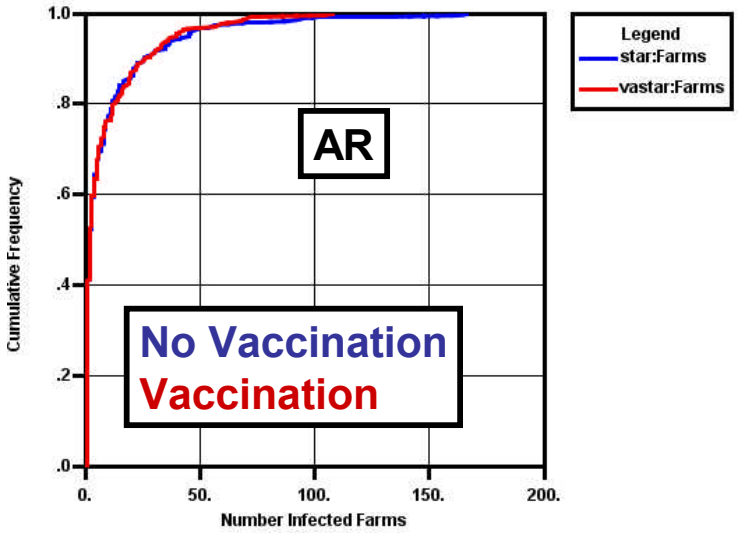
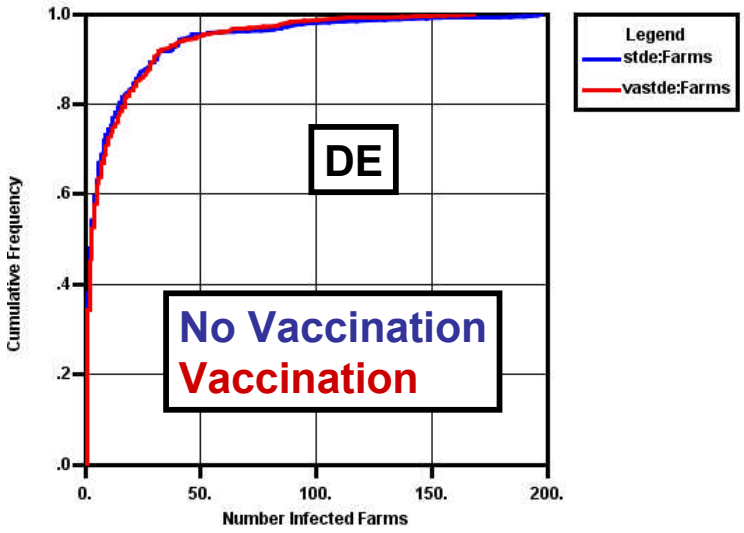


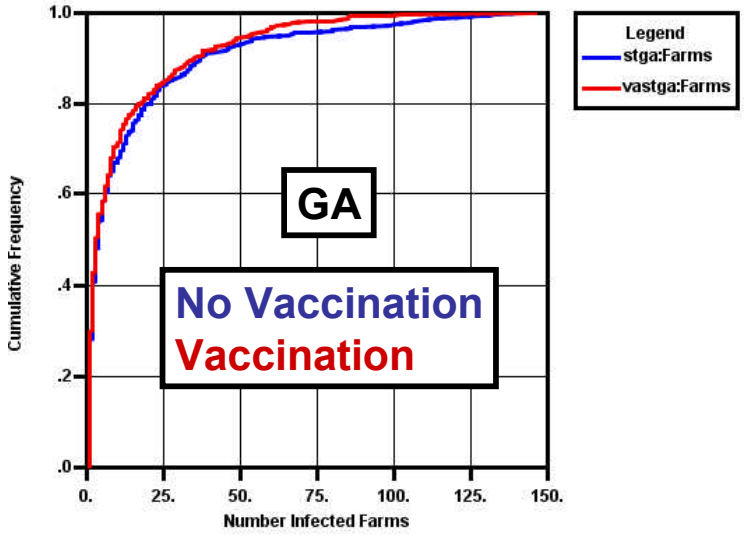
Figure 13. MESA heat map for indirect contacts due to social contact

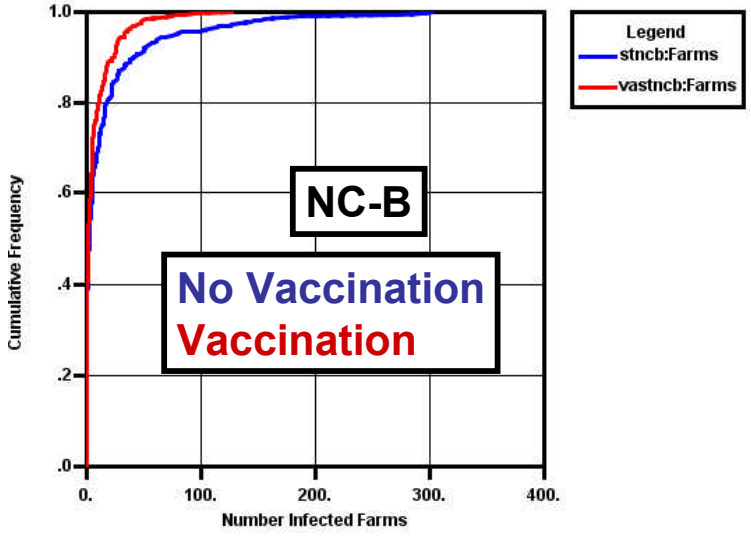


Vaccination: States-Broilers Farms

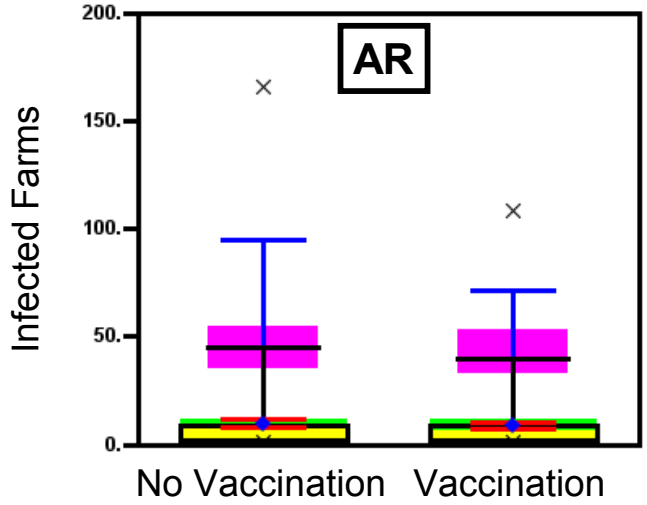


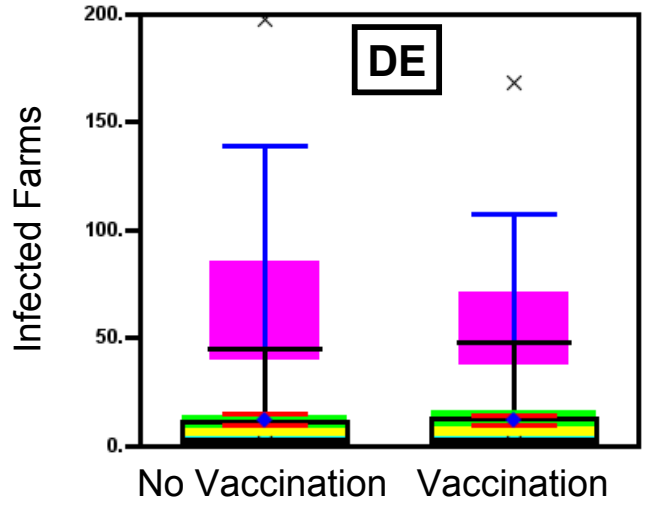


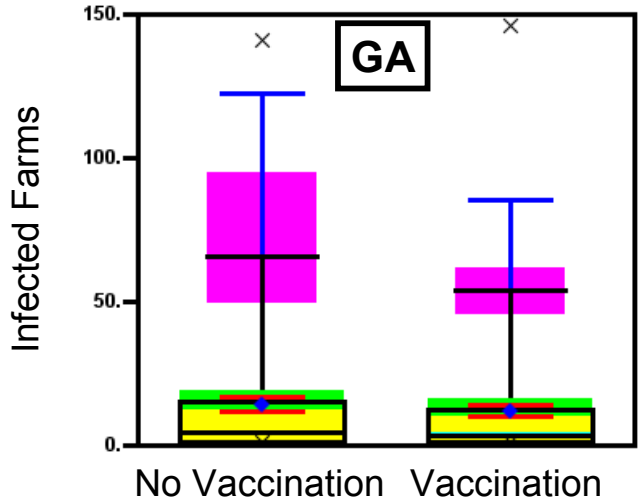


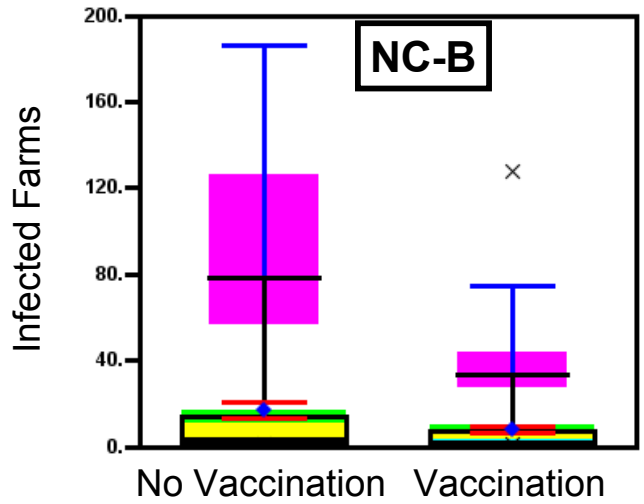


Vaccination: States-Broilers Farms

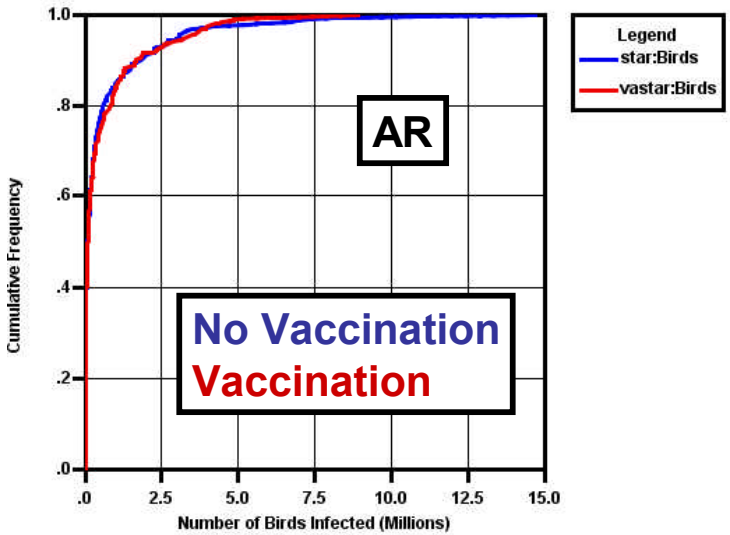


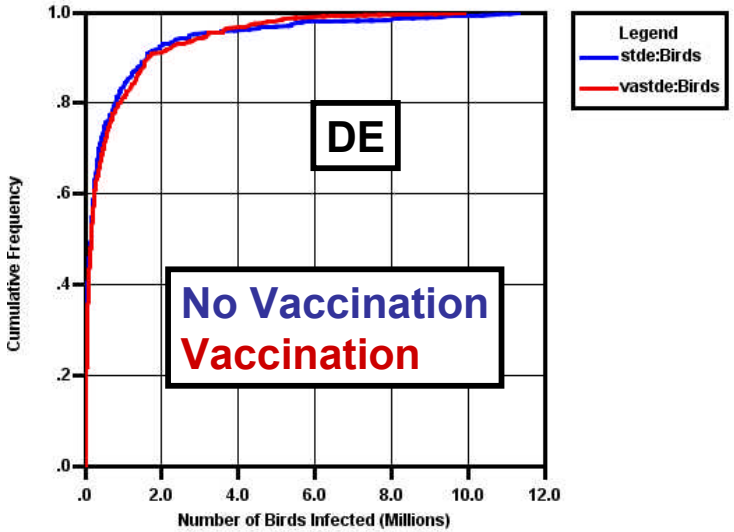


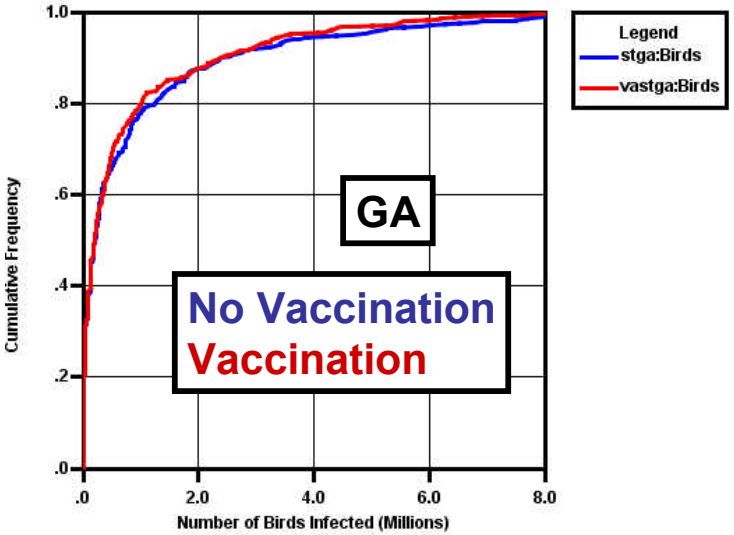


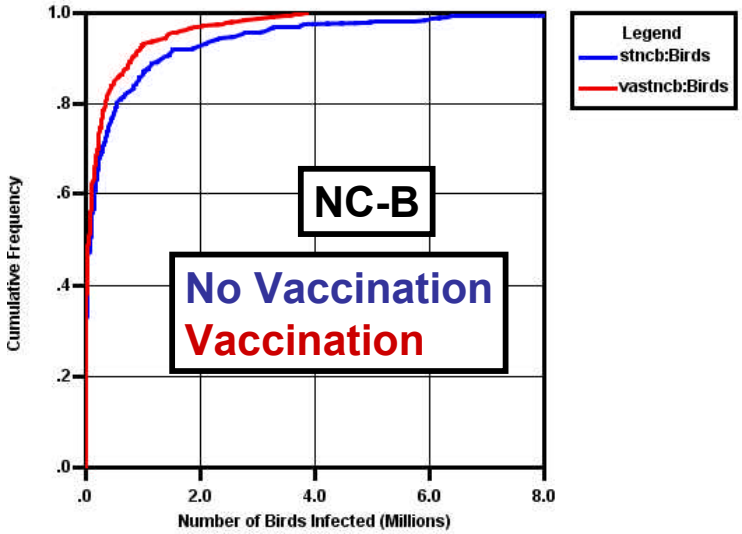


Vaccination: States-Broilers Birds

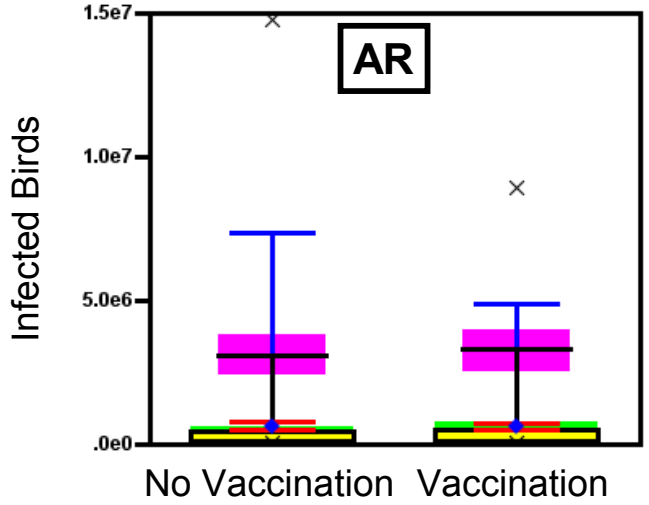


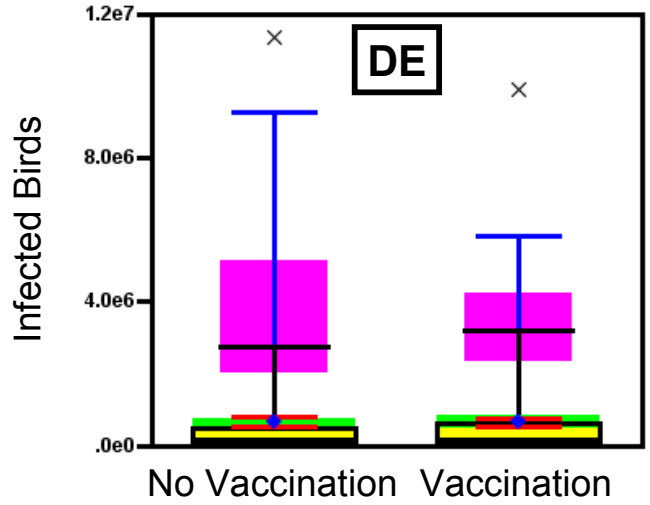


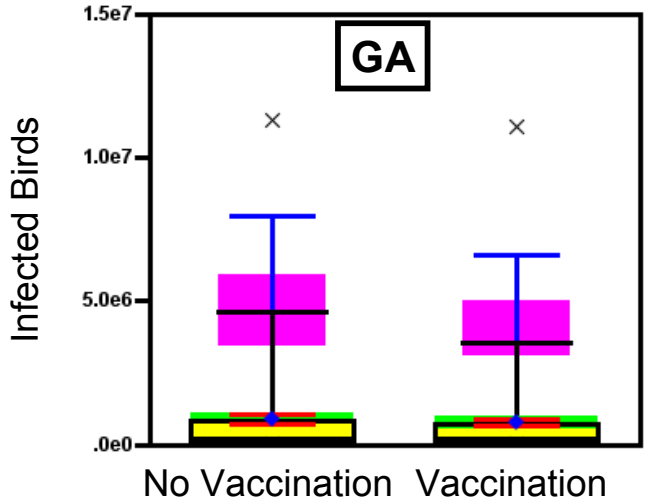


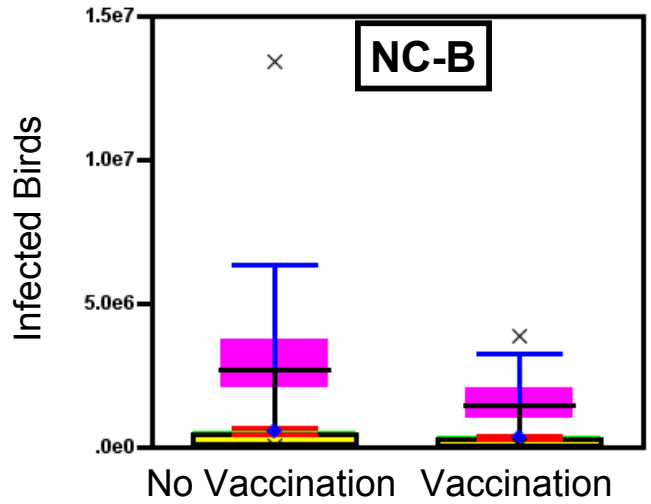


Vaccination: States-Broilers Birds

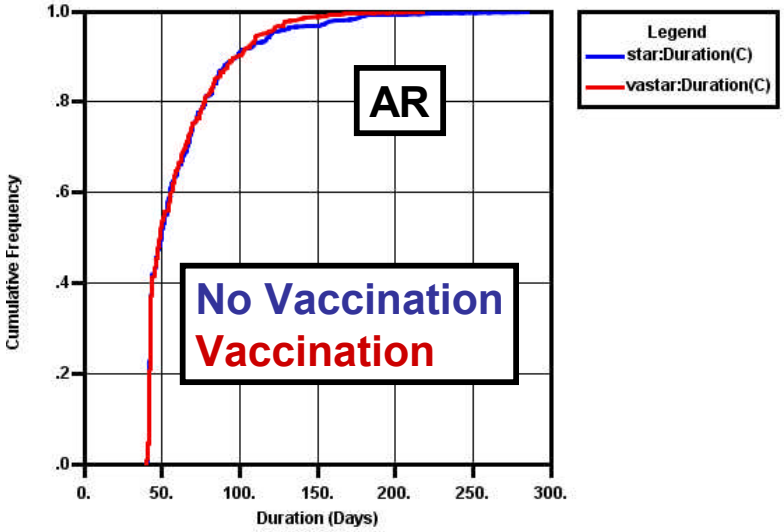


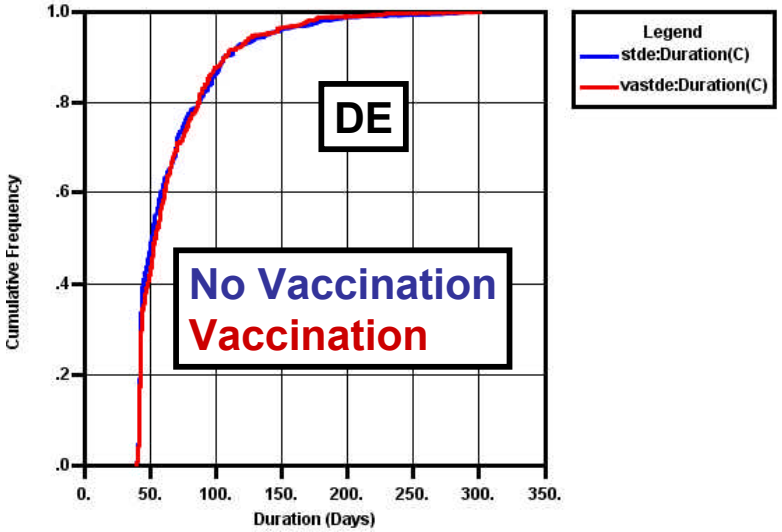


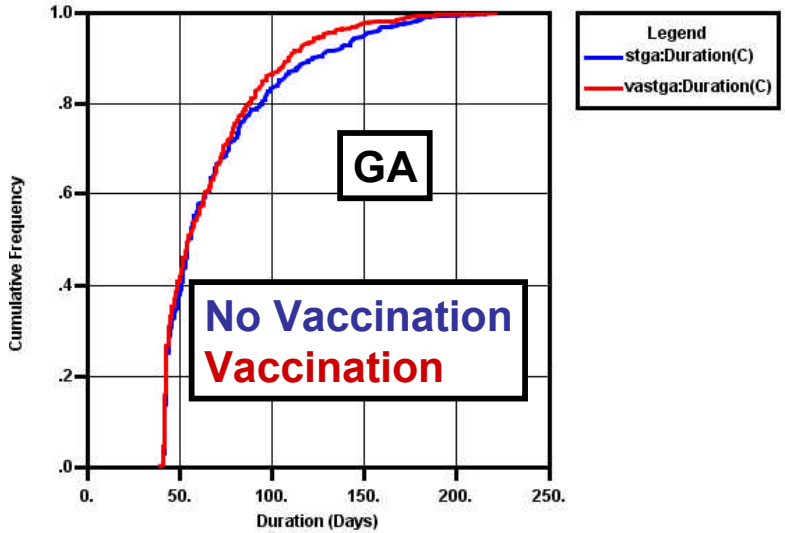


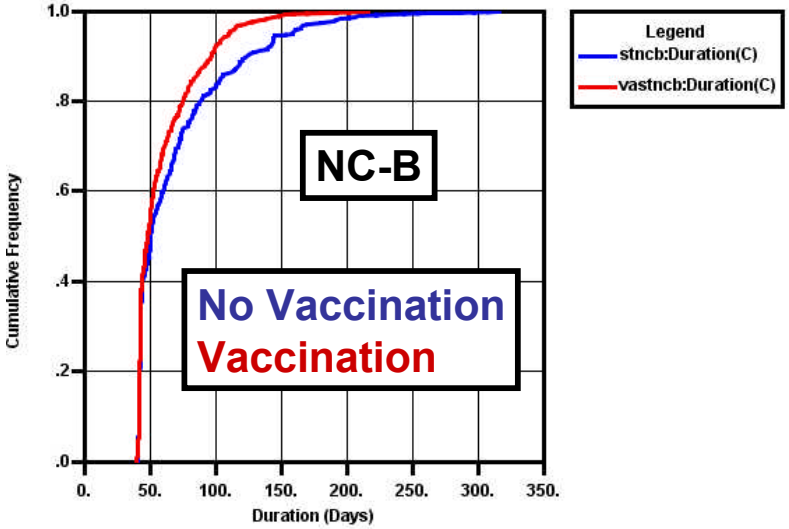


Vaccination: States-Broilers Duration

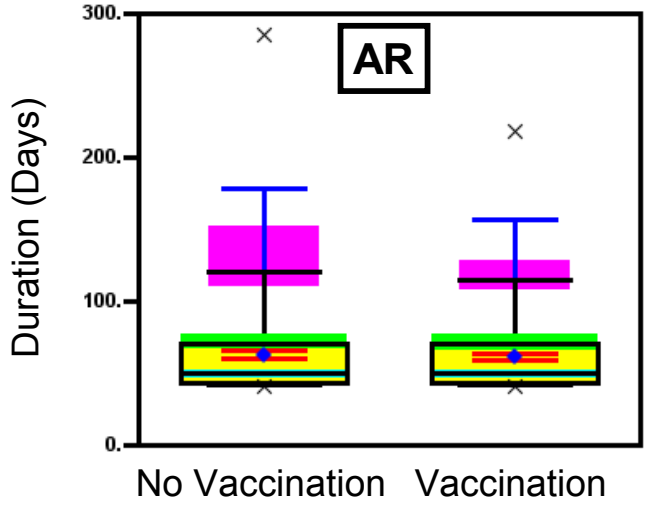


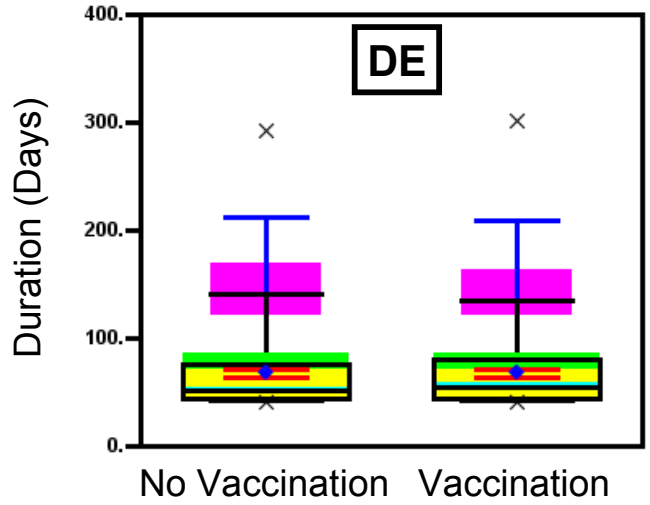


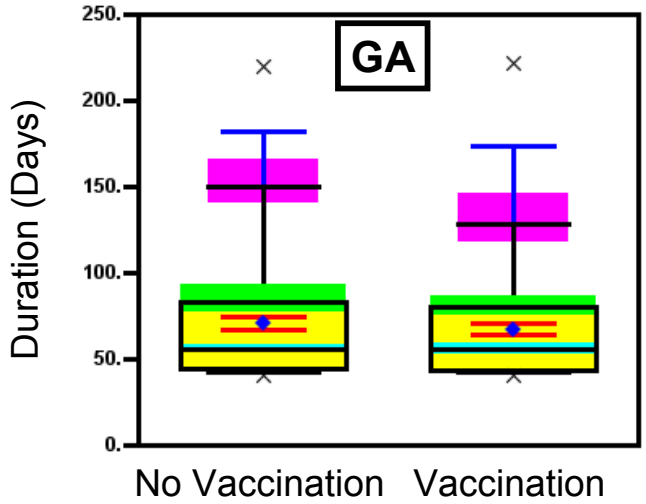


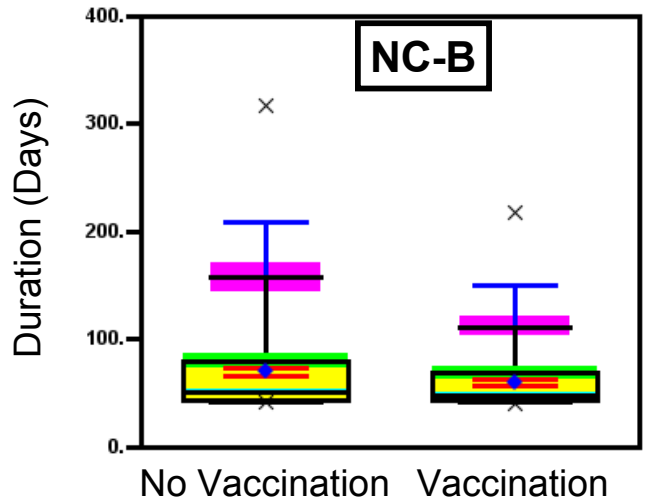


Vaccination: States-Broilers Duration

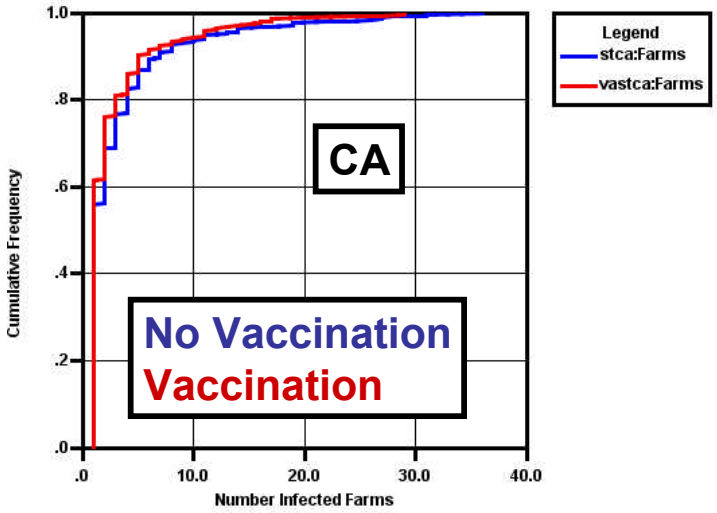


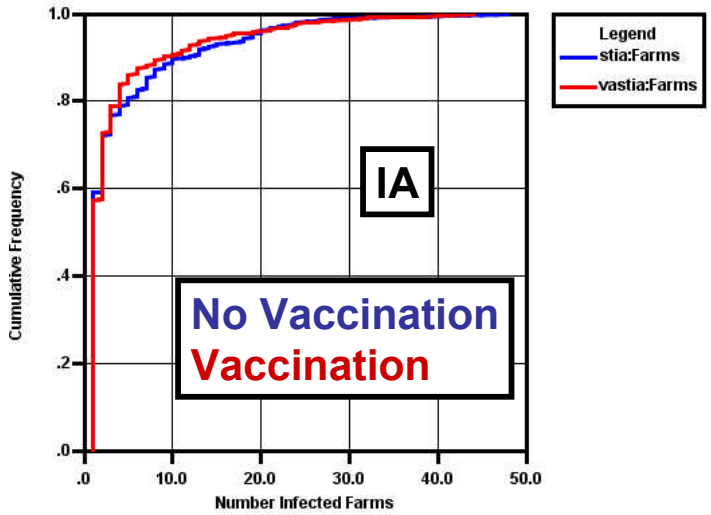


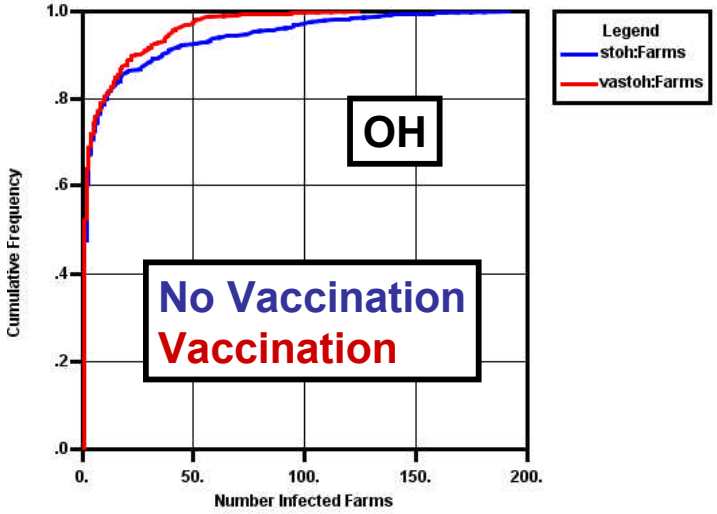


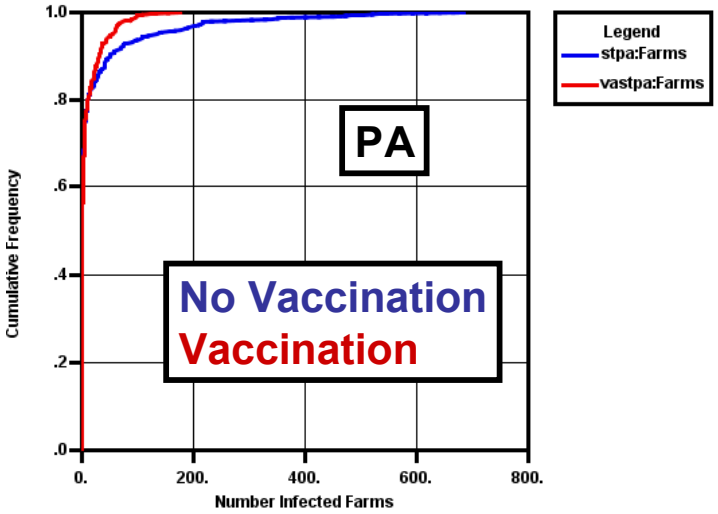


Vaccination: States-Layers Farms

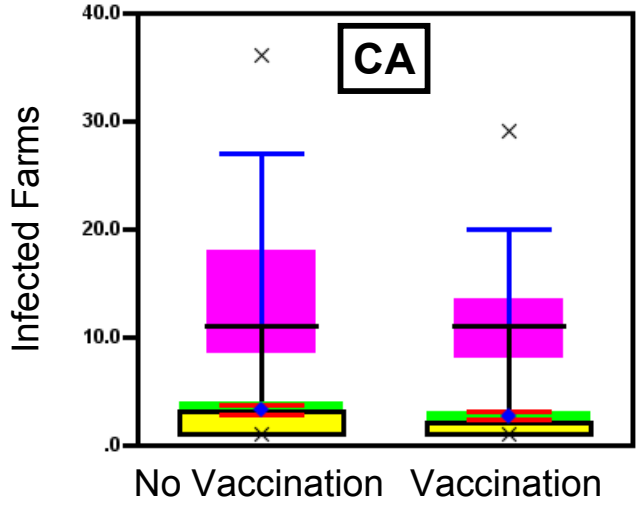


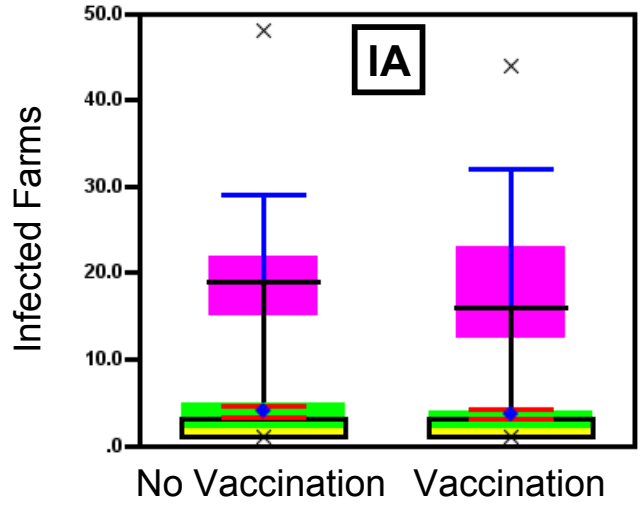


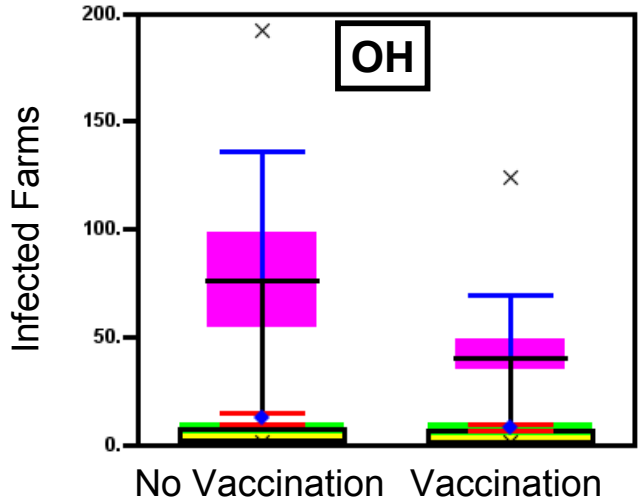


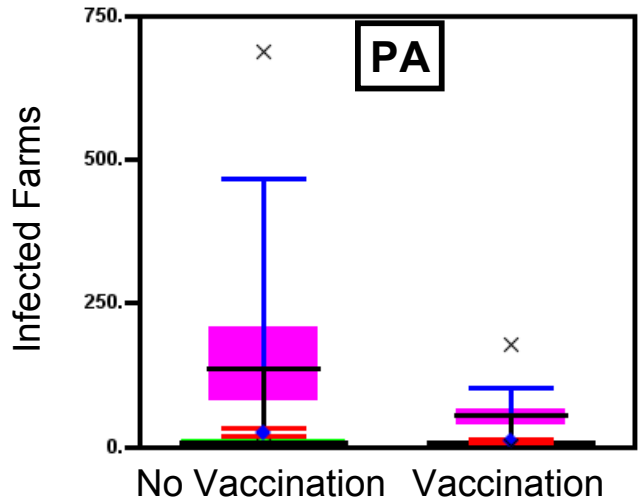


Vaccination: States-Layers Farms

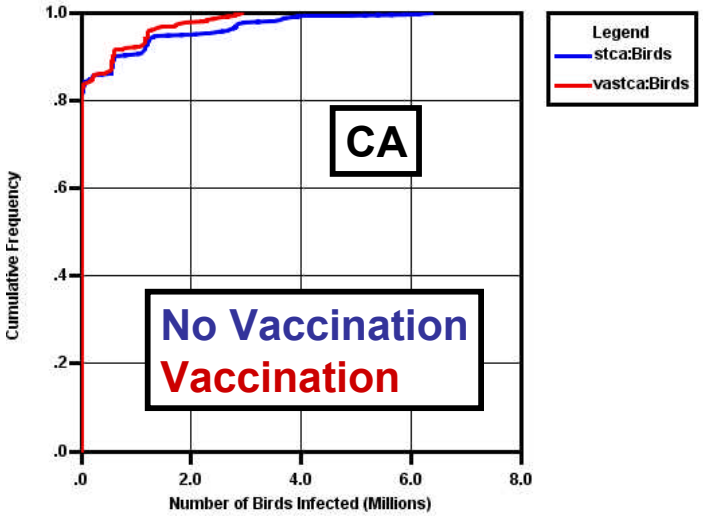


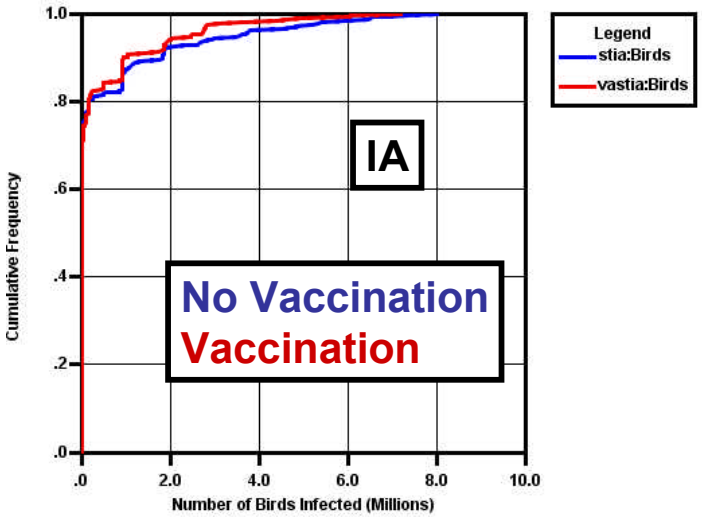


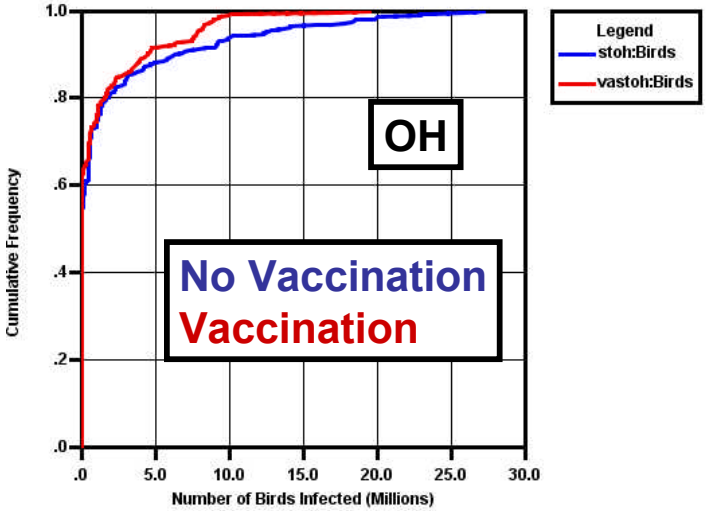


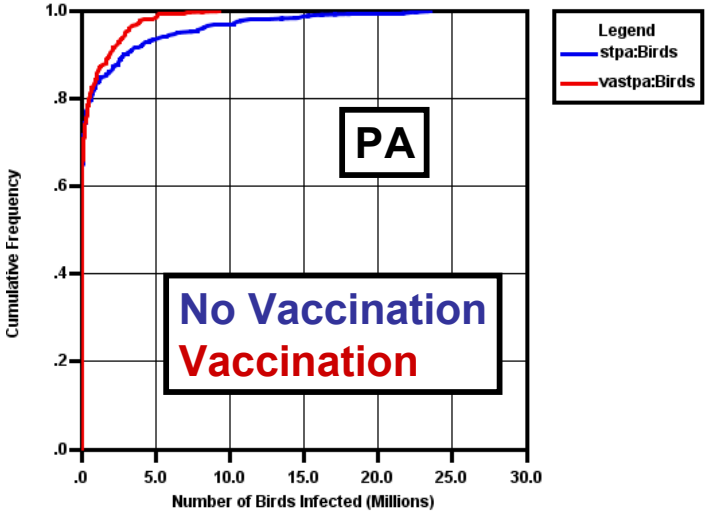


Vaccination: States-Layers Birds

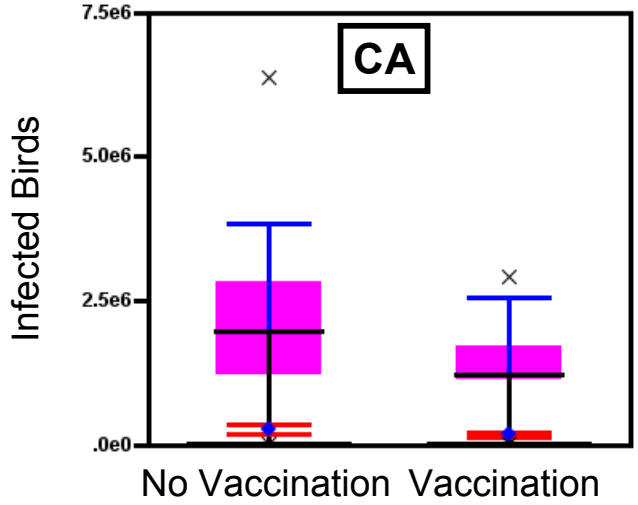


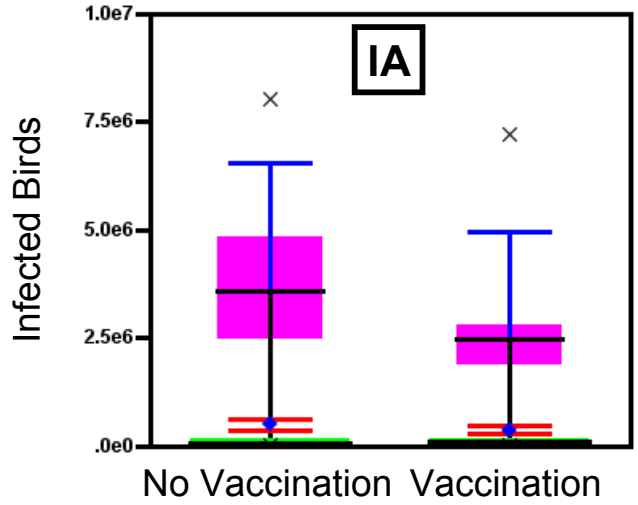


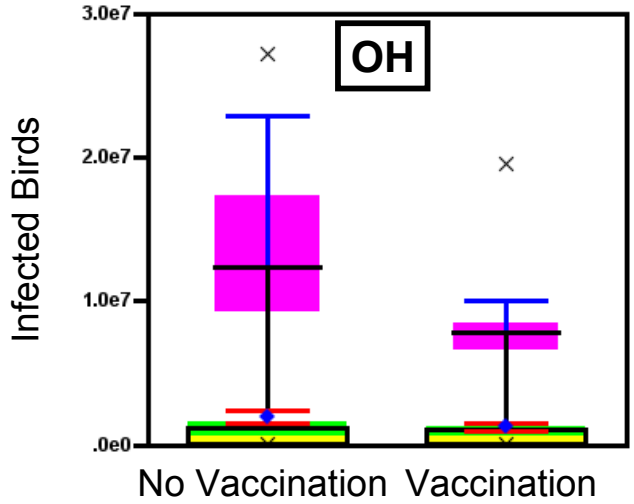


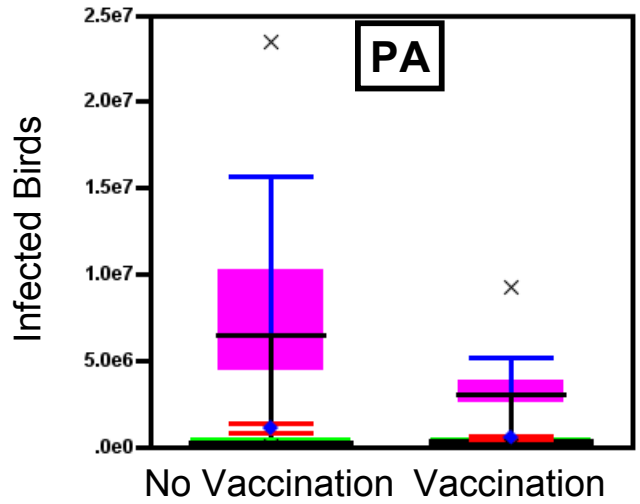


Vaccination: States-Layers Birds

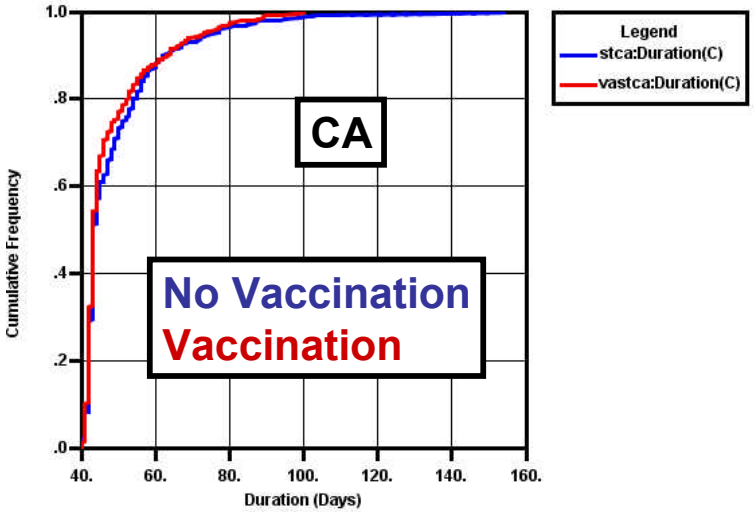


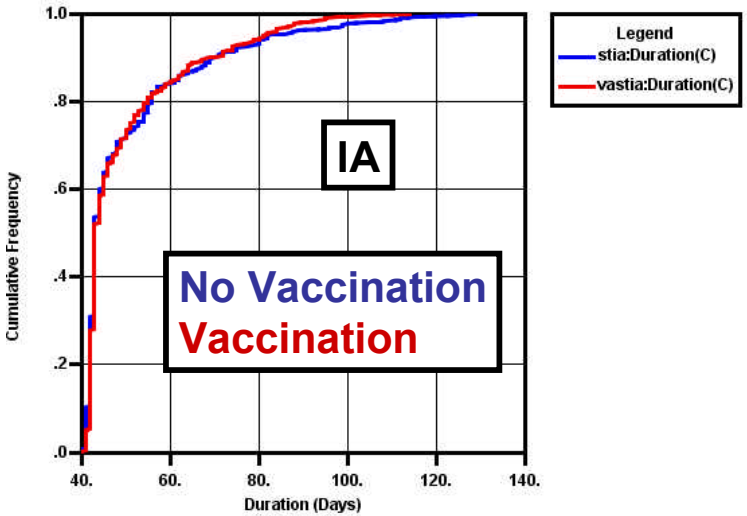


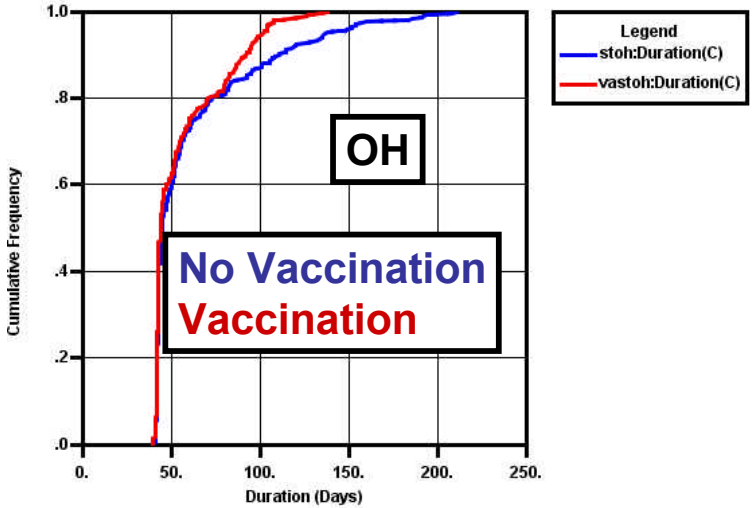


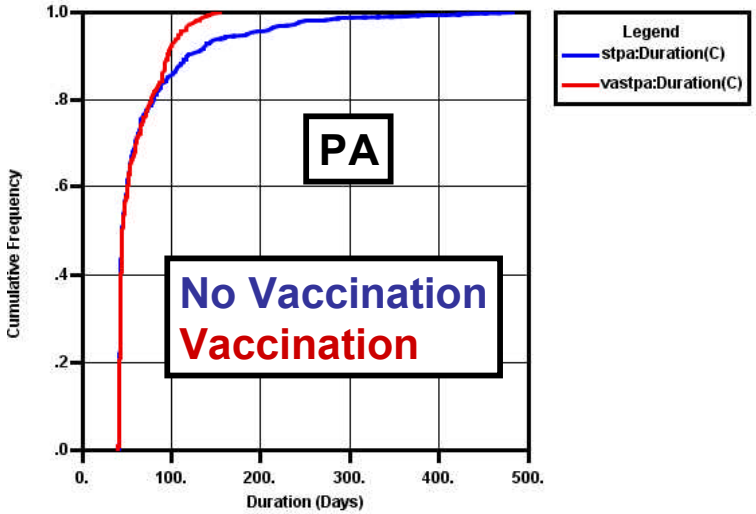


Vaccination: States-Layers Duration

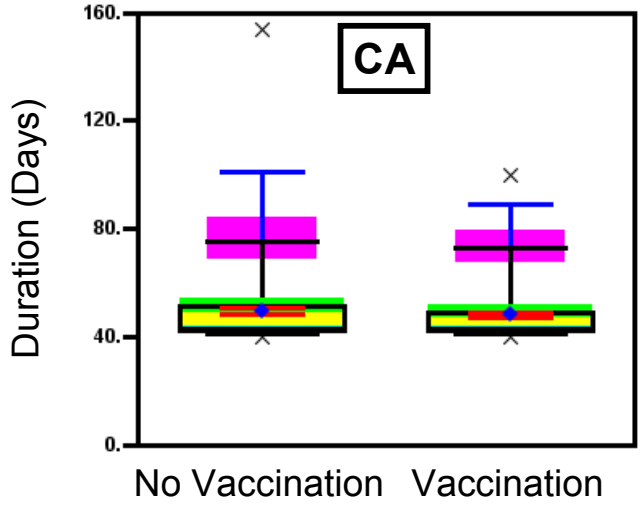


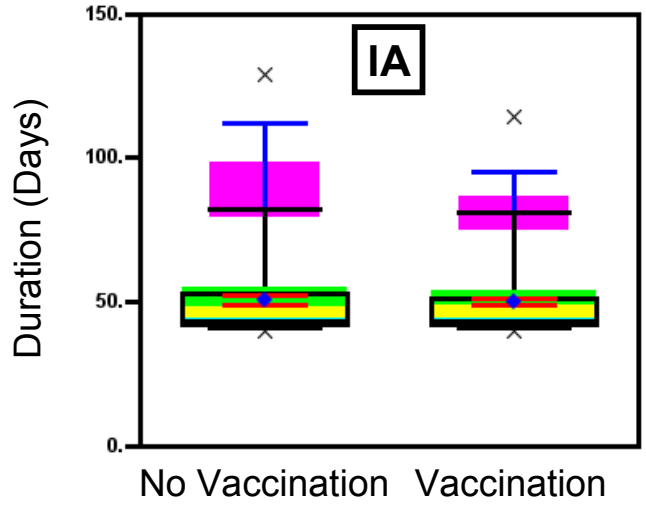


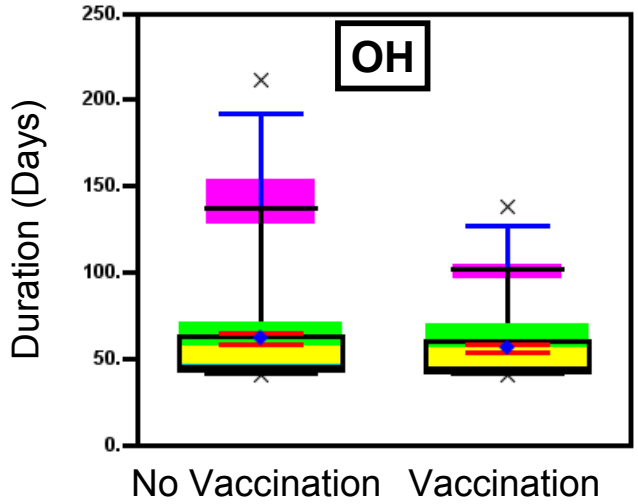


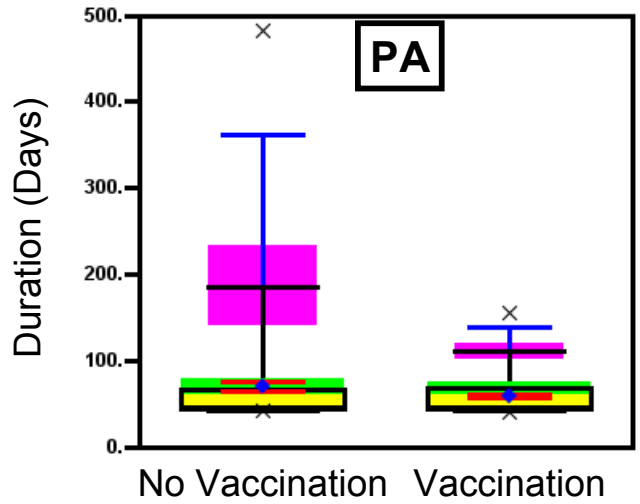


Vaccination: States-Layers Duration

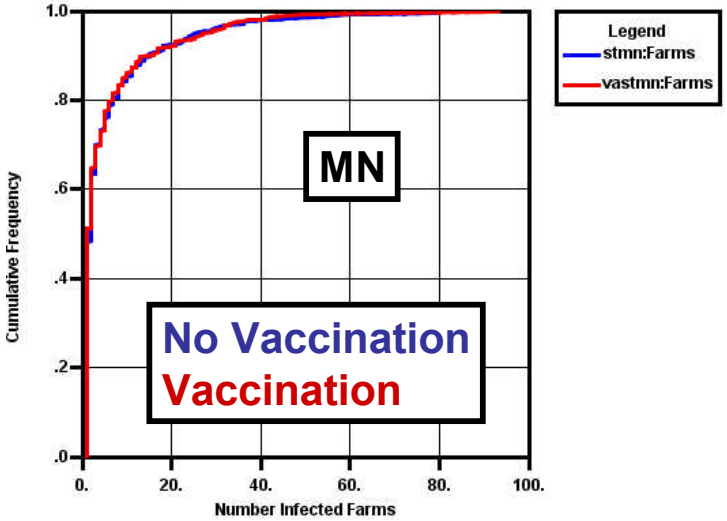


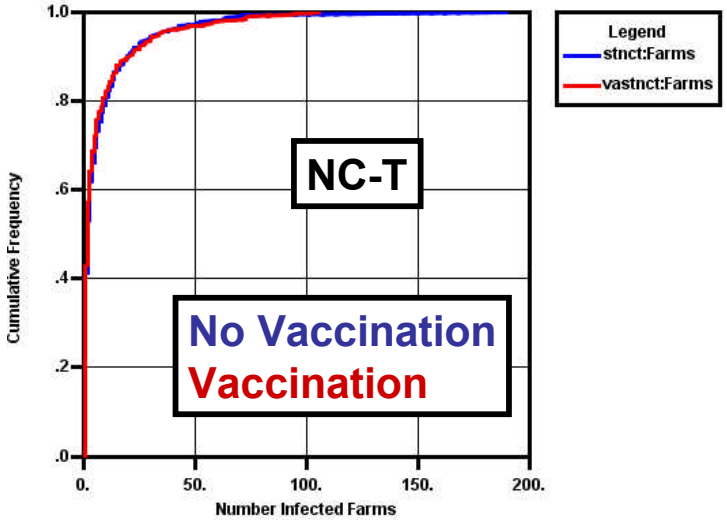


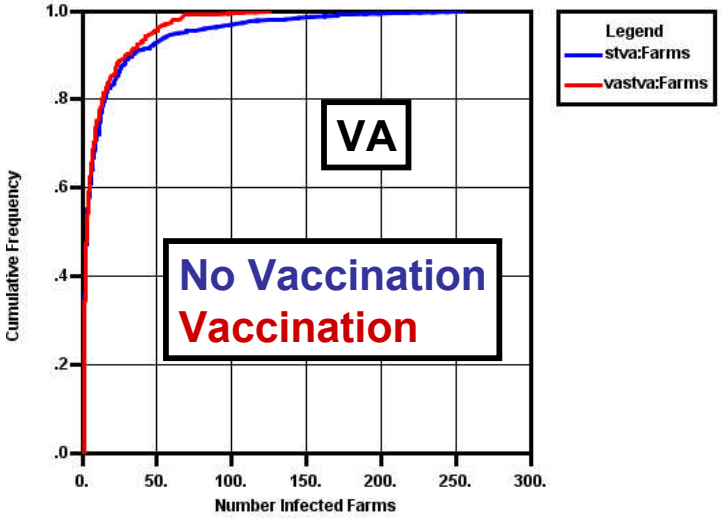




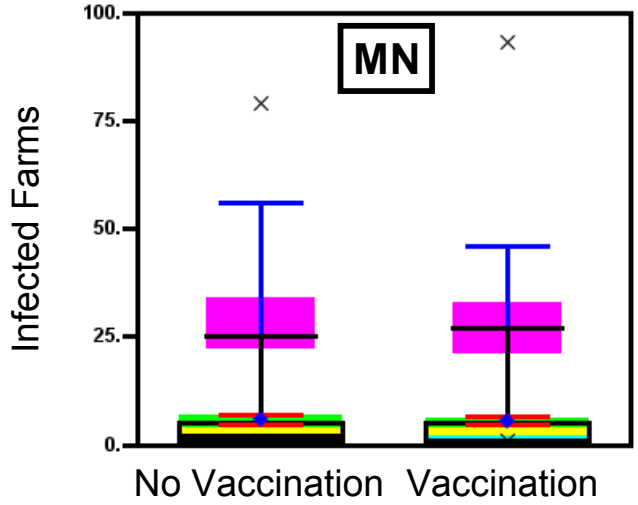
Vaccination: States-Mixed Farms

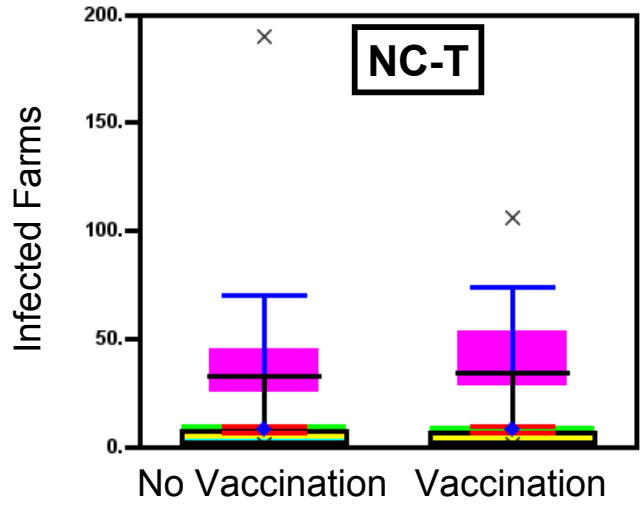


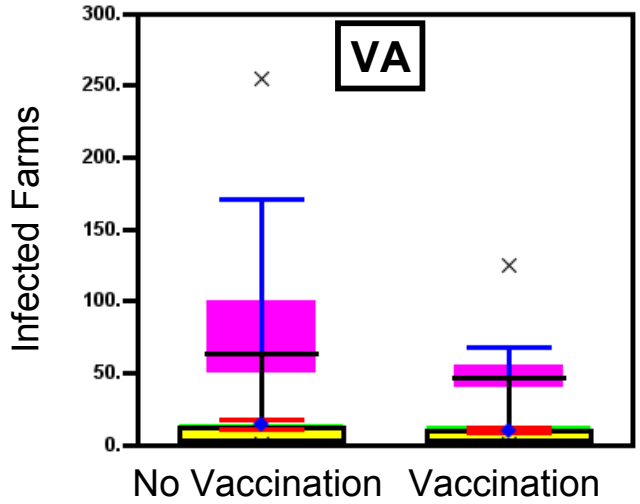




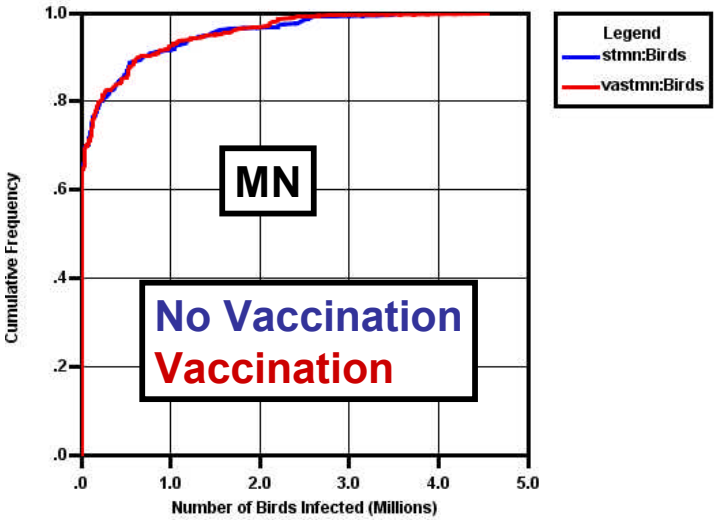
Vaccination: States-Mixed Farms

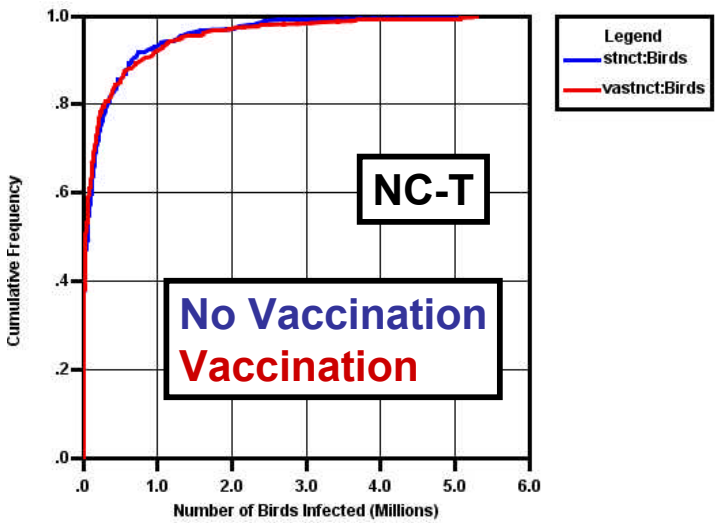


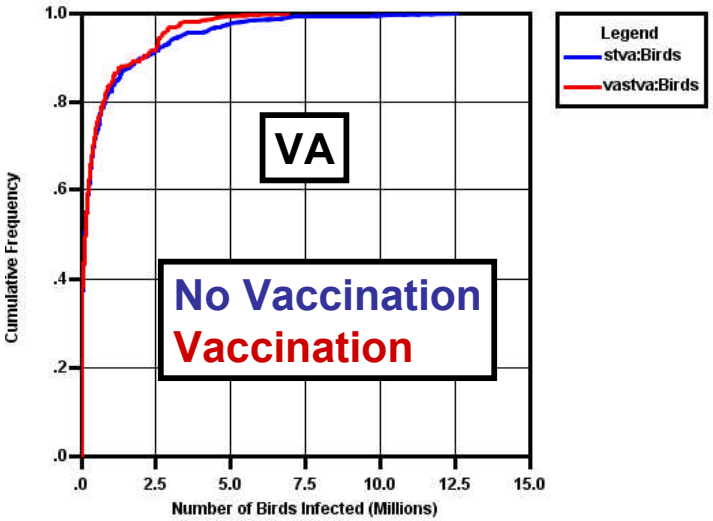




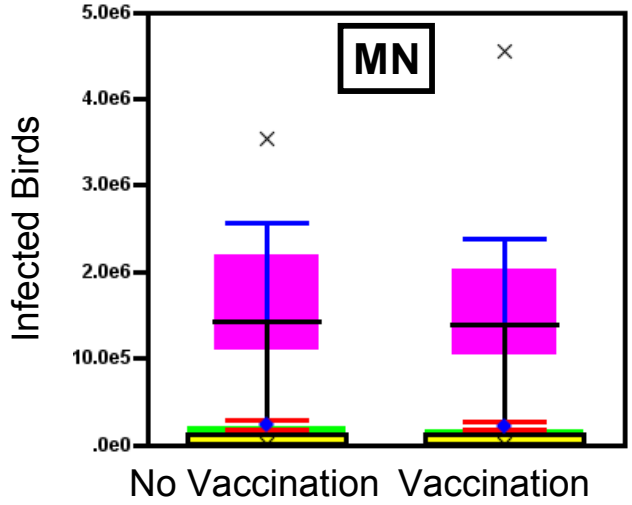
Vaccination: States-Mixed Birds

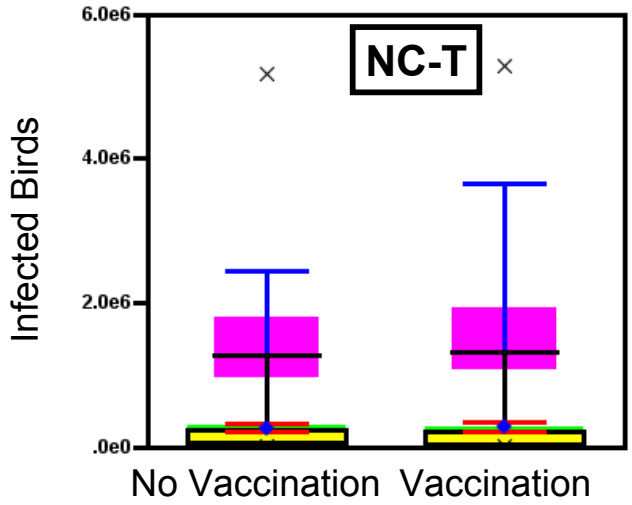


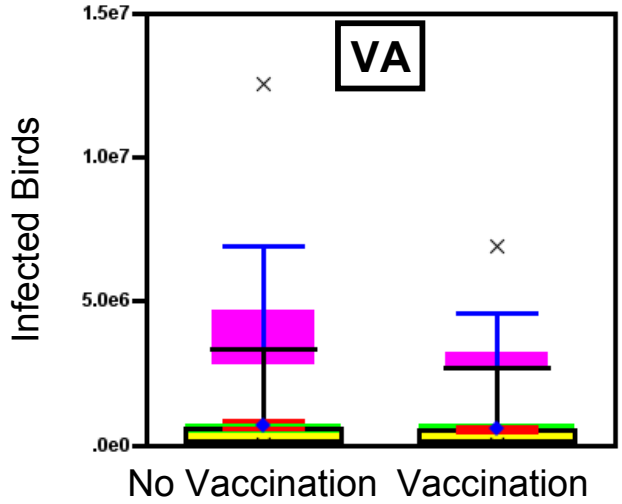




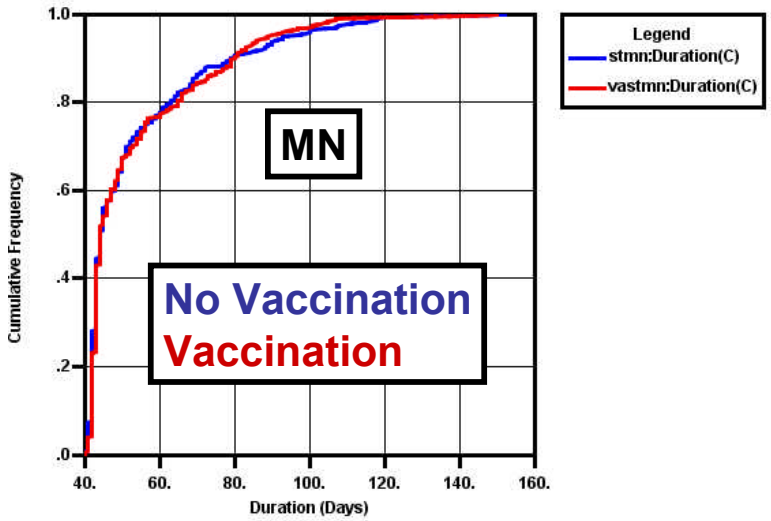
Vaccination: States-Mixed Birds

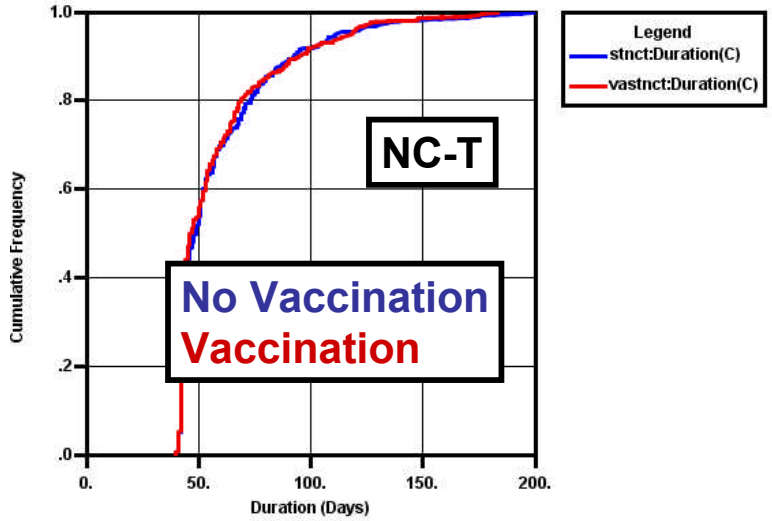


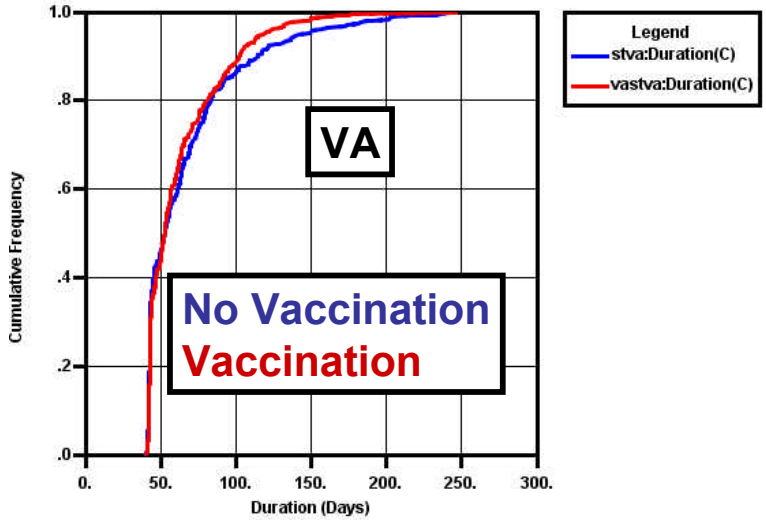




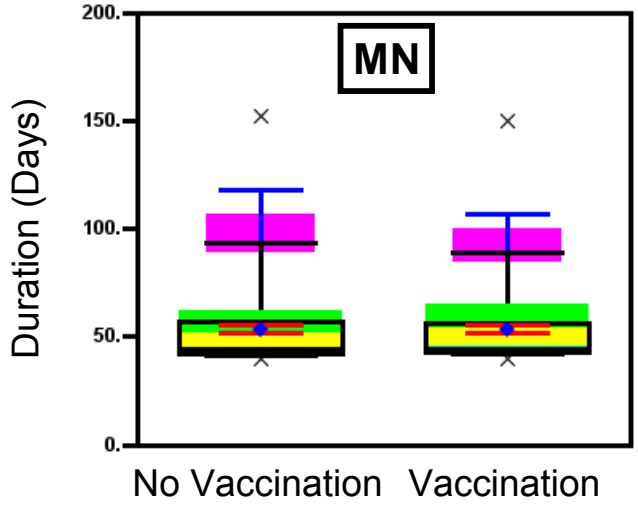
Vaccination: States-Mixed Duration

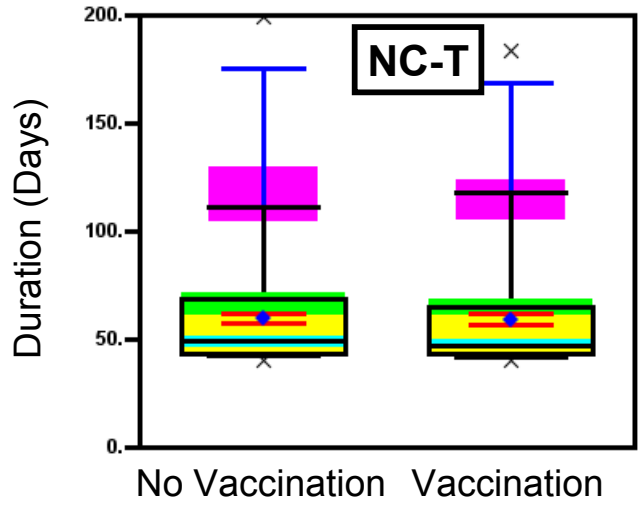


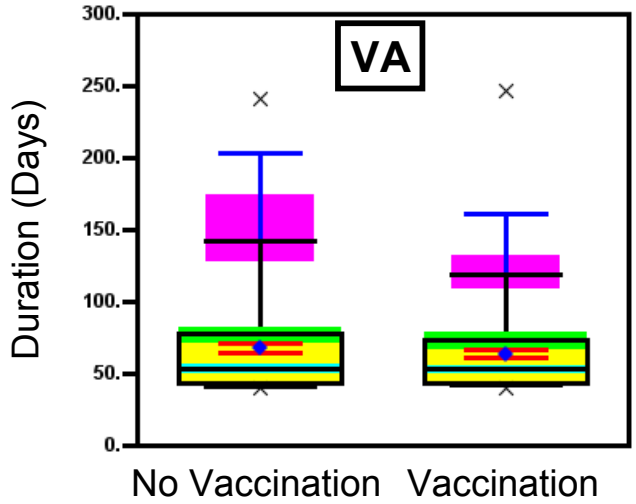




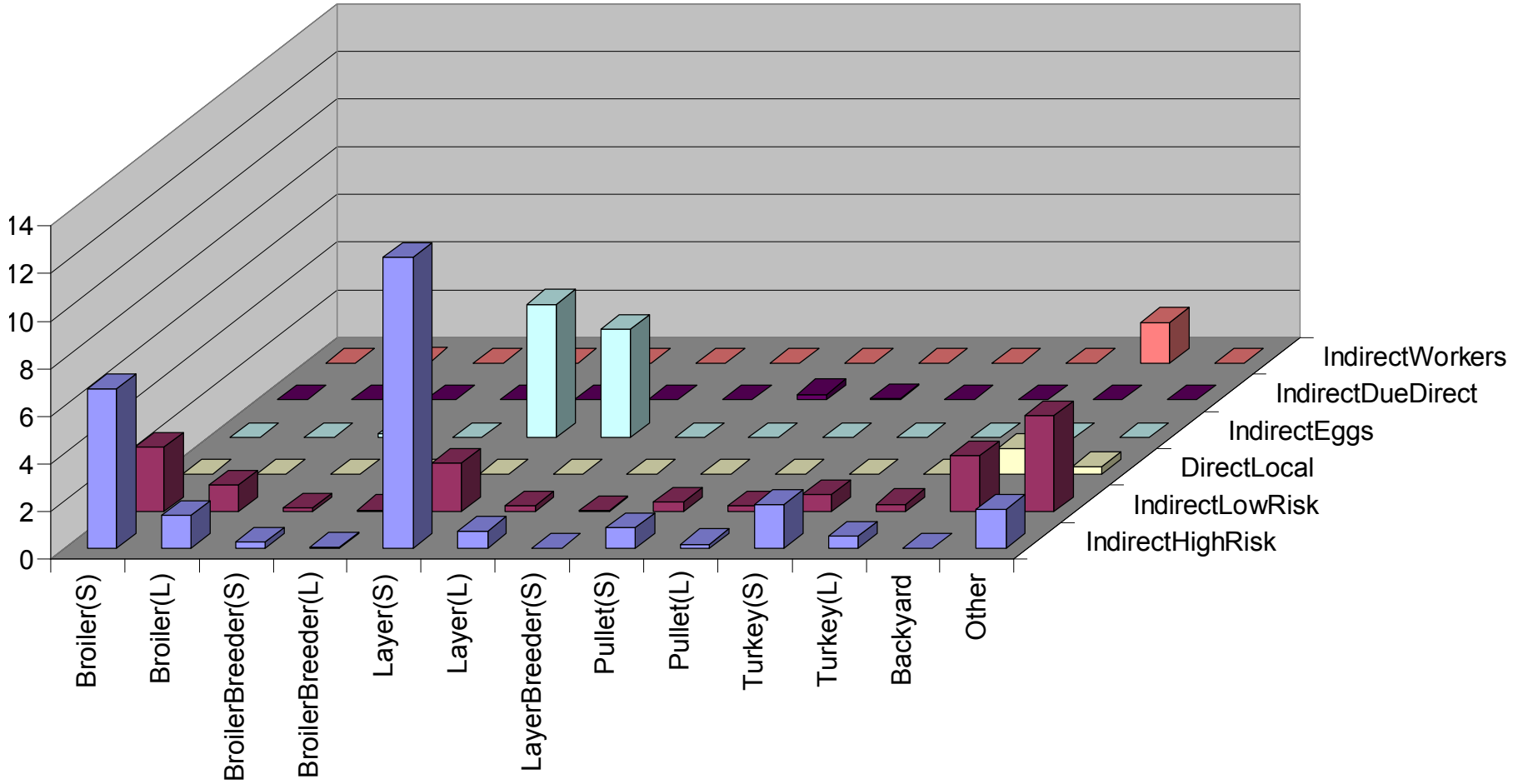
Vaccination: States-Mixed Duration



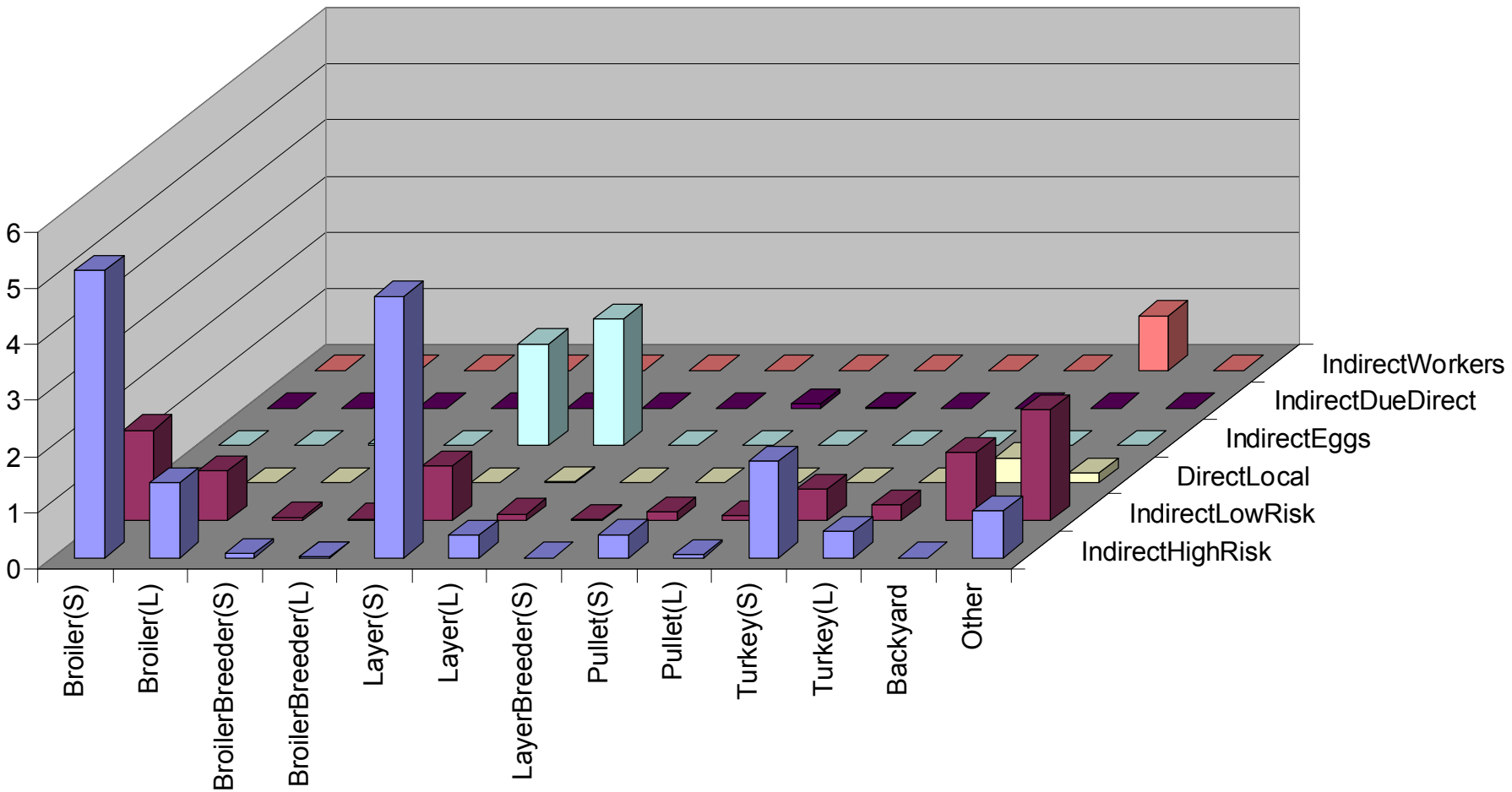




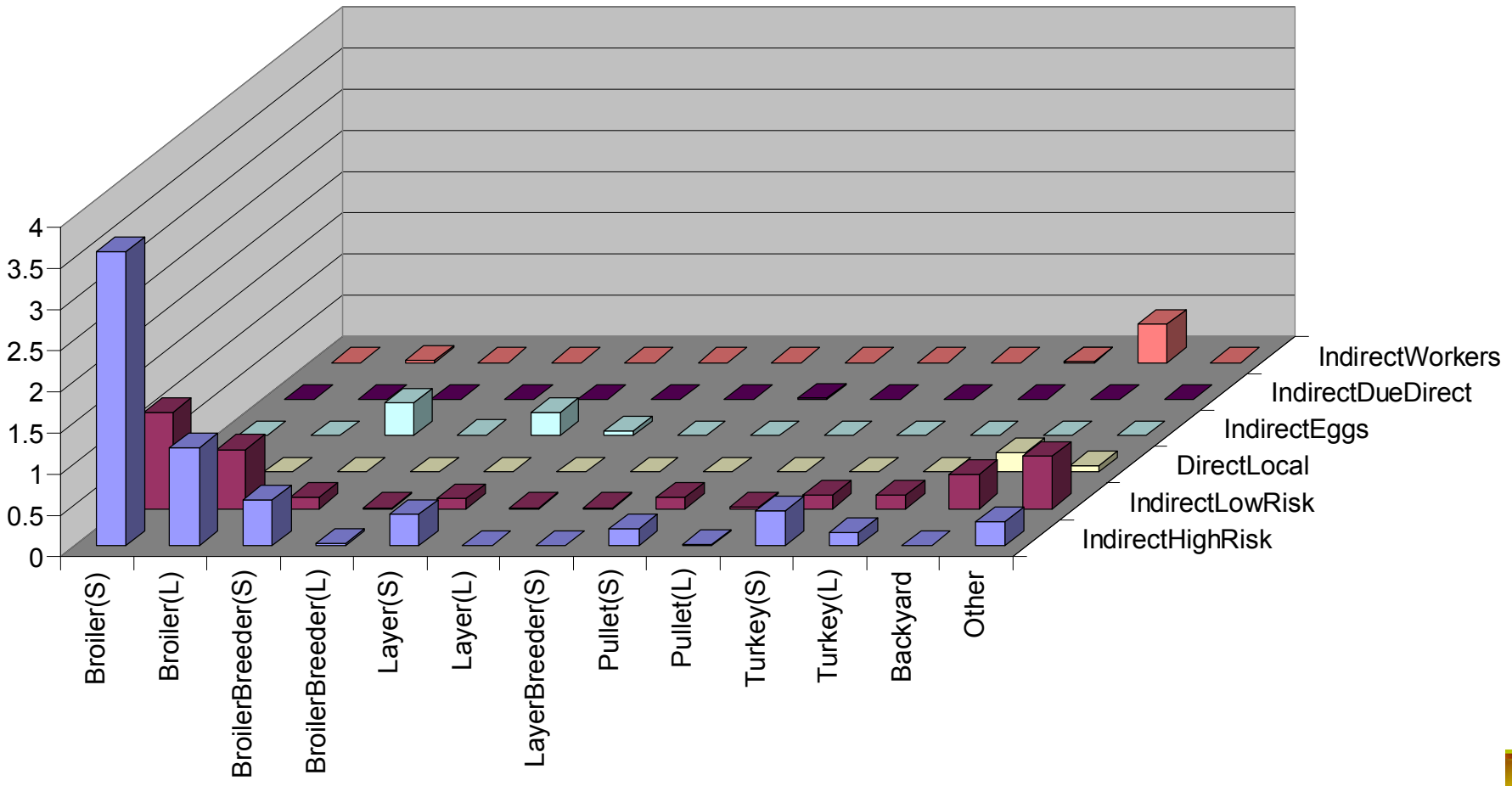
Average number of flocks infected with HPAI following introduction into one commercial broiler, layer or turkey facility in each of Stearns County, MN, Lancaster County, PA, and Southampton County, VA (Scenario 2)



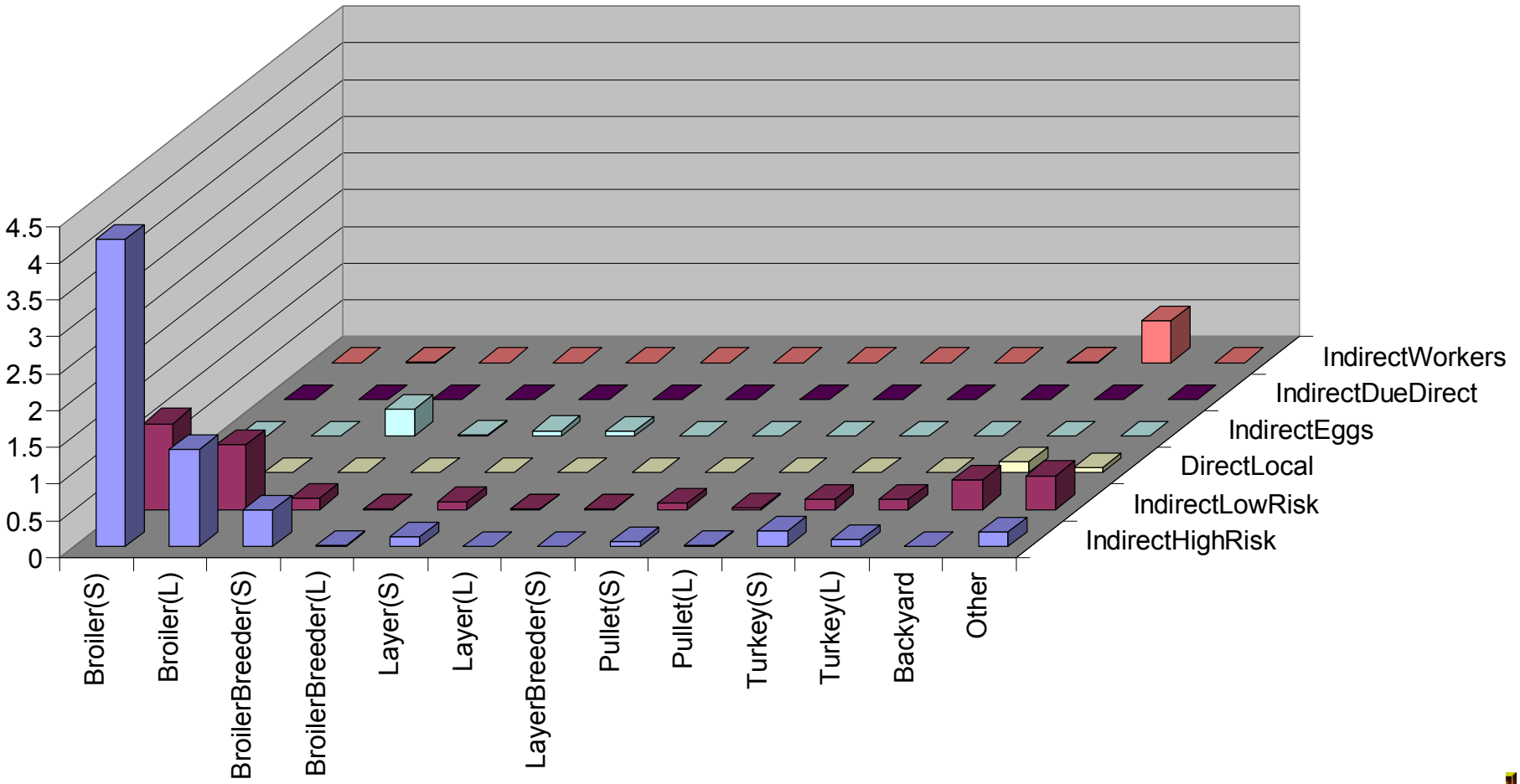
Average number of flocks infected with HPAI for Scenario 2 with vaccination on triggers (Scenario V-2)



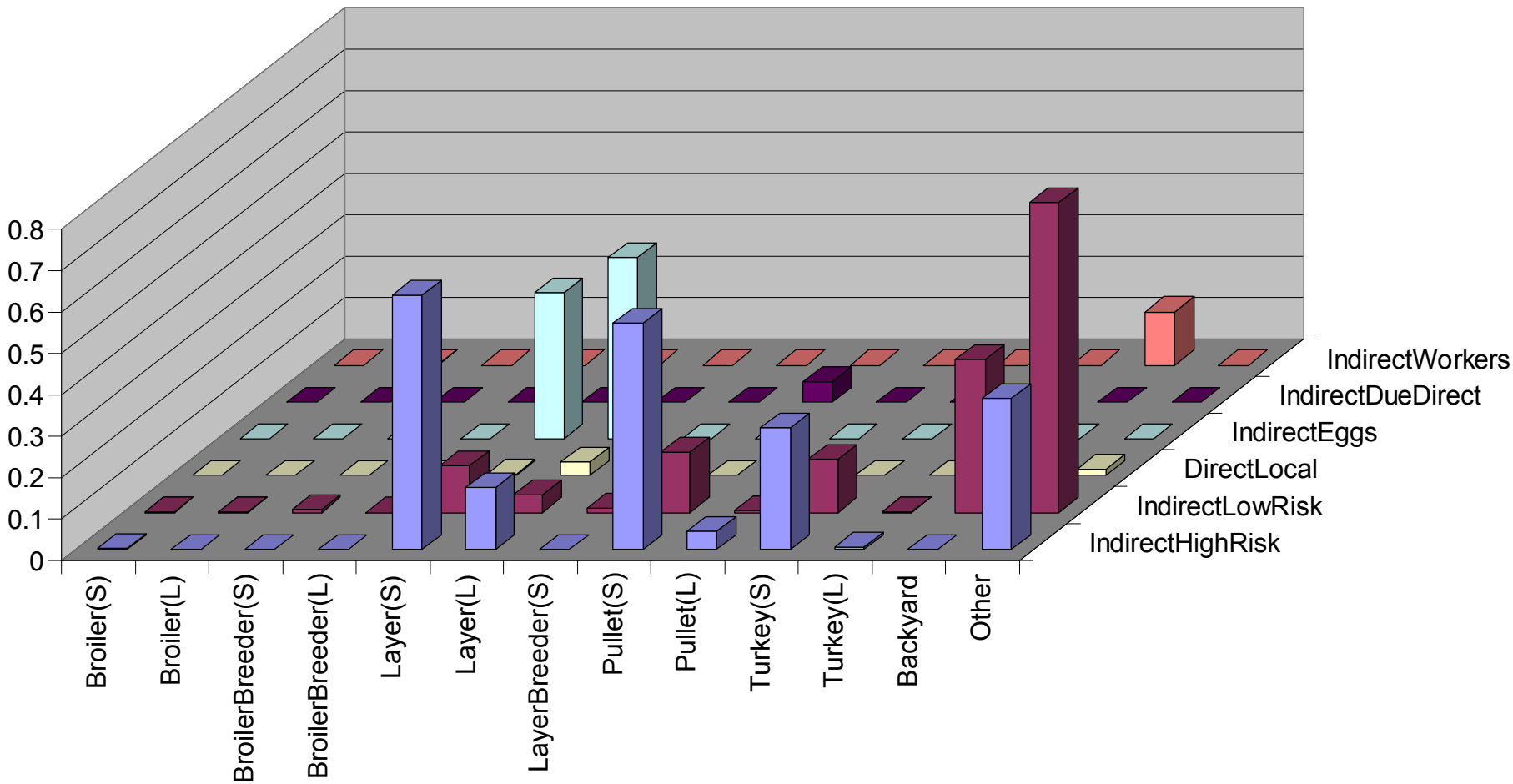
Average number of flocks infected with HPAI following introduction into one commercial broiler and one backyard in Benton County, AR (Scenario 3)



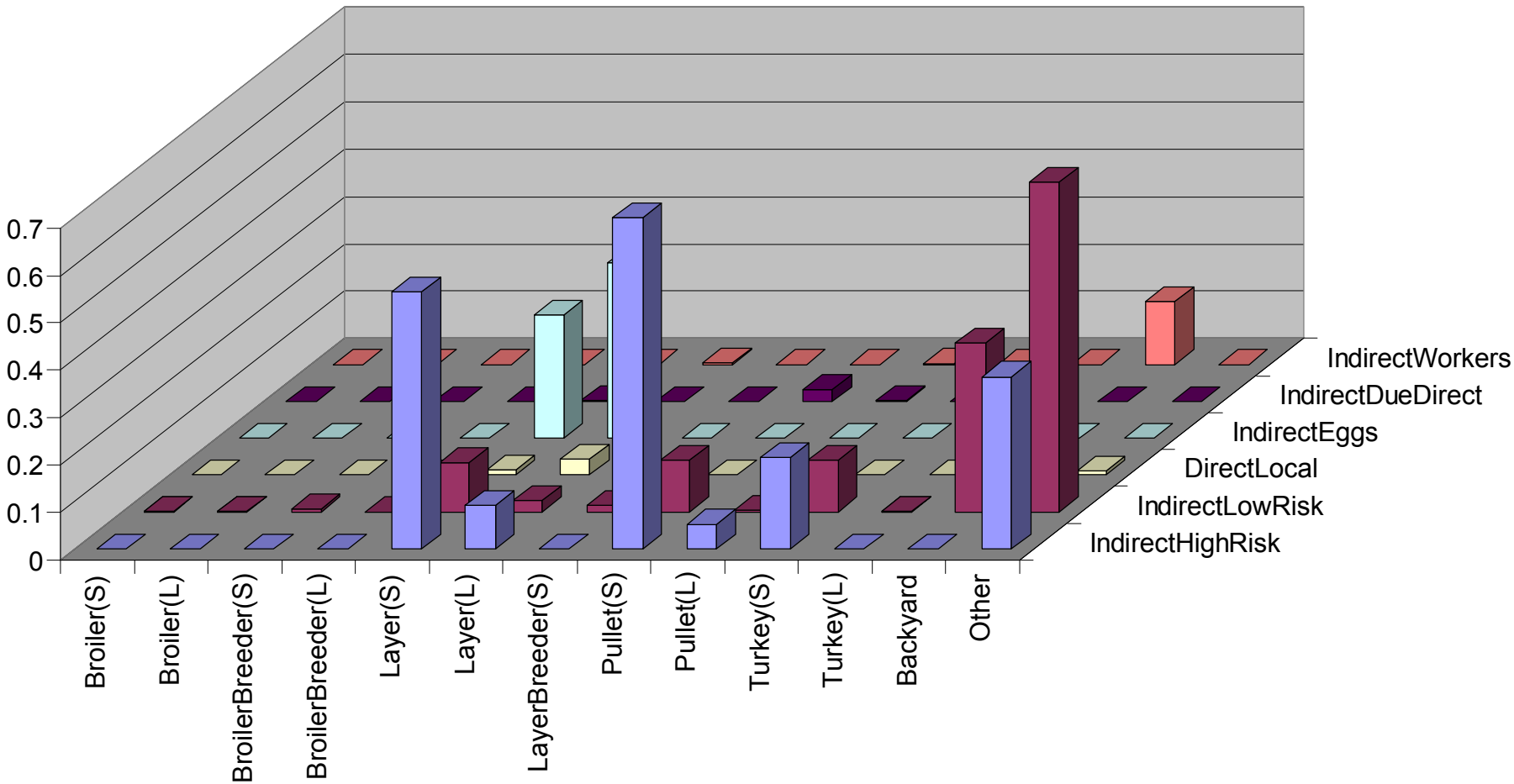
Average number of flocks infected with HPAI for Scenario 3 with vaccination on triggers (Scenario V-3)



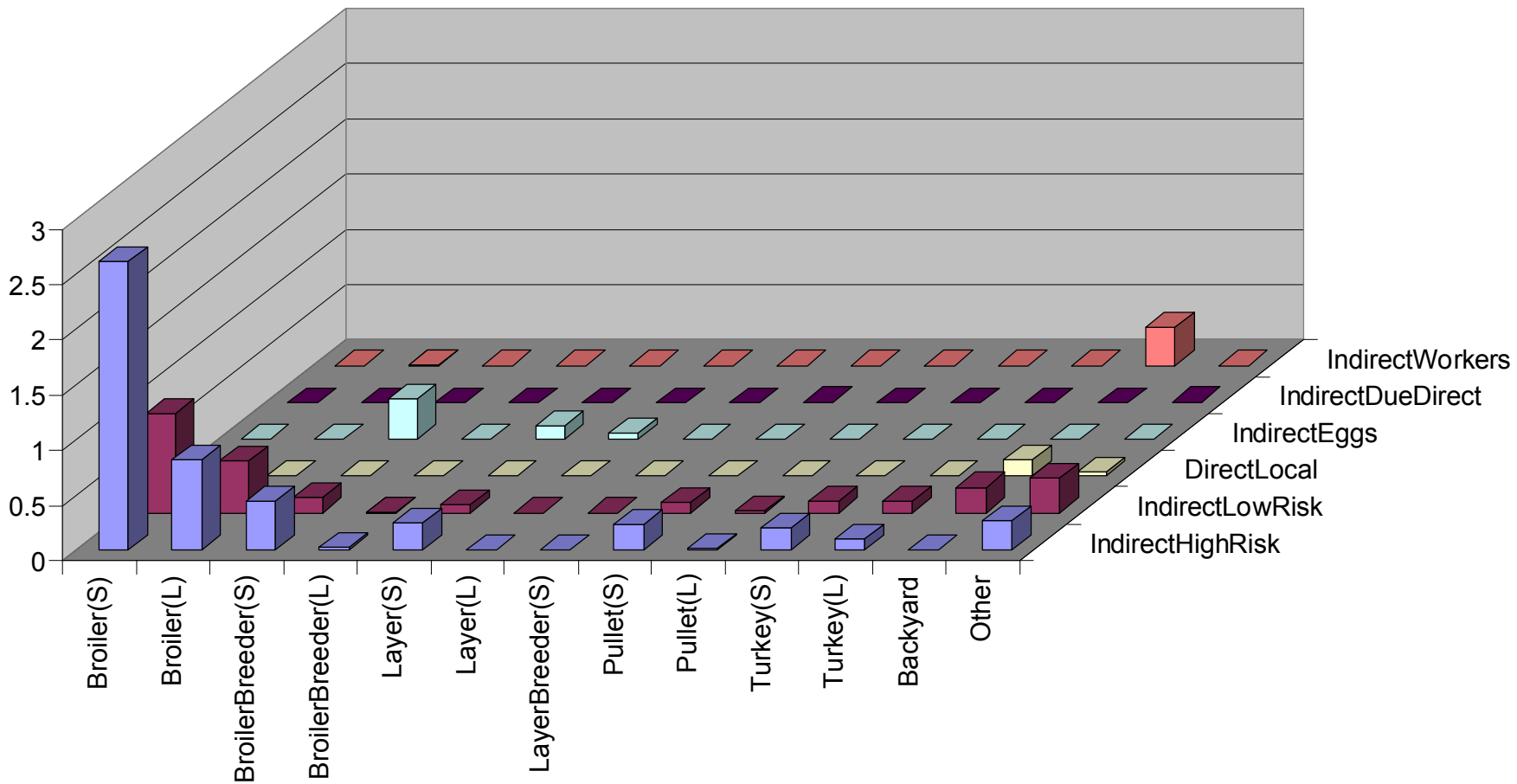
Average number of flocks infected with HPAI following introduction into one commercial layer in Guthrie County, IA (Scenario 4)



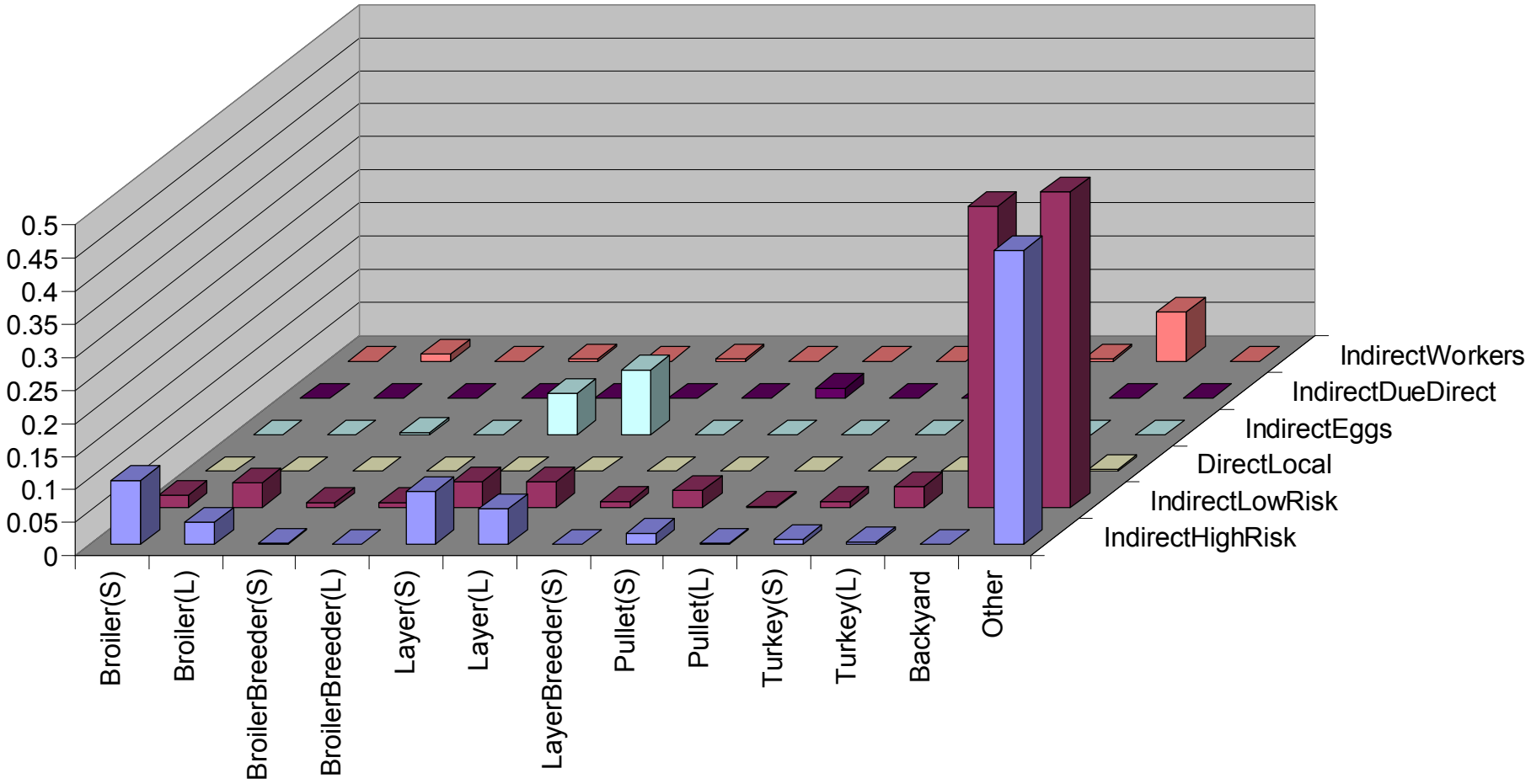
Average number of flocks infected with HPAI for Scenario 4 with vaccination on triggers (Scenario V-4)



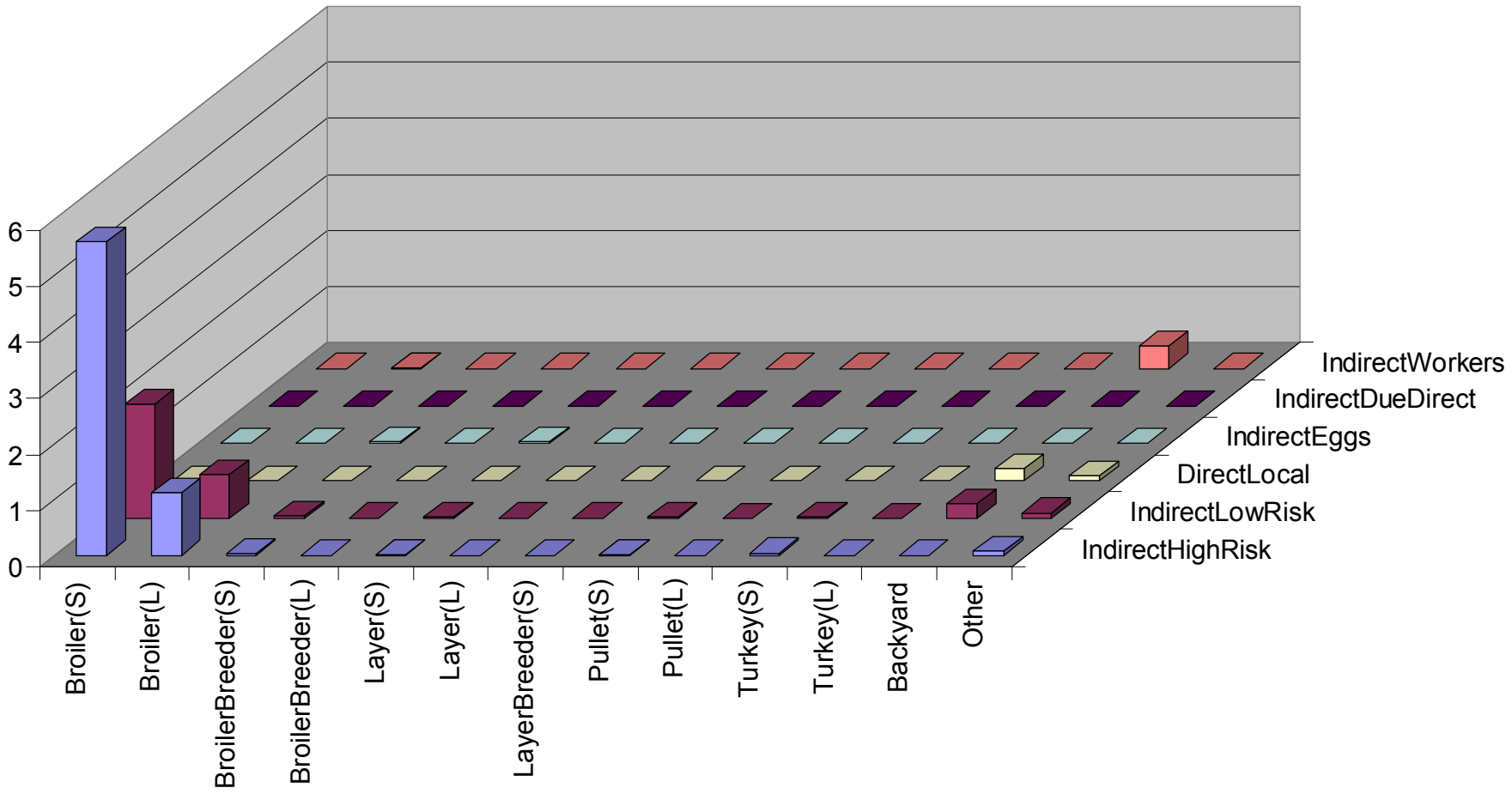
Average number of flocks infected with HPAI following one introduction into poultry in Benton County, Arkansas



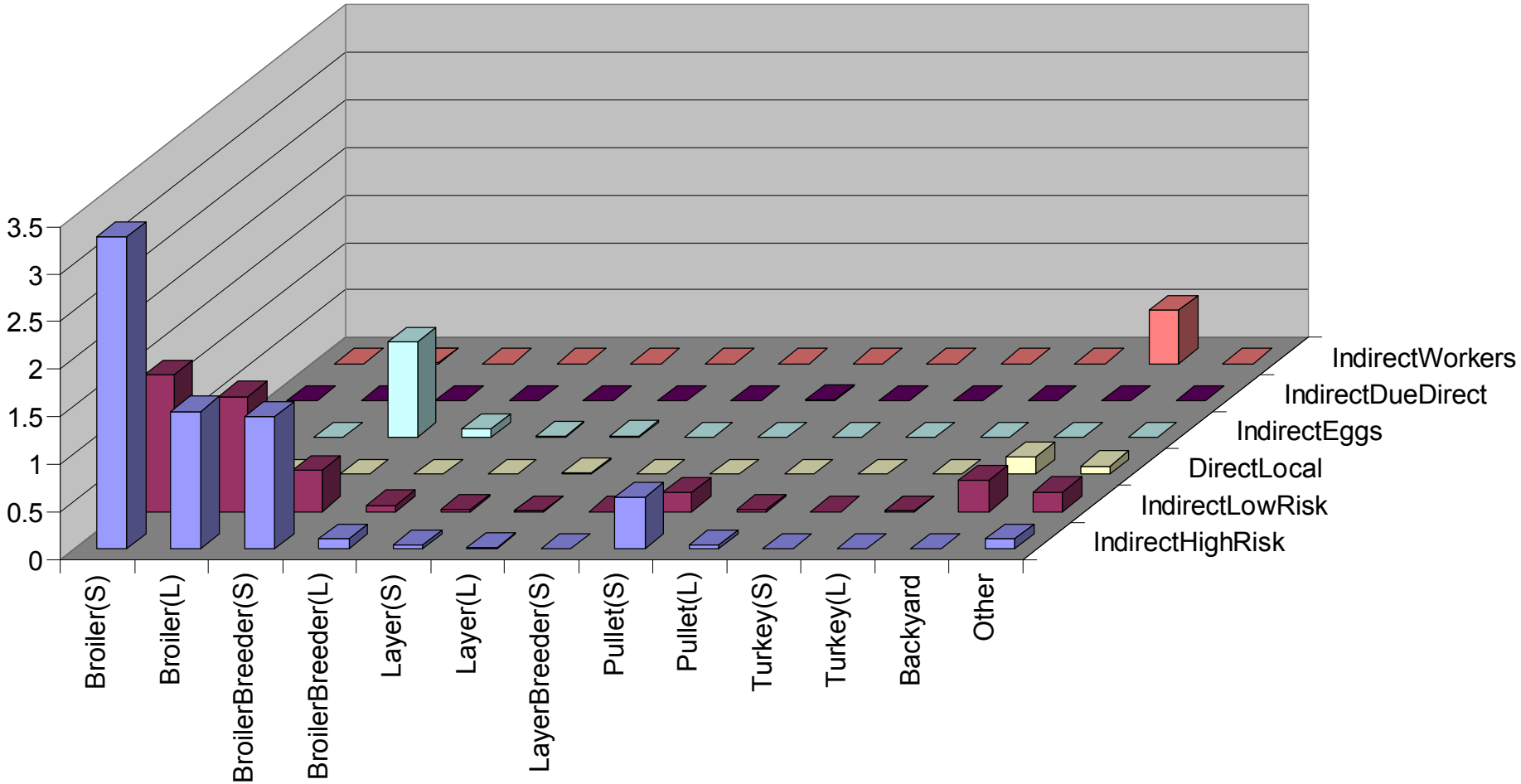
Average number of flocks infected with HPAI following one introduction into poultry in Stanislaus County, California



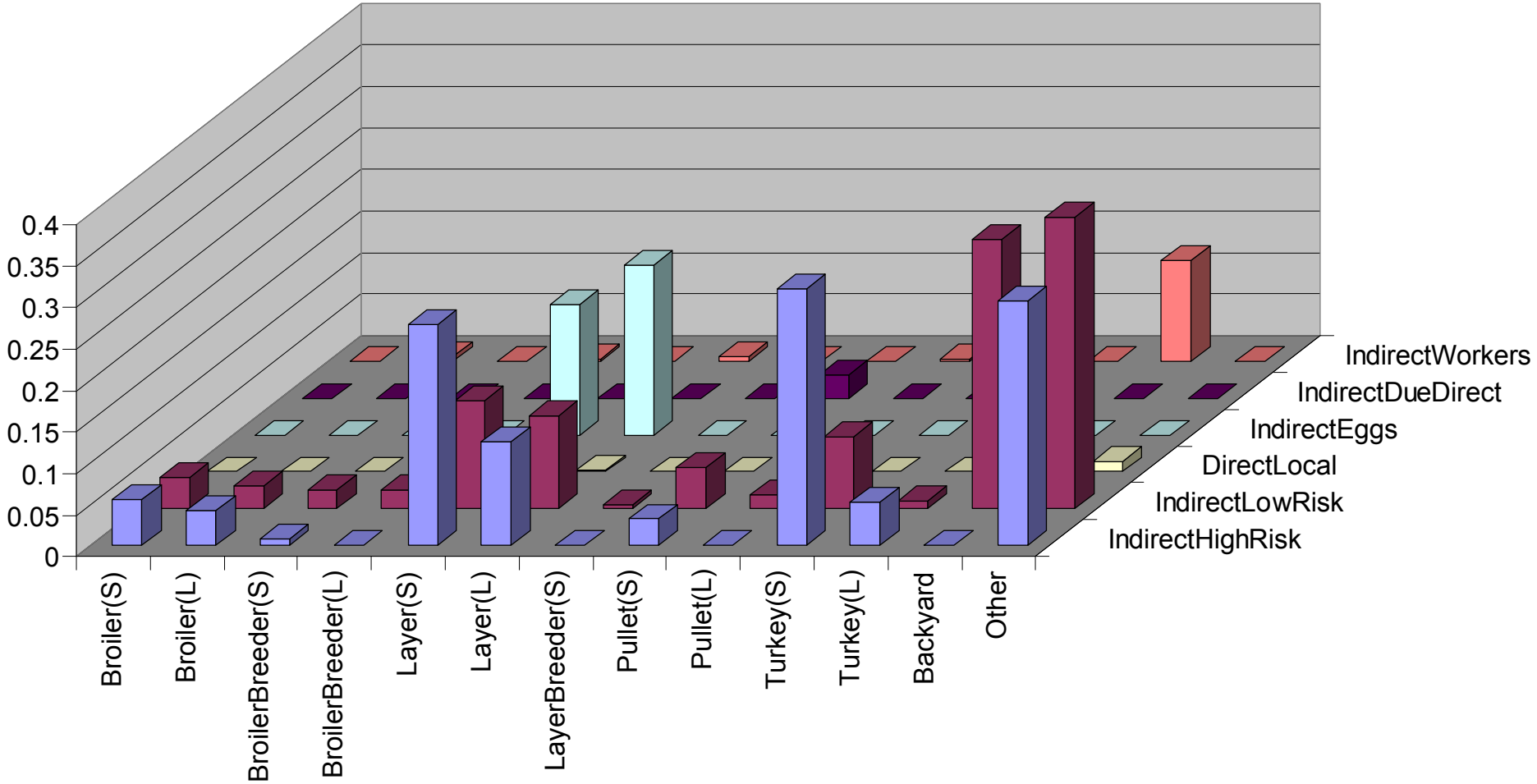
Average number of flocks infected with HPAI following one introduction into poultry in Sussex County, Delaware



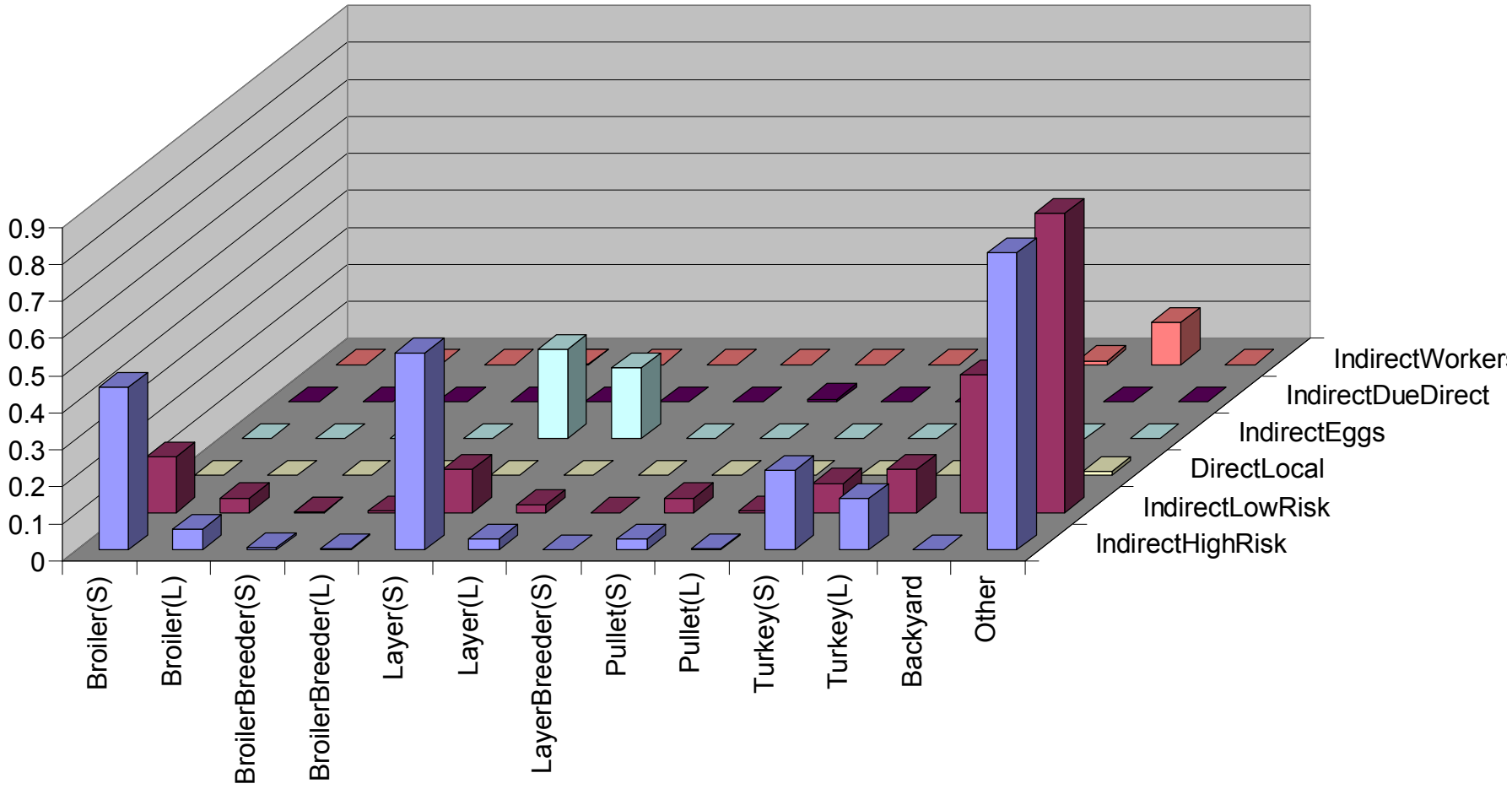
Average number of flocks infected with HPAI following one introduction into poultry in Banks County, Georgia



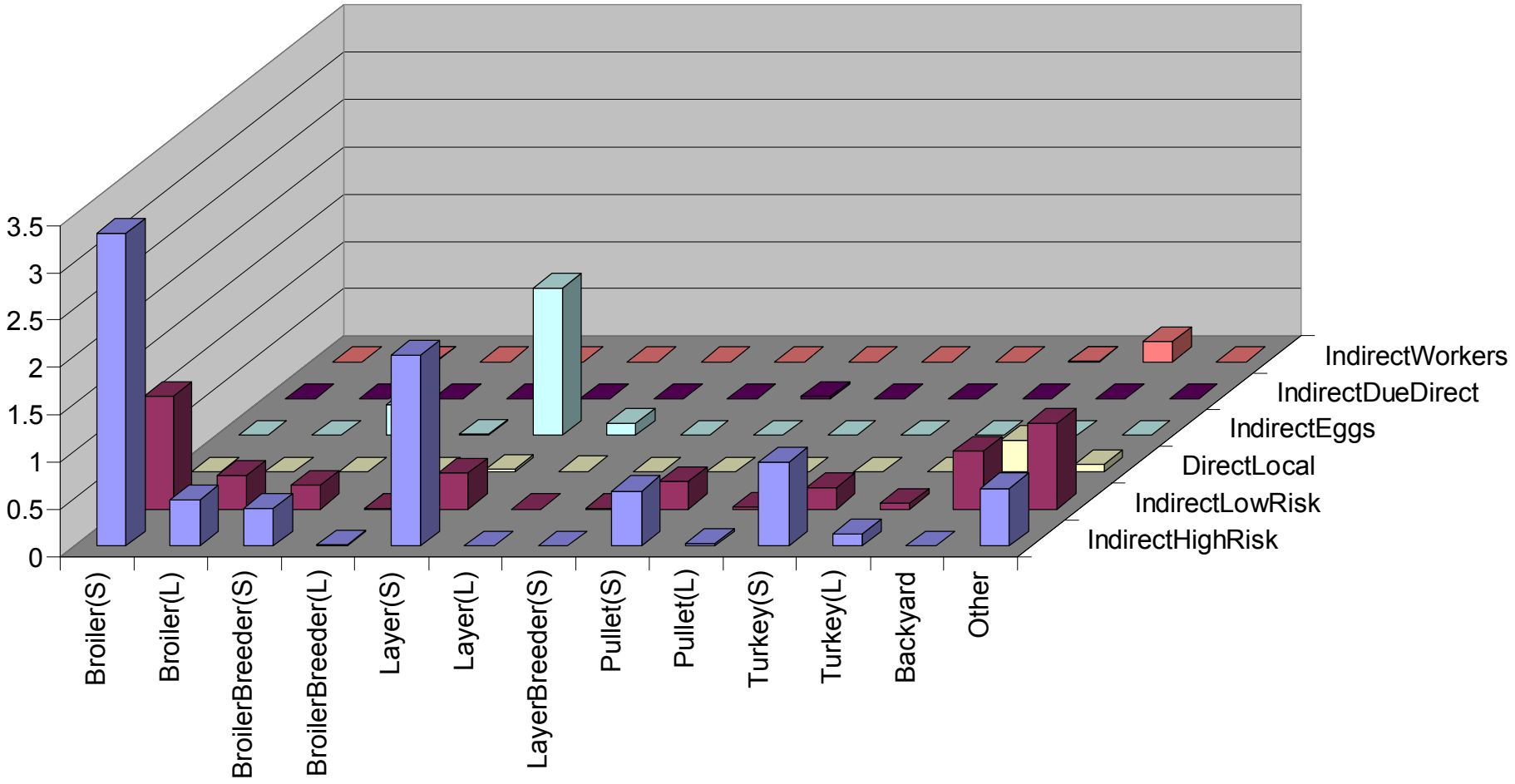
Average number of flocks infected with HPAI following one introduction into poultry in Sioux County, Iowa



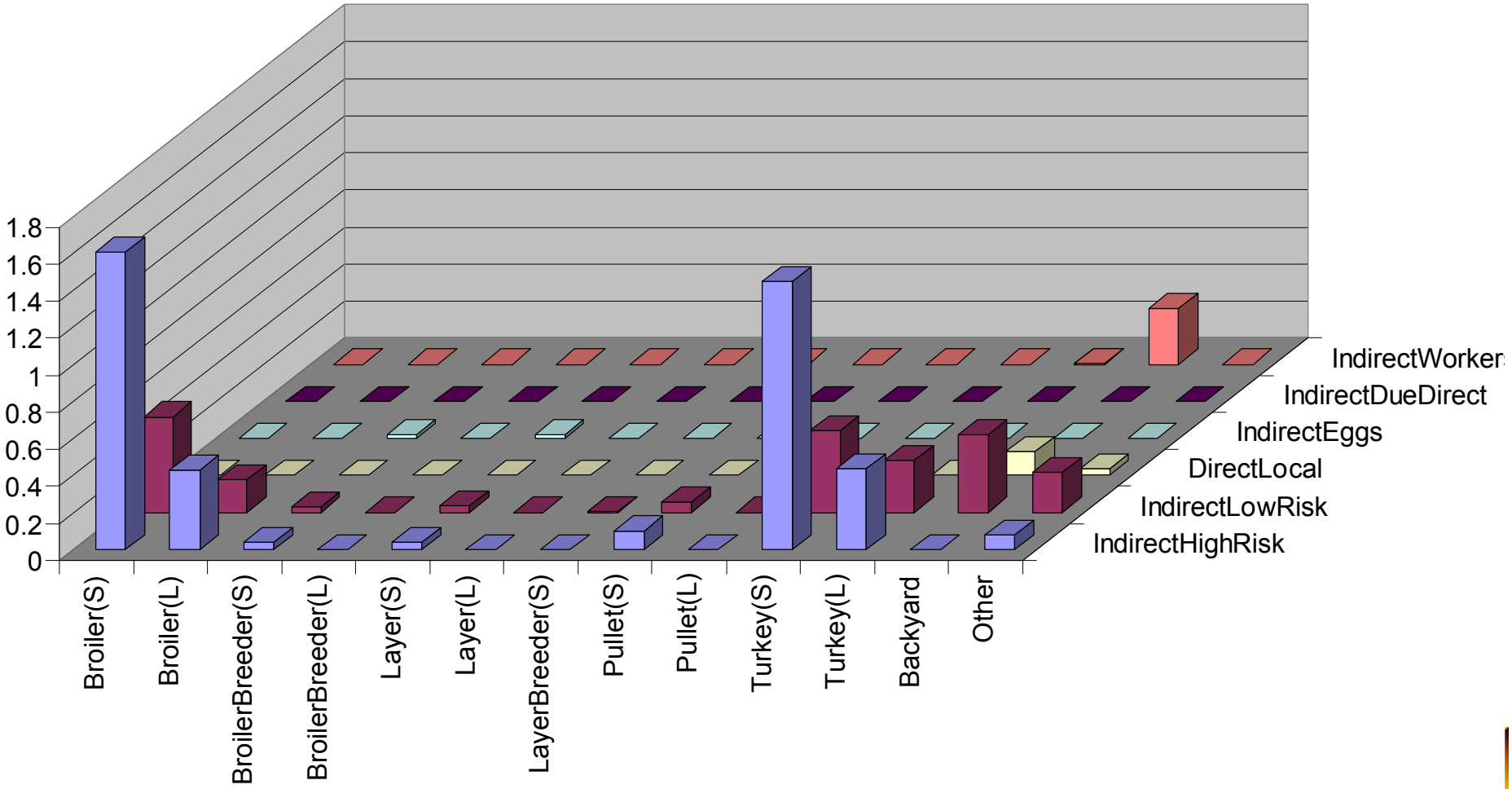
Average number of flocks infected with HPAI following one introduction into poultry in Stearns County, Minnesota



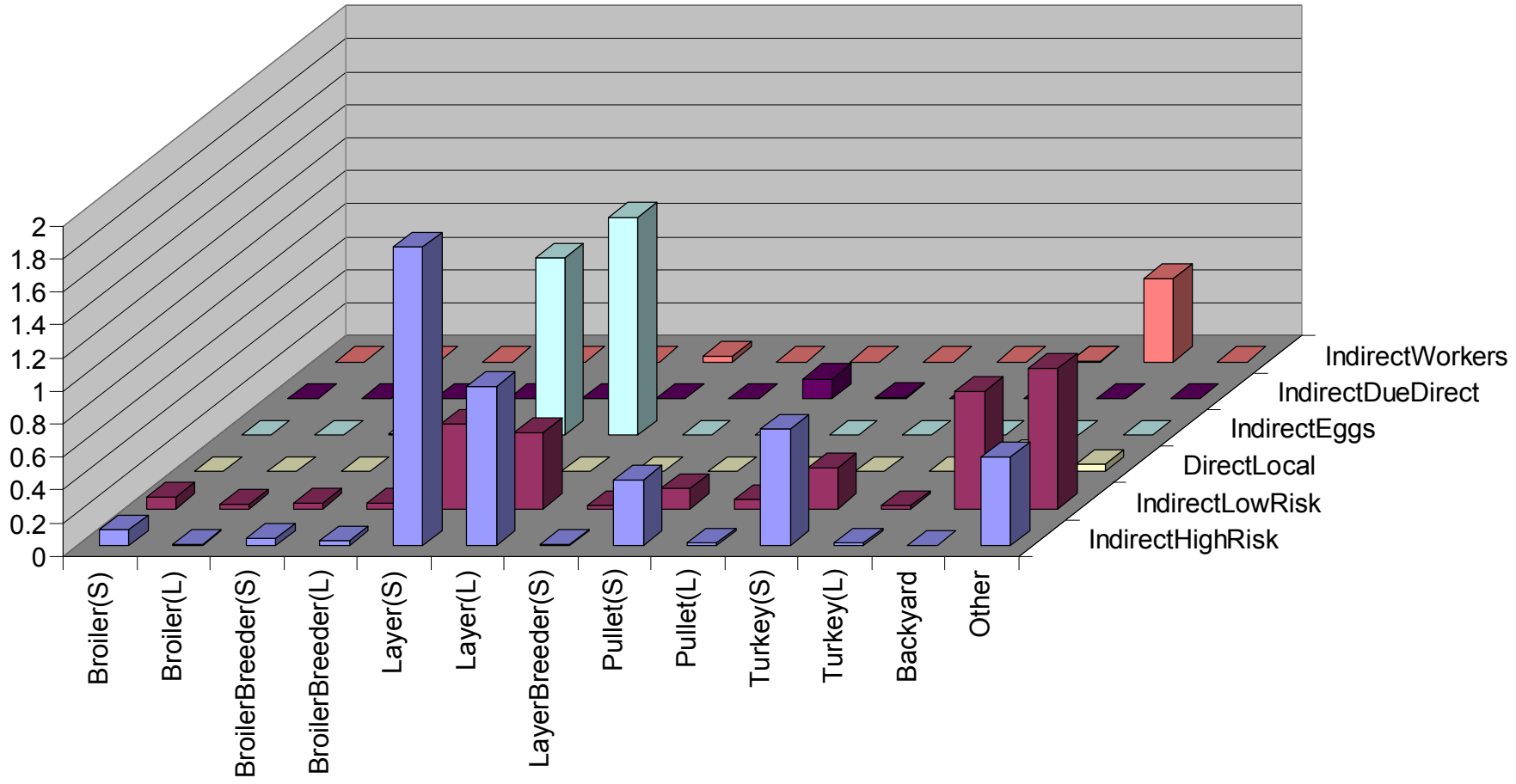
Average number of flocks infected with HPAI following one introduction into poultry in Wilkes County, North Carolina



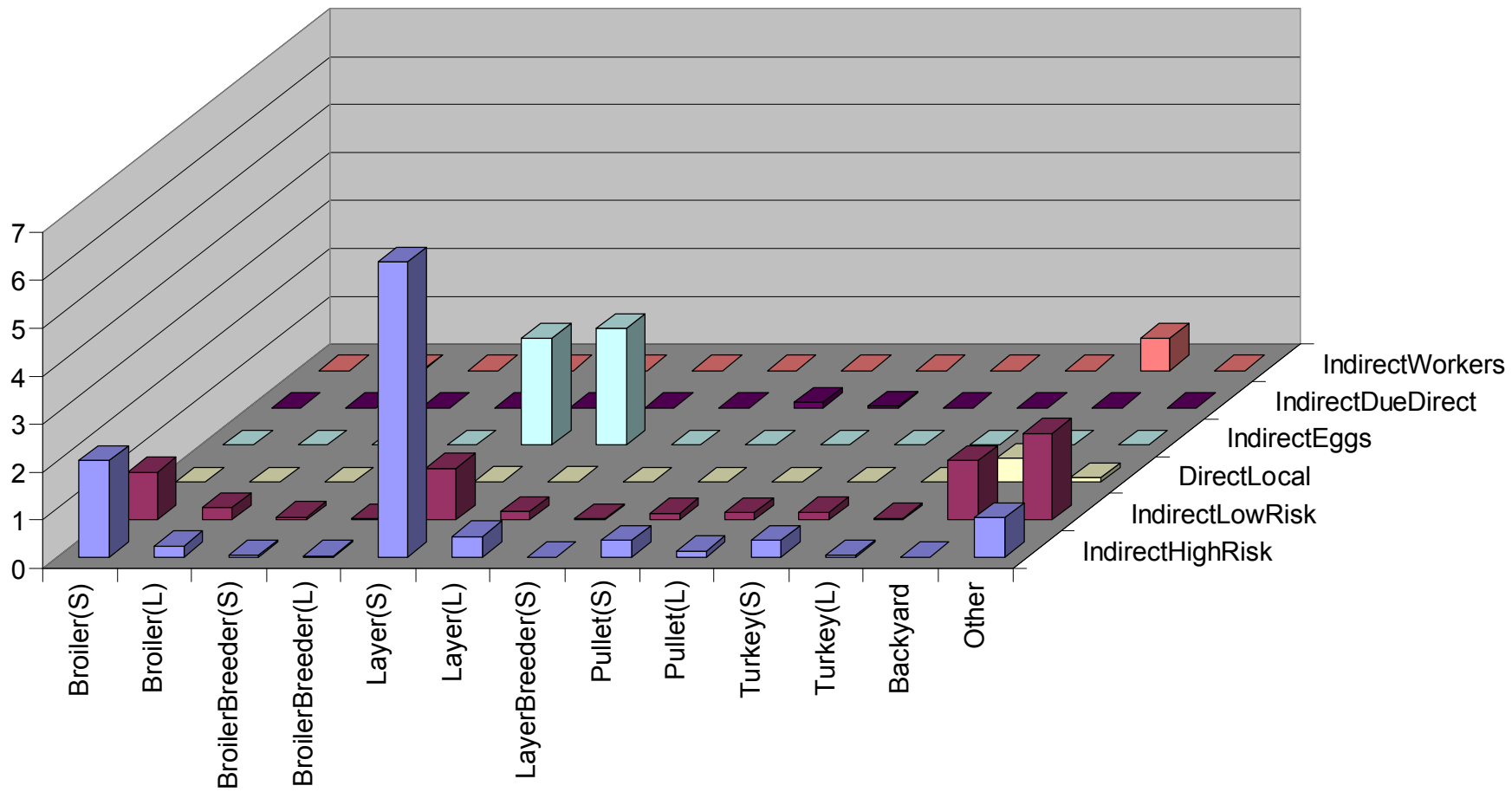
Average number of flocks infected with HPAI following one introduction into poultry in Duplin County, North Carolina



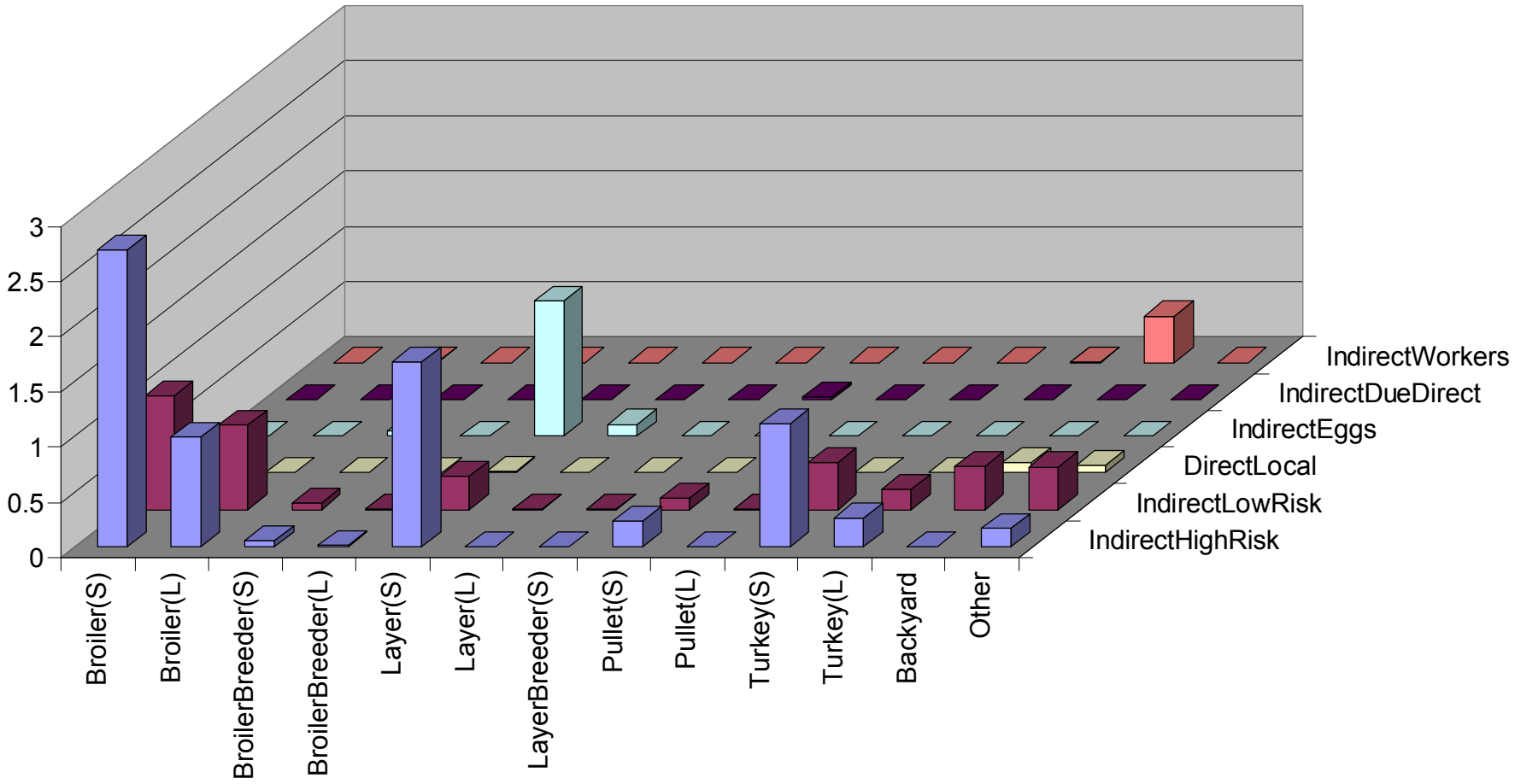
Average number of flocks infected with HPAI following one introduction into poultry in Mercer County, Ohio



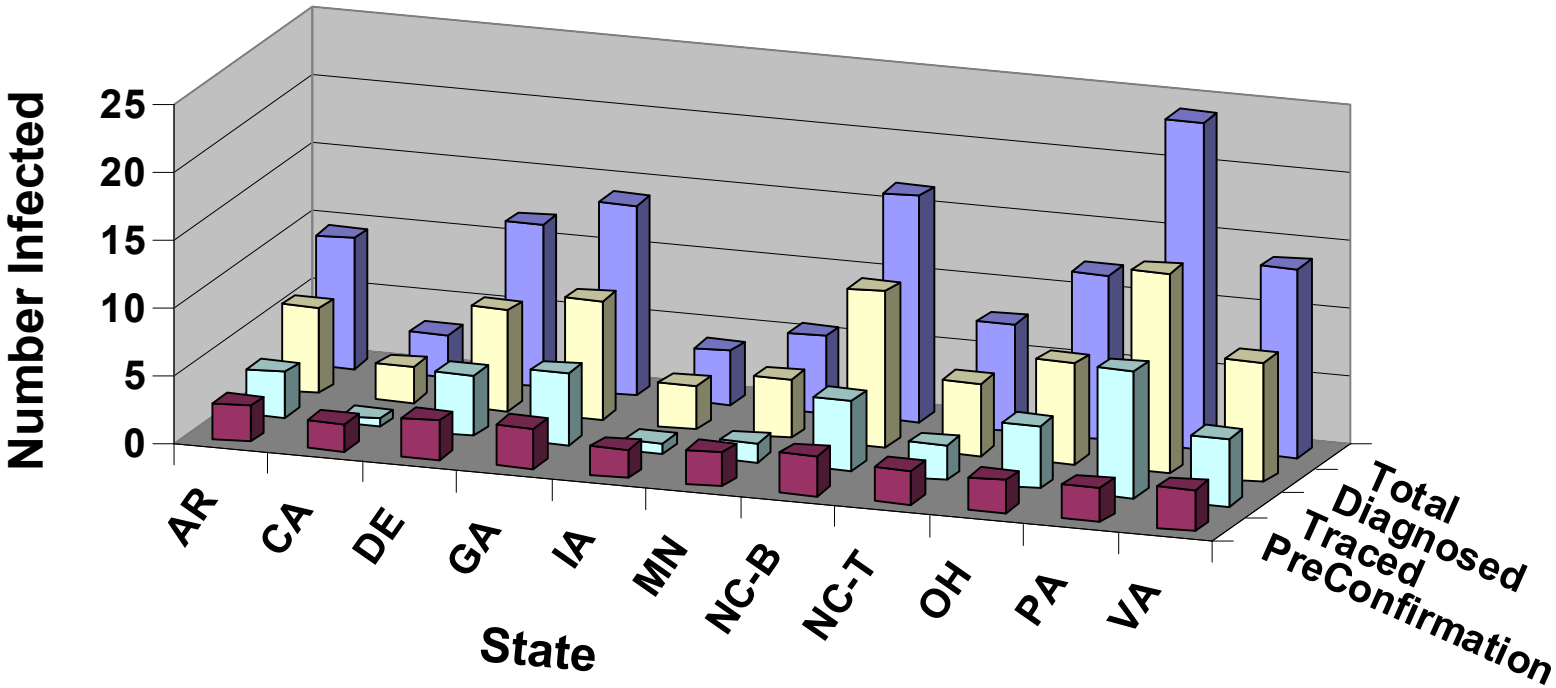
Average number of flocks infected with HPAI following one introduction into poultry in Lancaster County, Pennsylvania



Average number of flocks infected with HPAI following one introduction into poultry in Rockingham County, Virginia

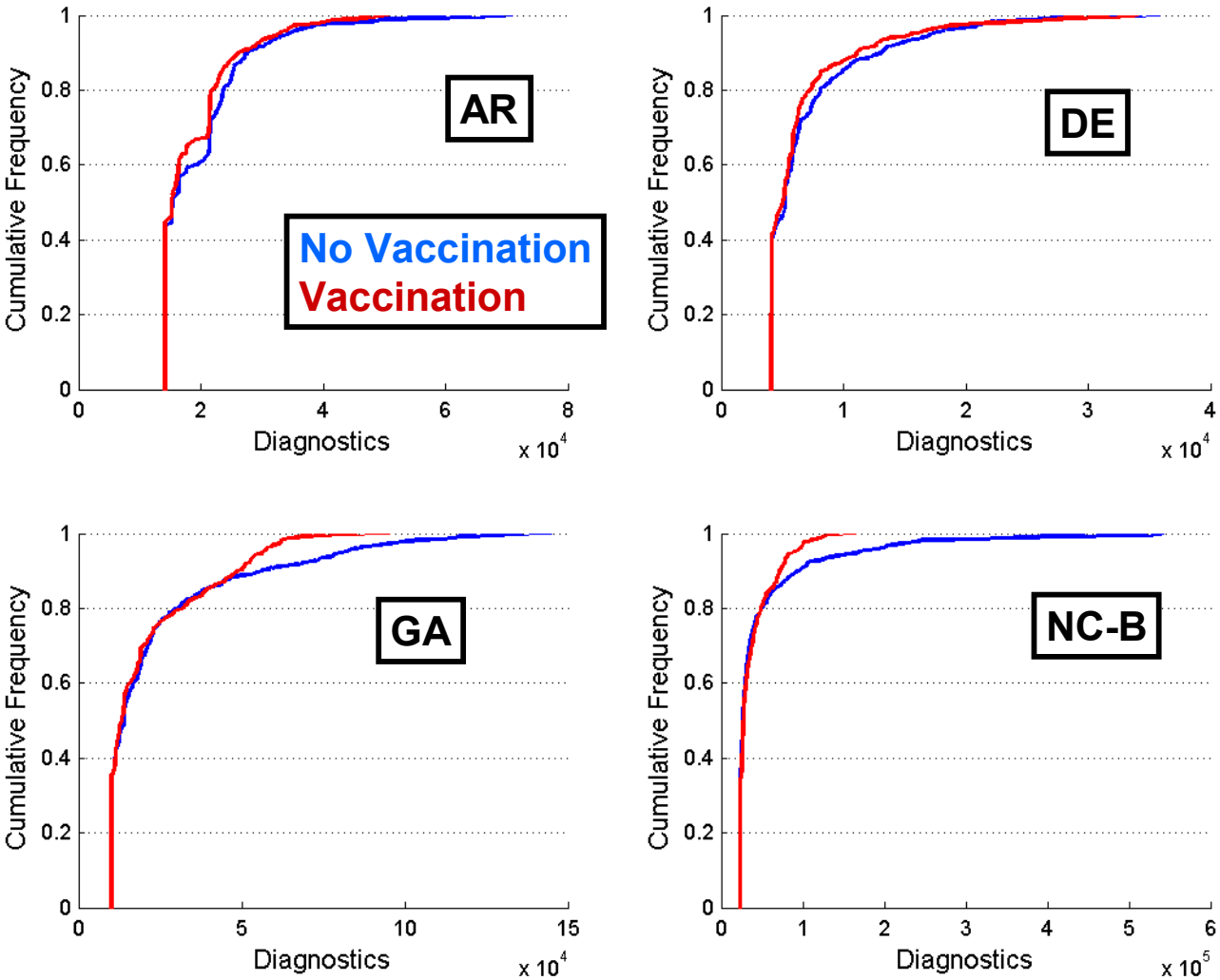


Evolution of disease differs by state

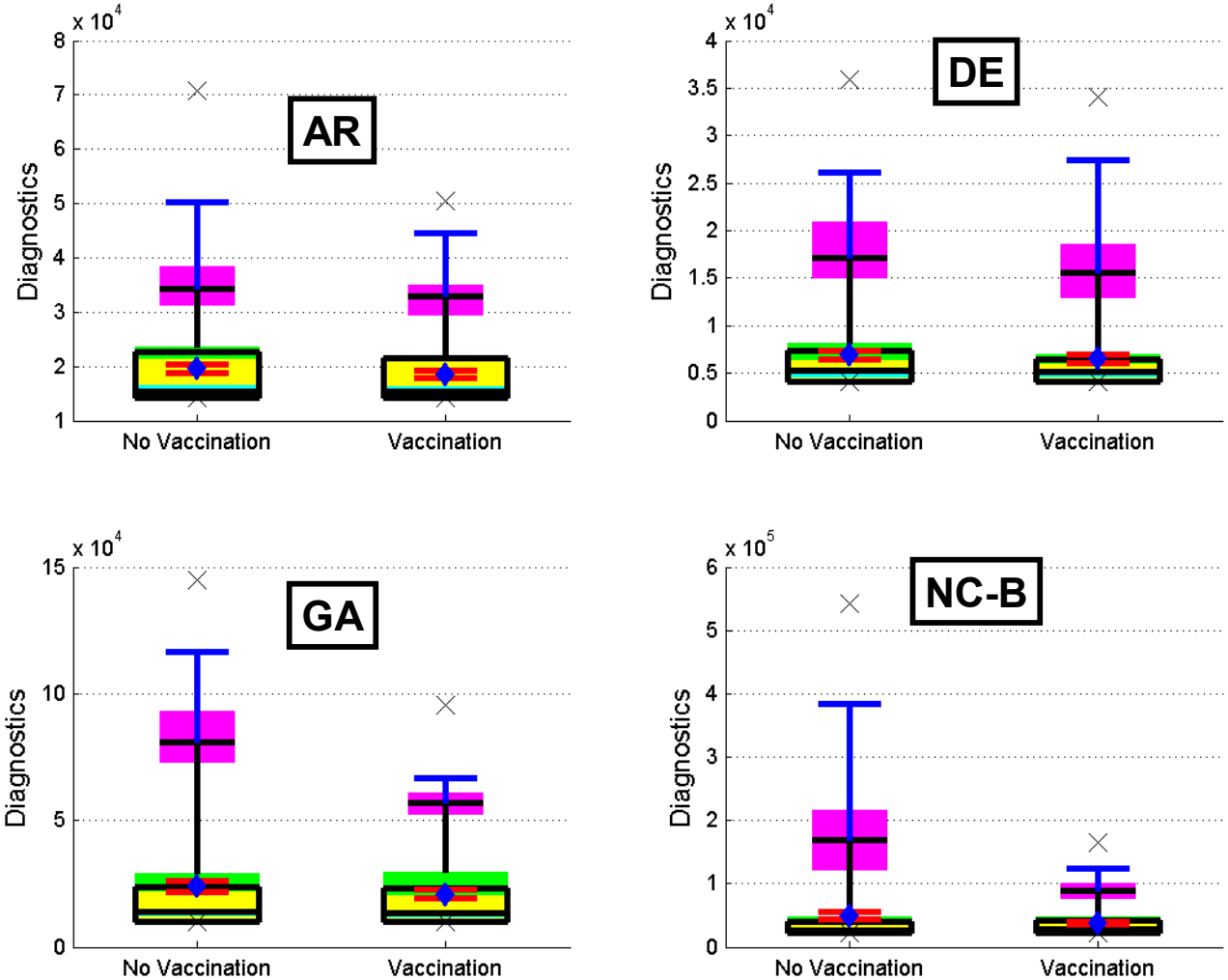


Additional State Scenarios

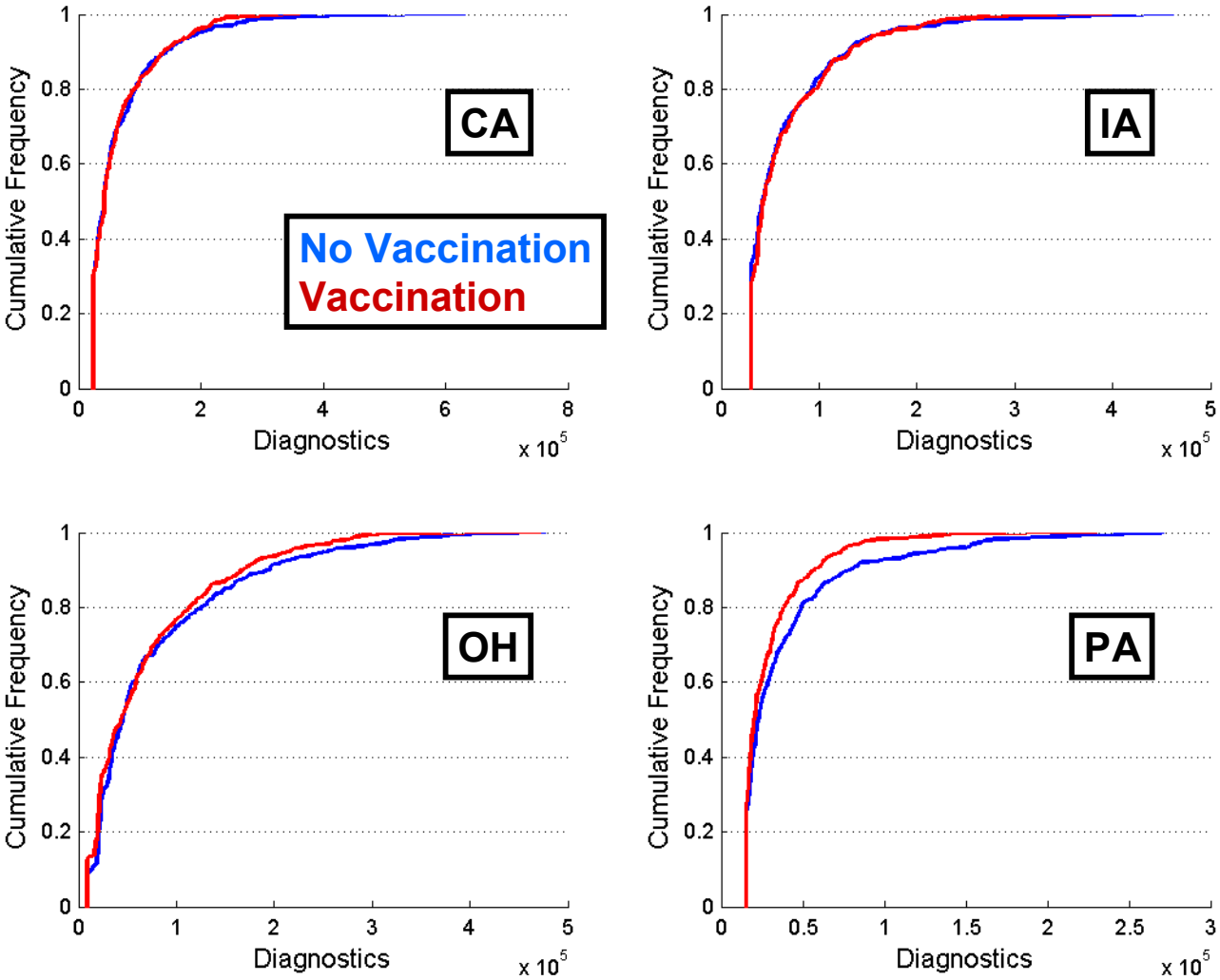
Broiler State Scenarios: Total Diagnostics



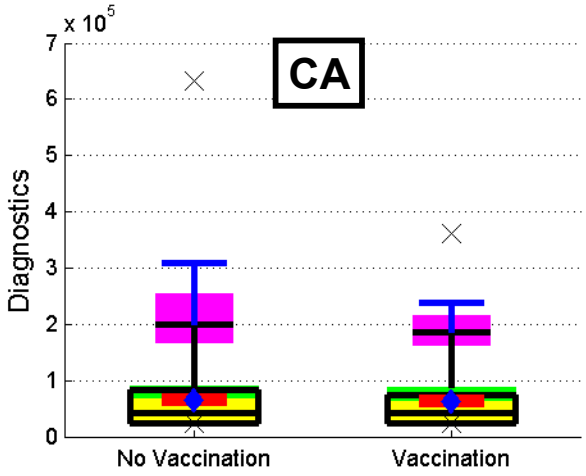
Broiler State Scenarios: Total Diagnostics

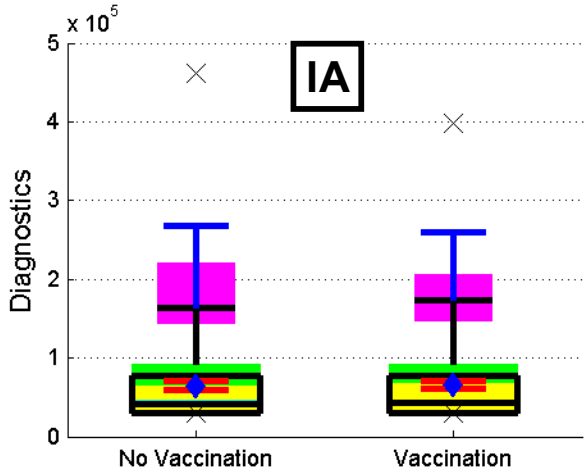


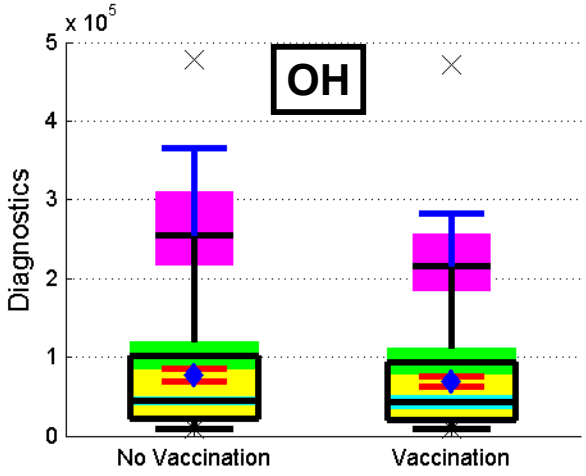
Layer State Scenarios: Total Diagnostics

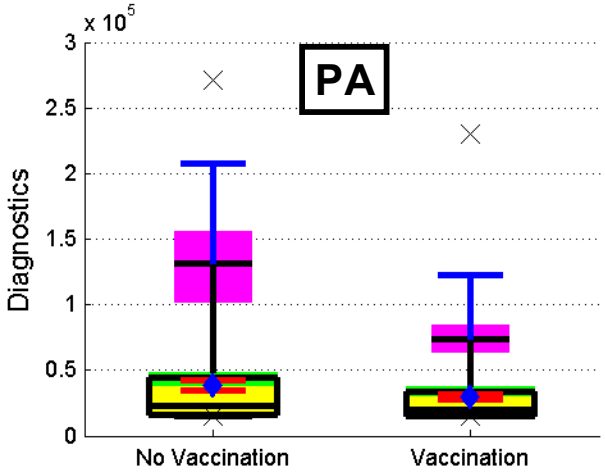


Layer State Scenarios: Total Diagnostics

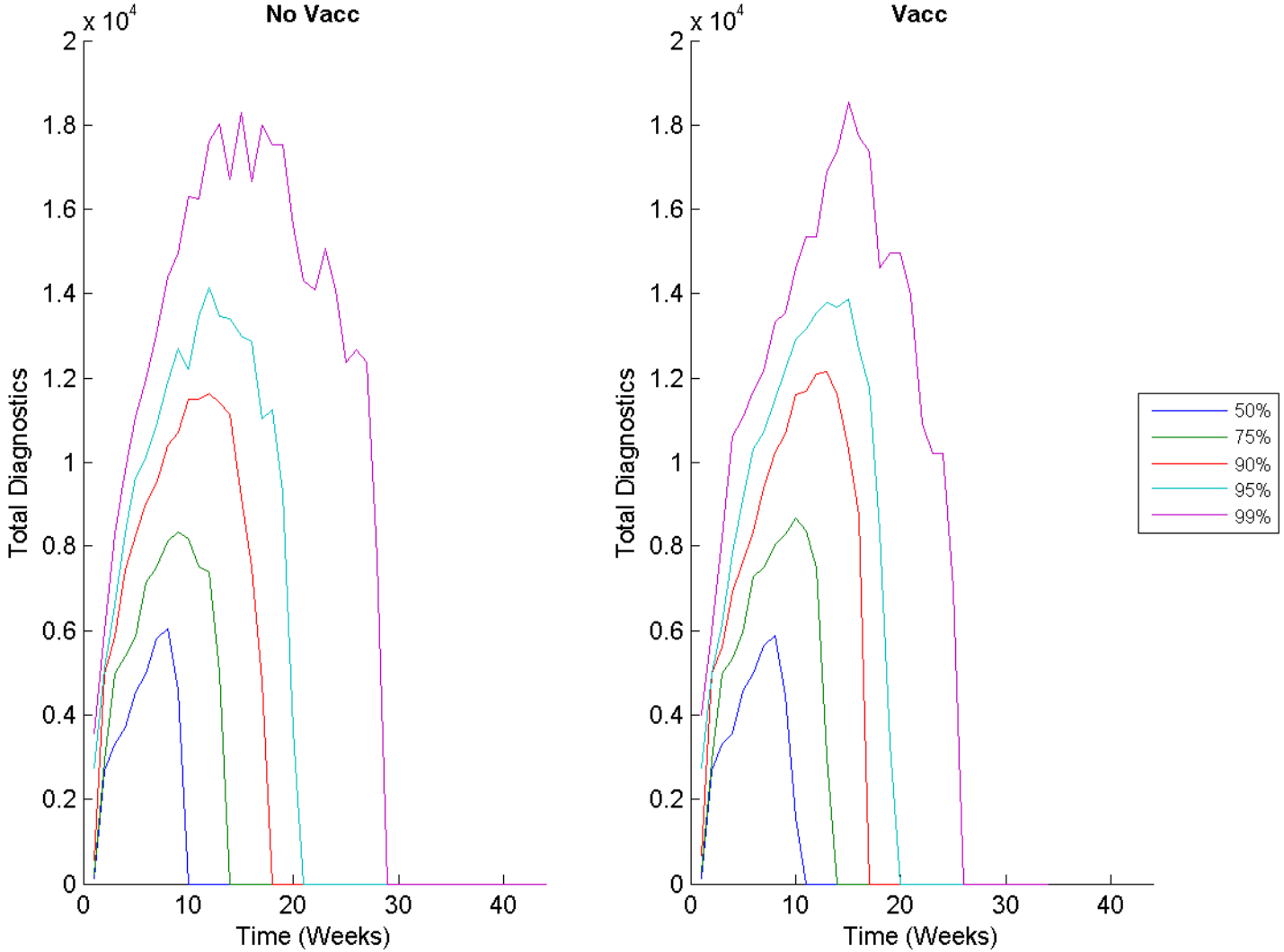




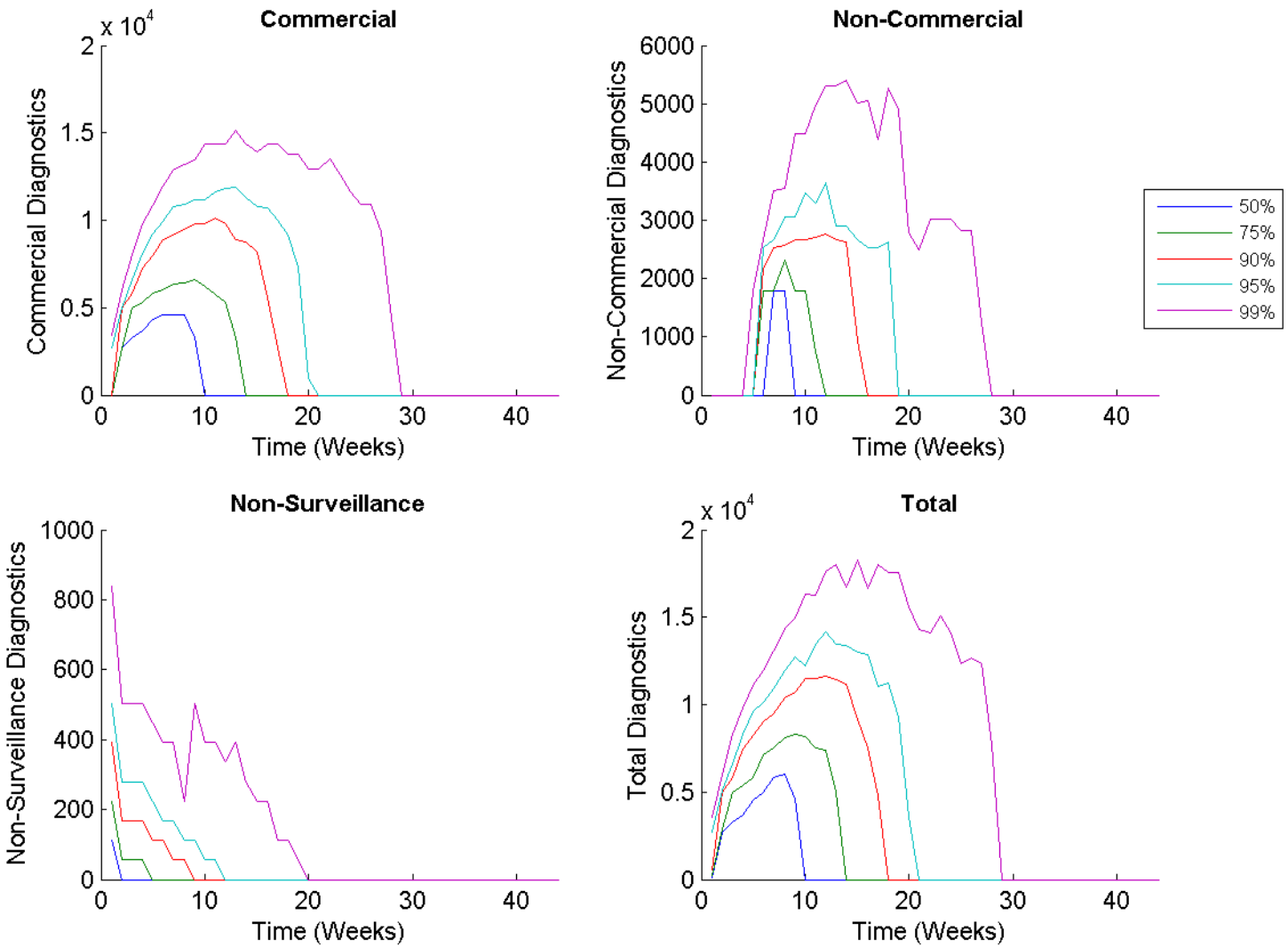




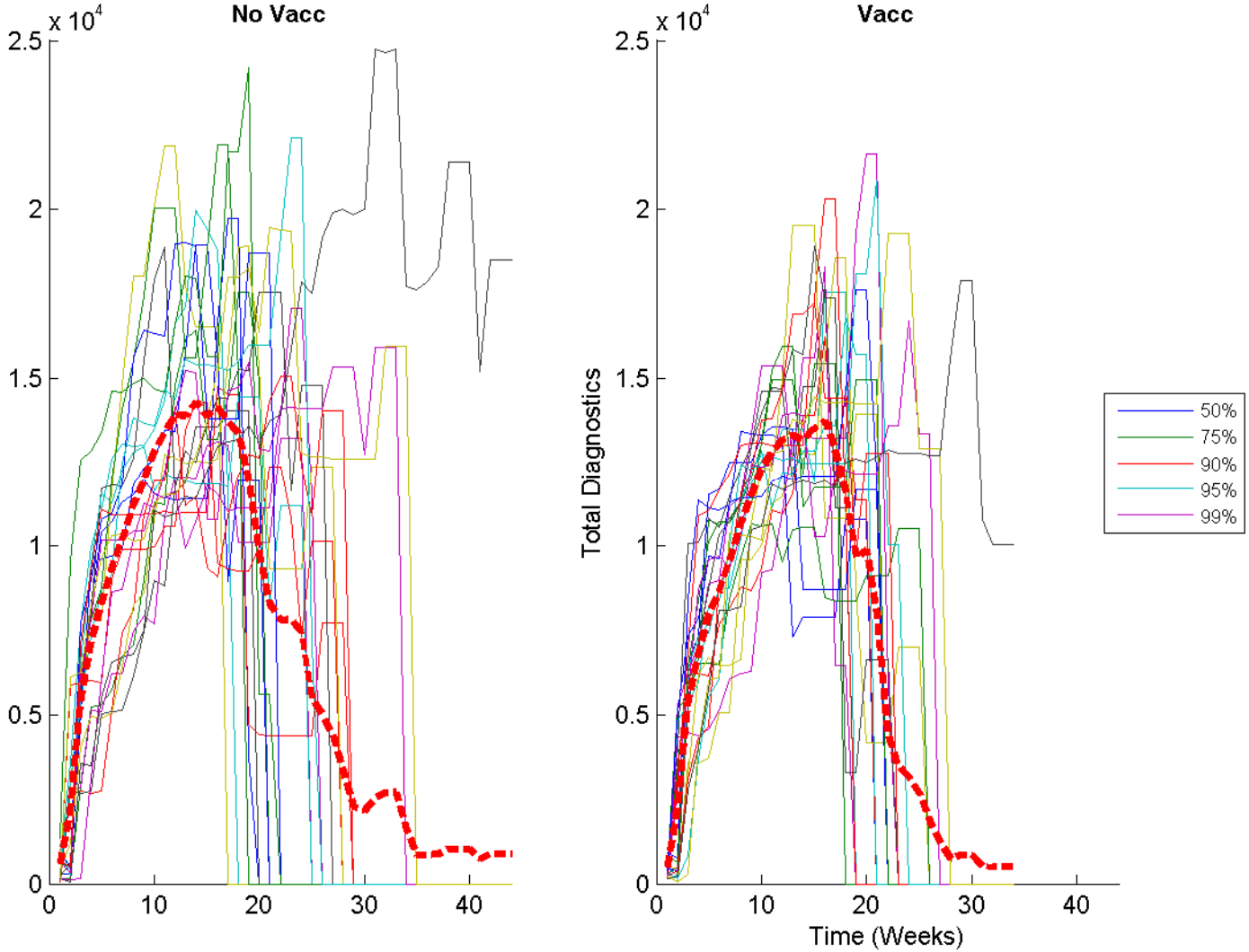
AR: Total Diagnostics



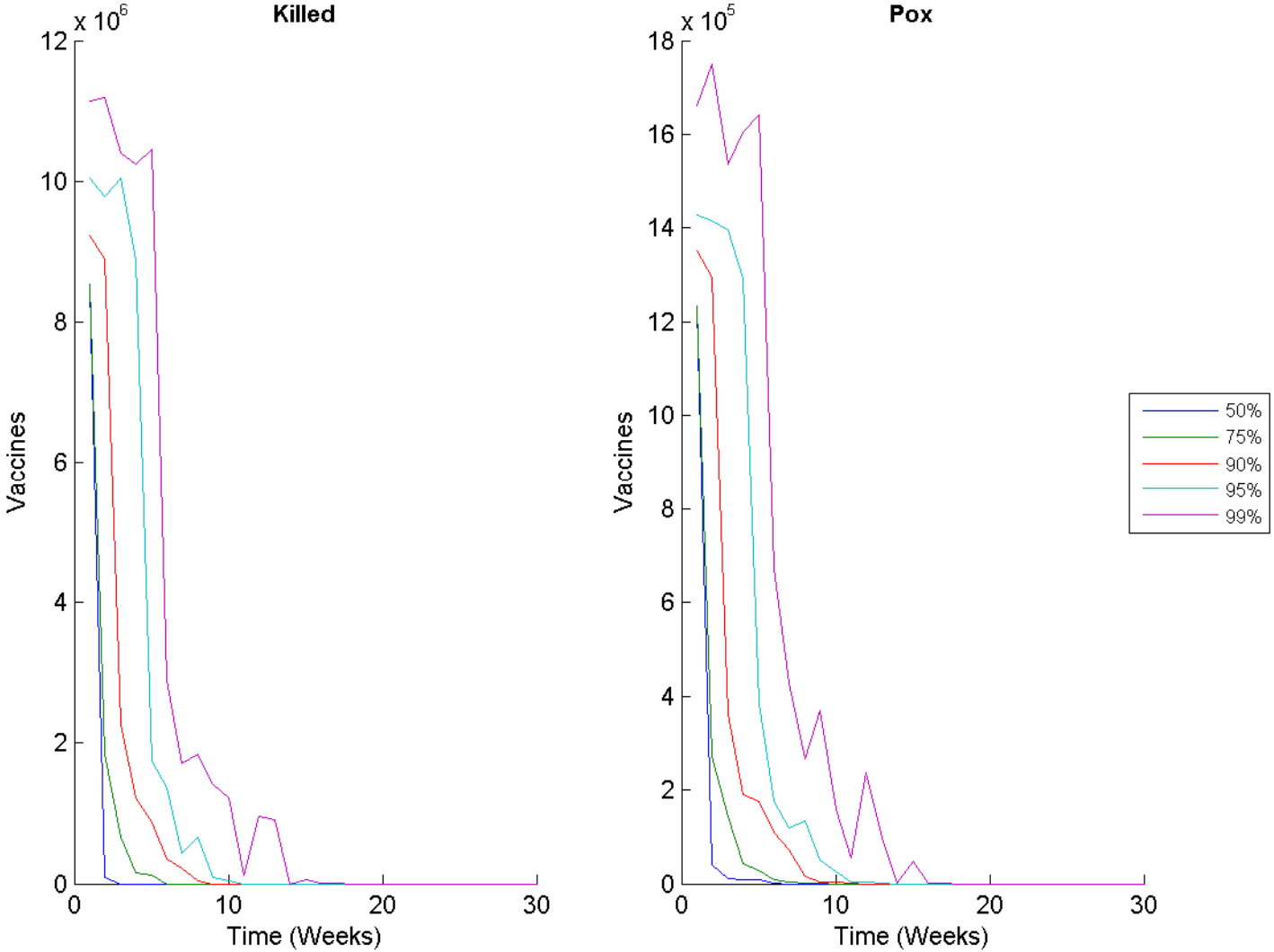
AR: Components vs. Total Diagnostics



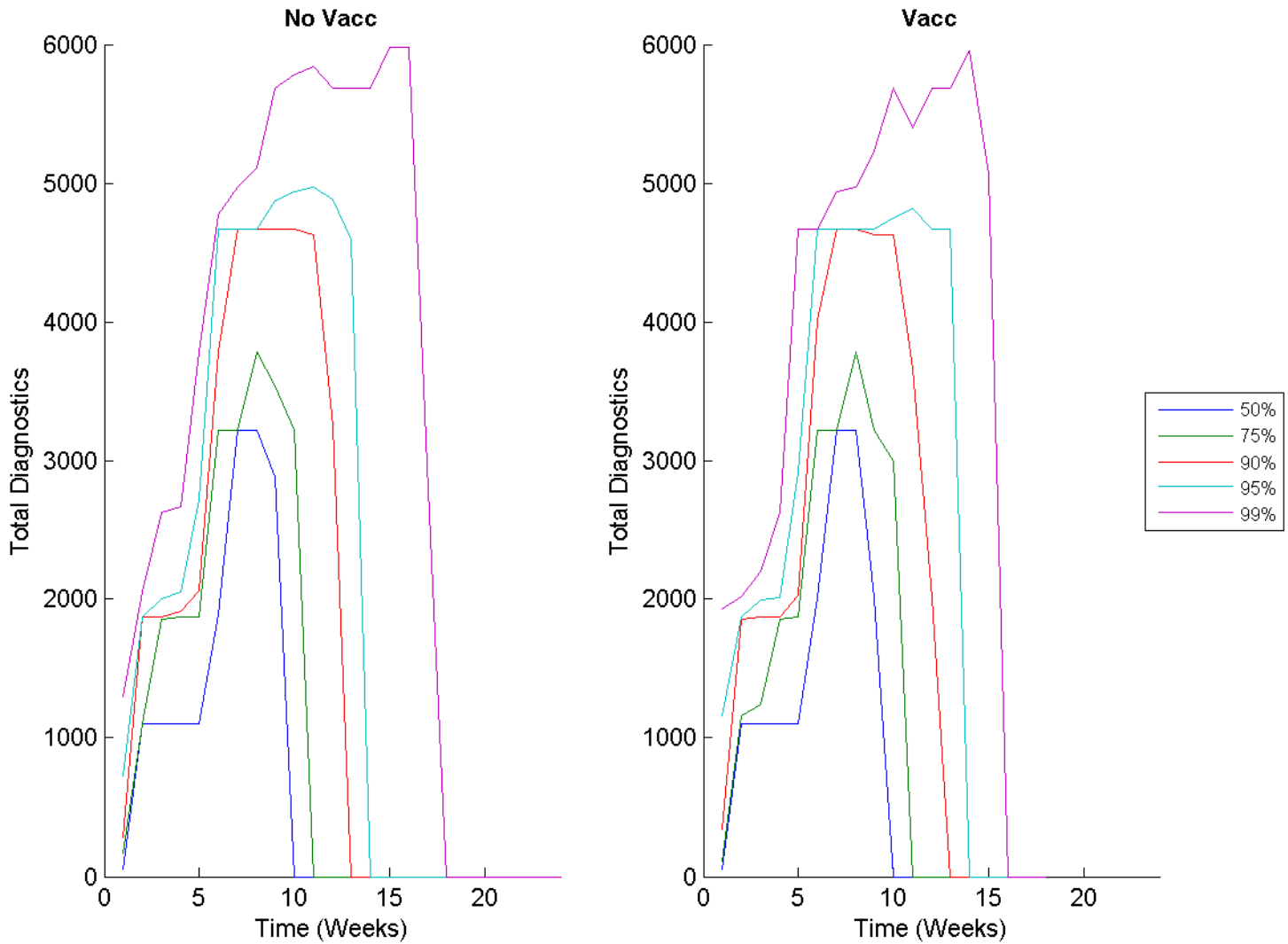
AR: Total Diagnostics over Time for the Largest 5% of Outbreaks



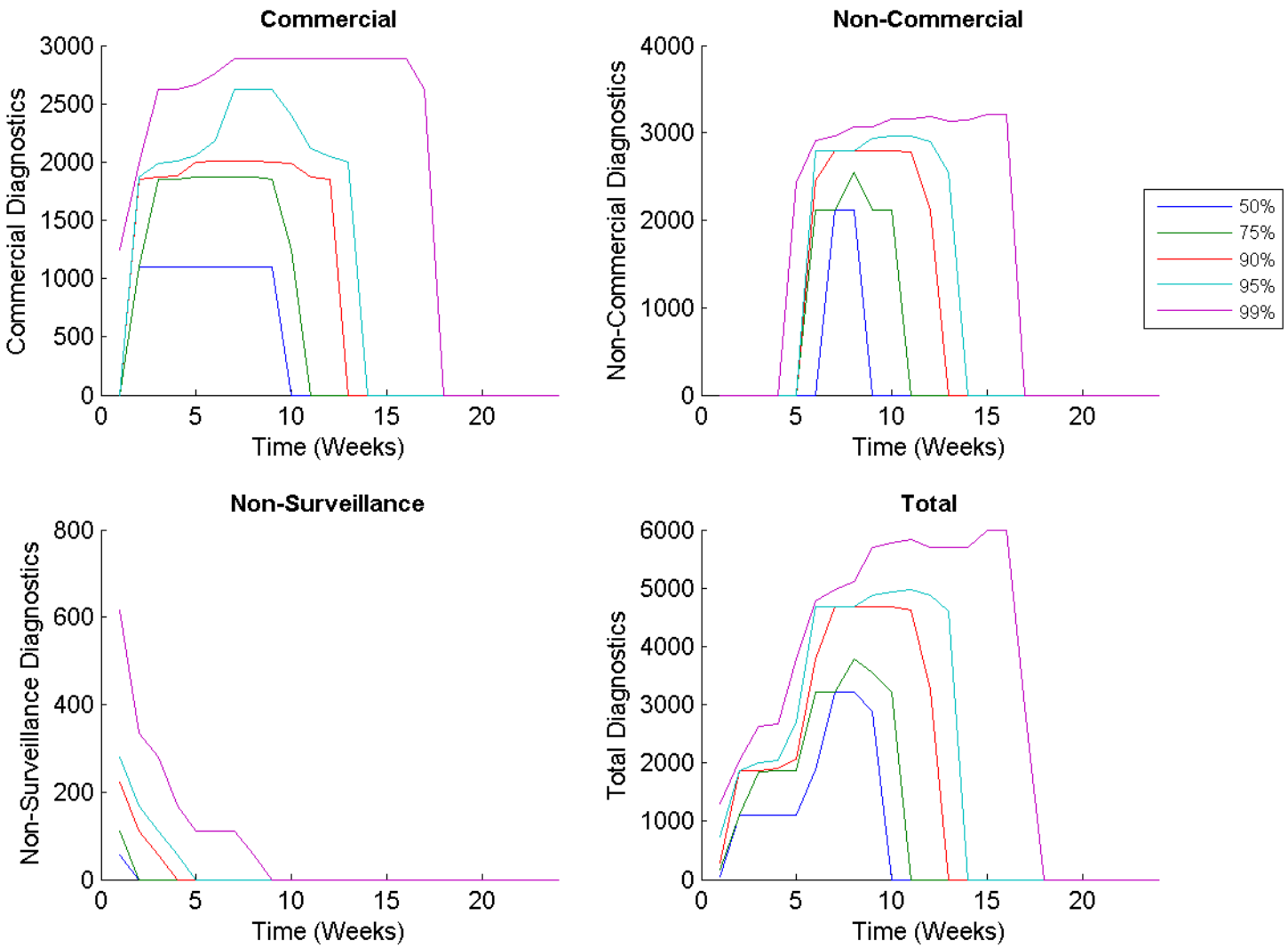
AR: Vaccinations



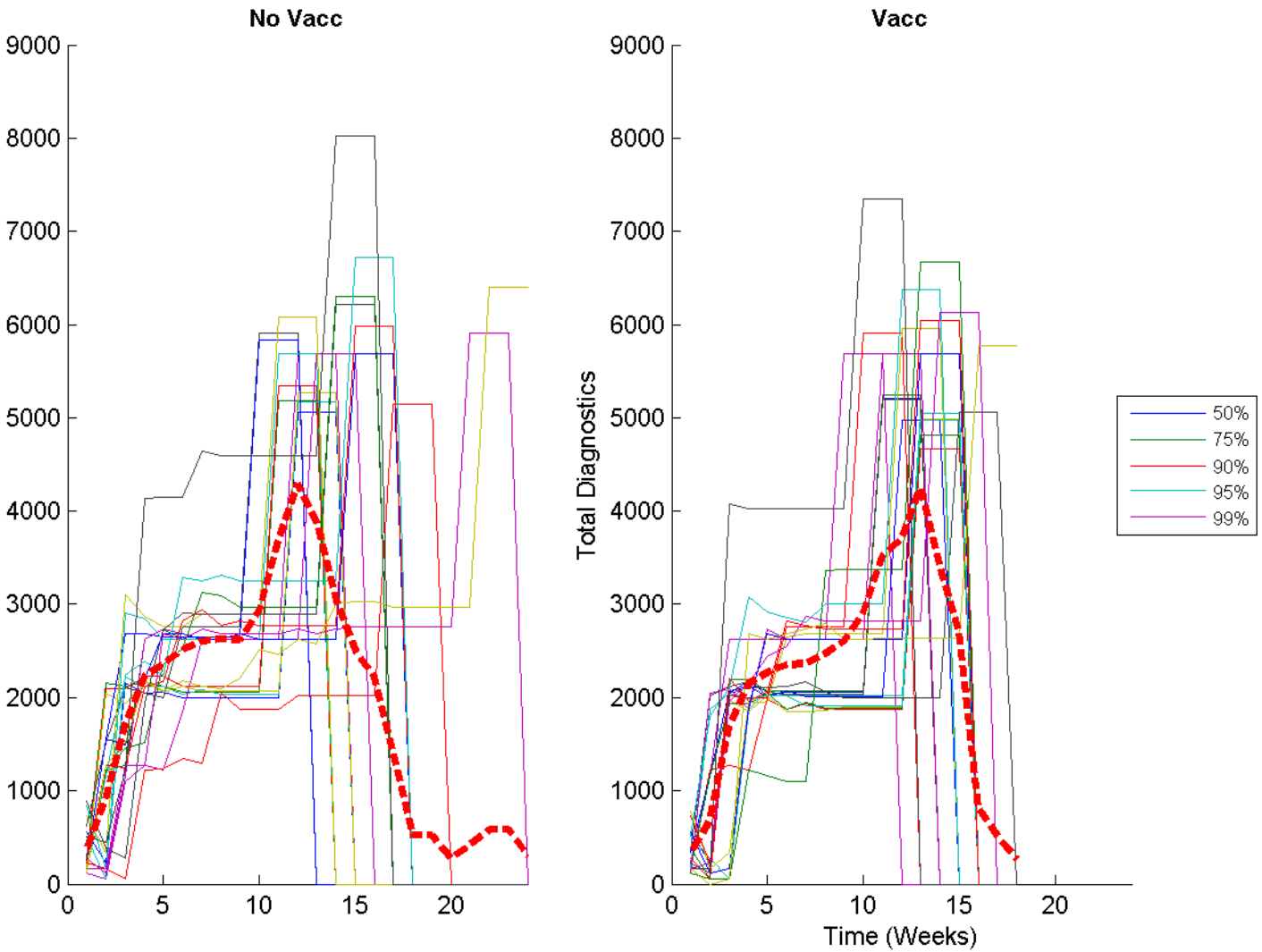
CA: Total Diagnostics



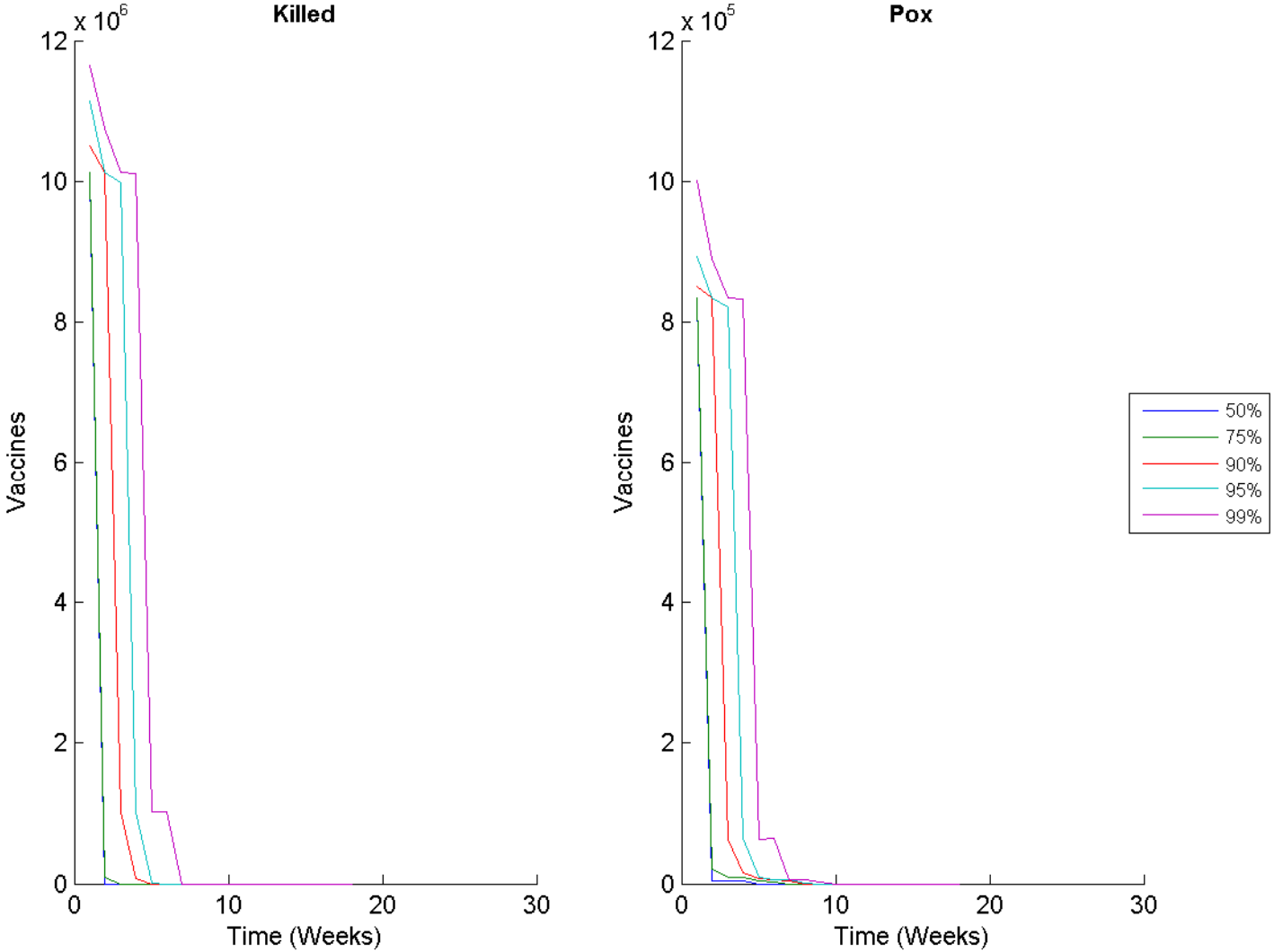
CA: Components vs. Total Diagnostics



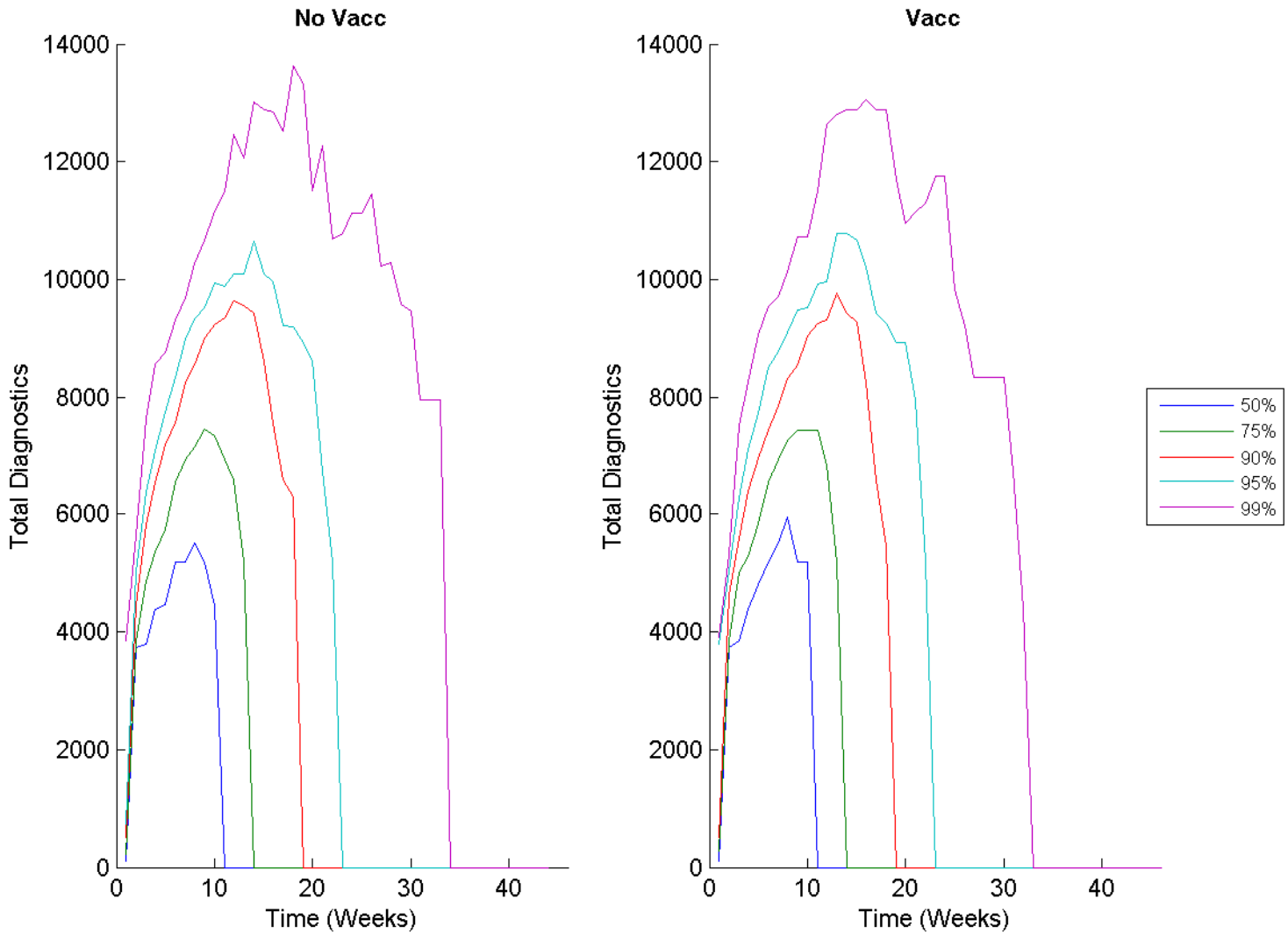
CA: Total Diagnostics over Time for the Largest 5% of Outbreaks



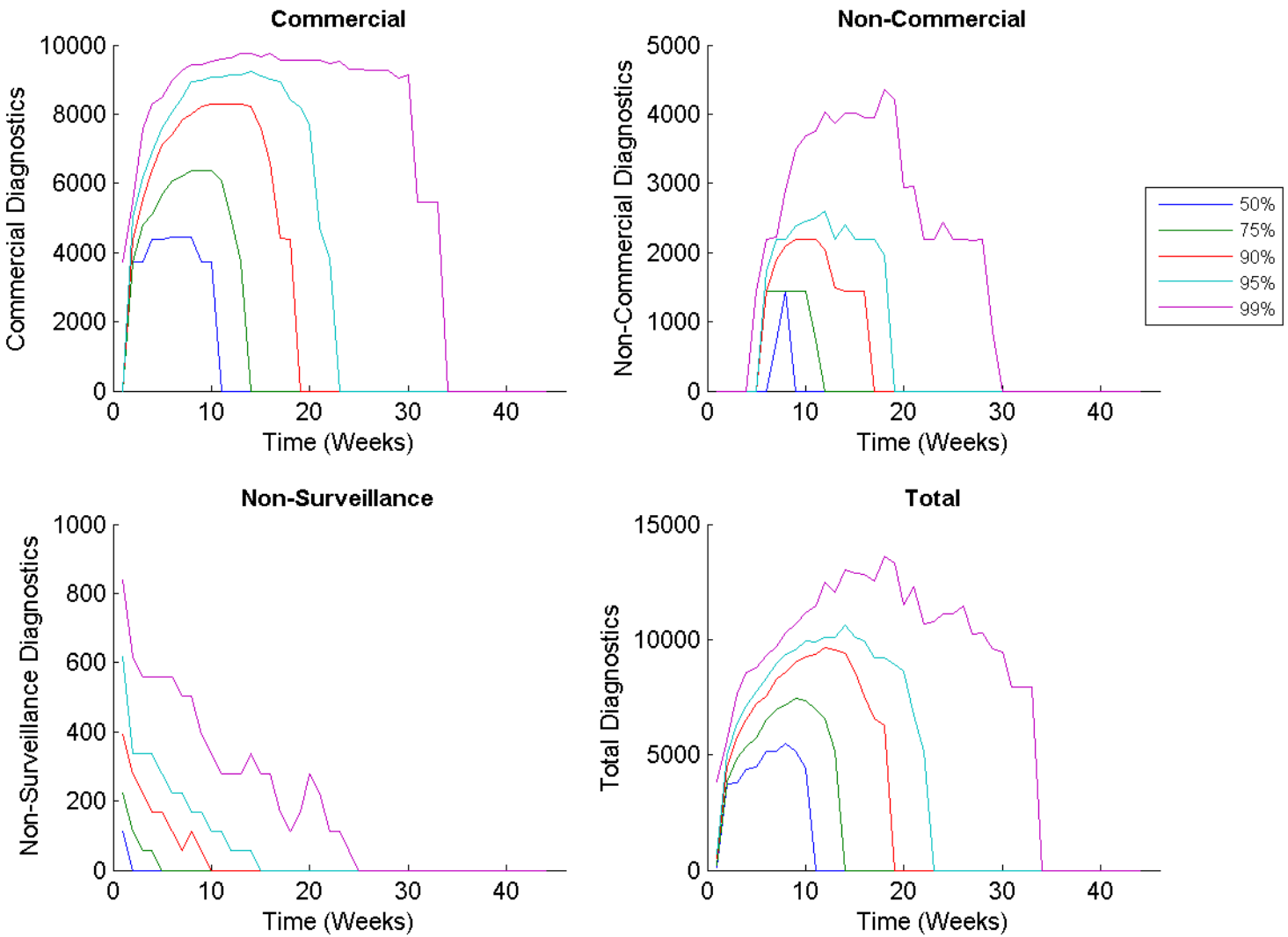
CA: Vaccinations



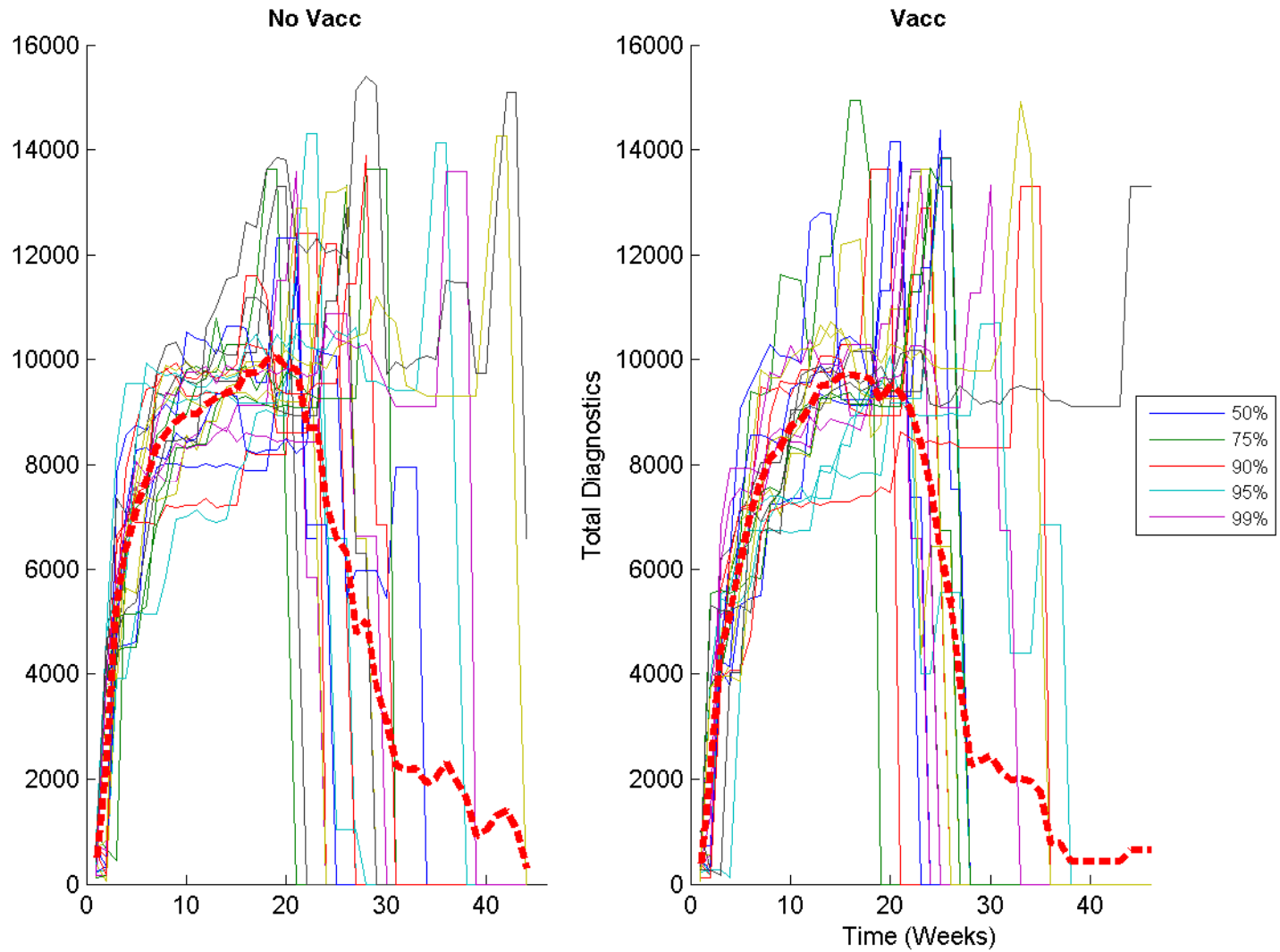
DE: Total Diagnostics



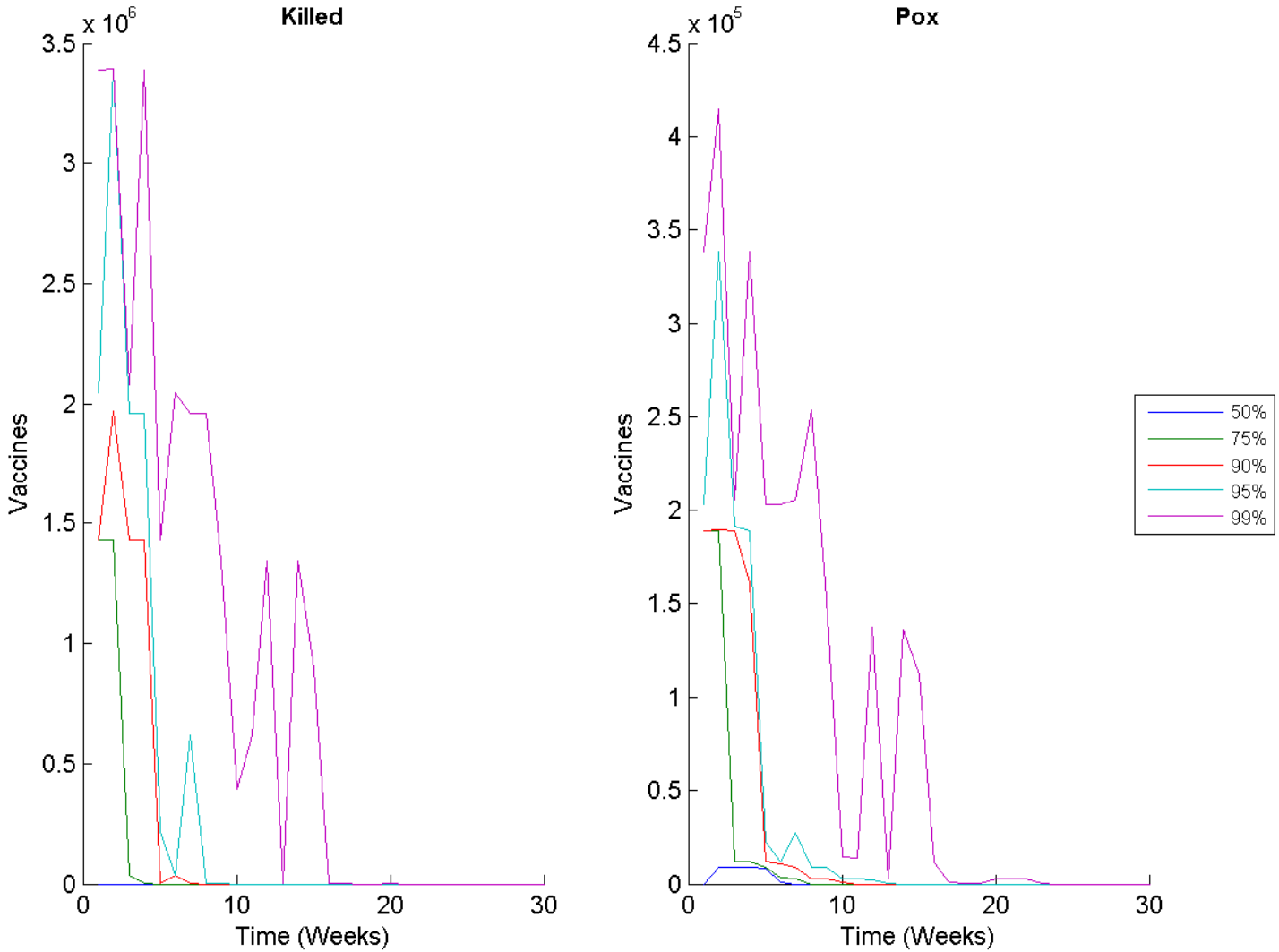
DE: Components vs. Total Diagnostics



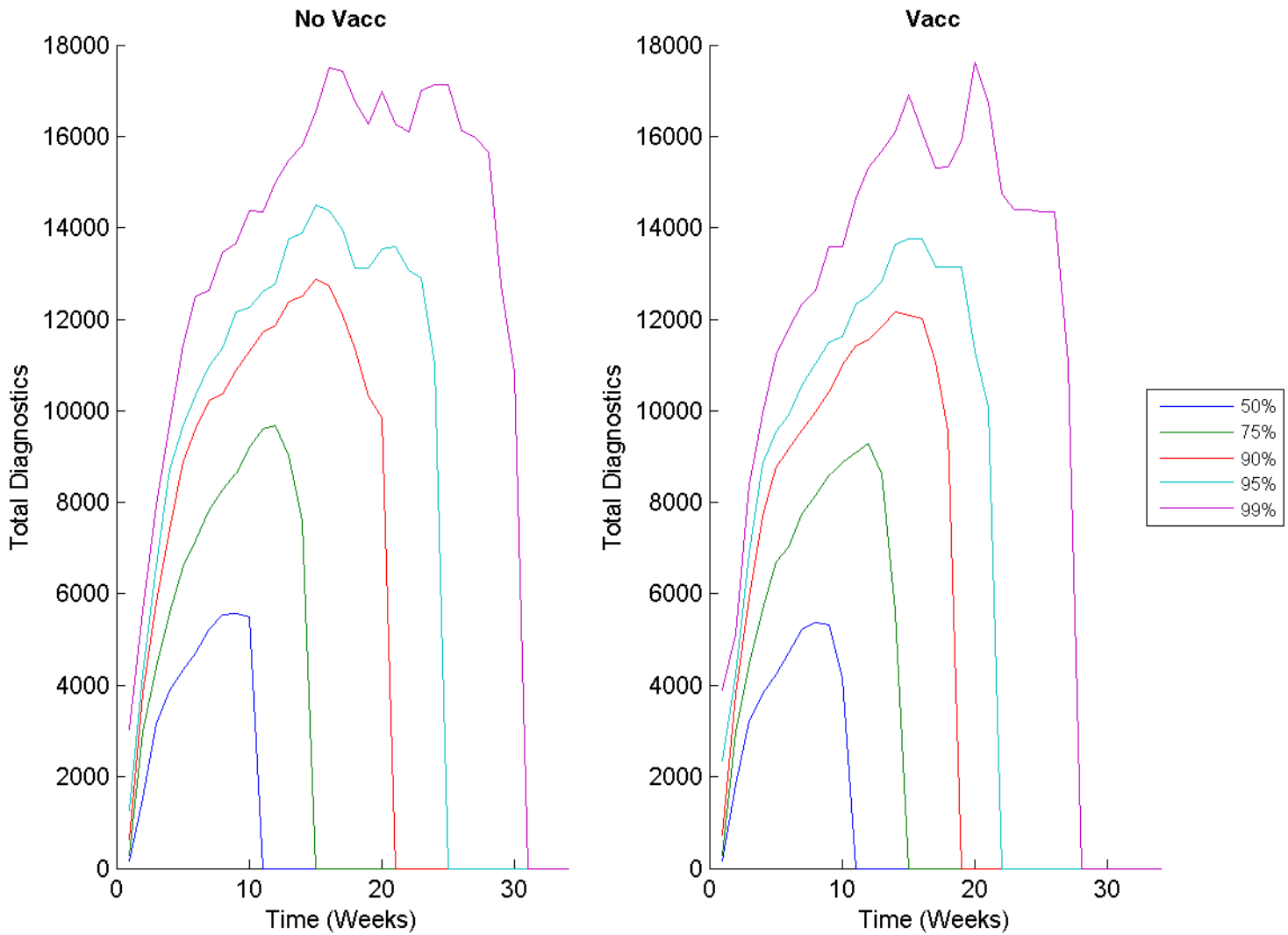
DE: Total Diagnostics over Time for the Largest 5% of Outbreaks



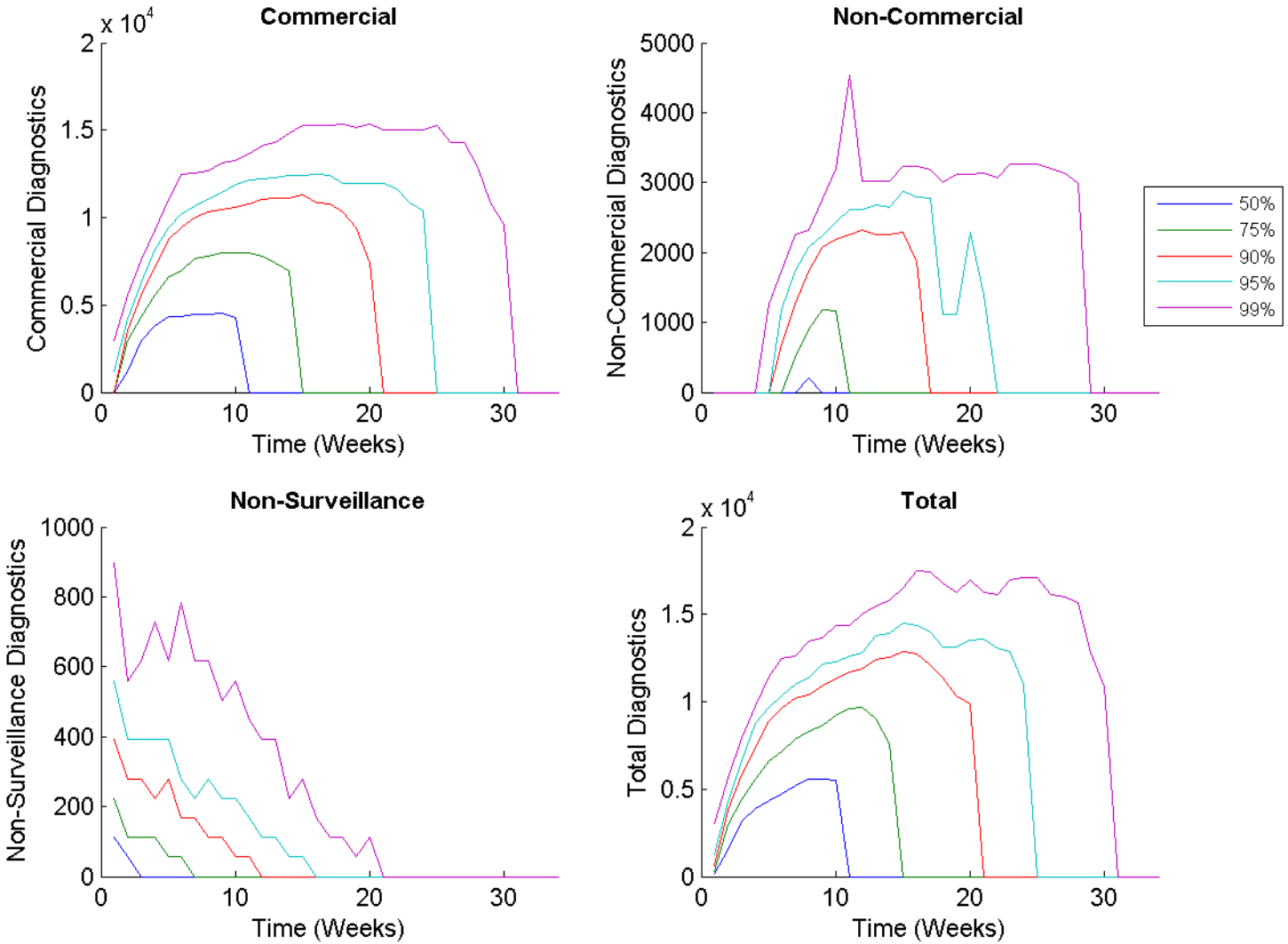
DE: Vaccinations



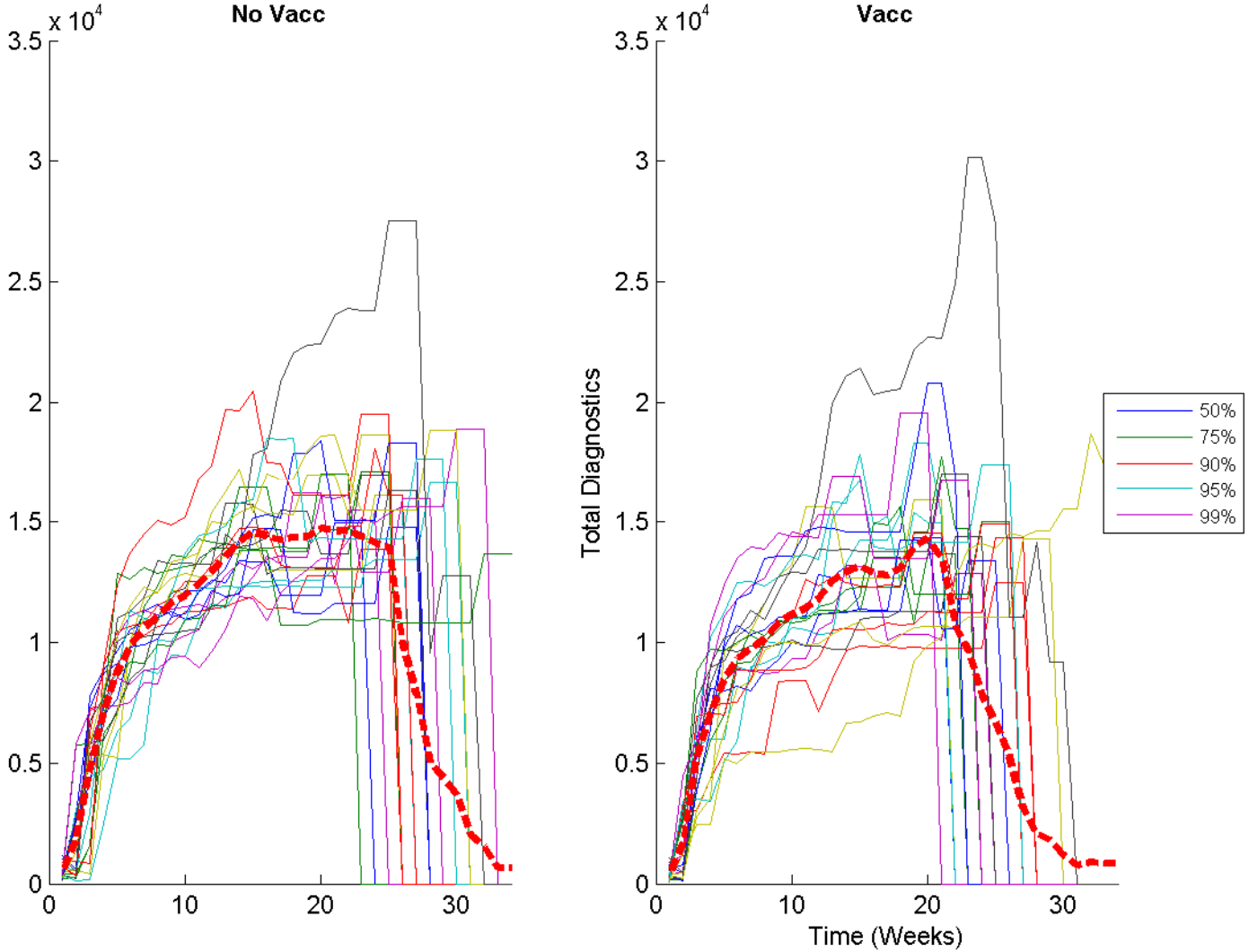
GA: Total Diagnostics



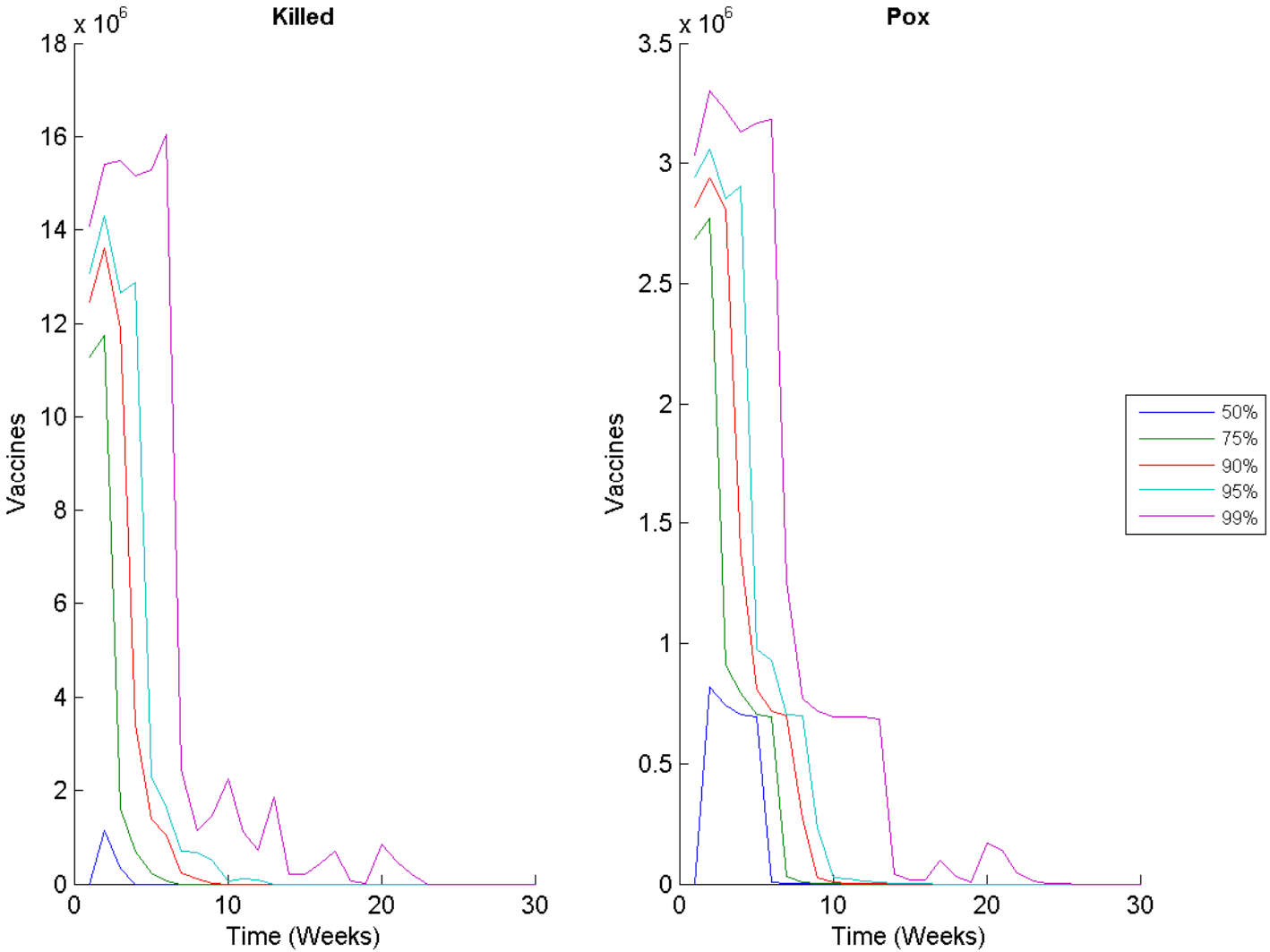
GA: Components vs. Total Diagnostics



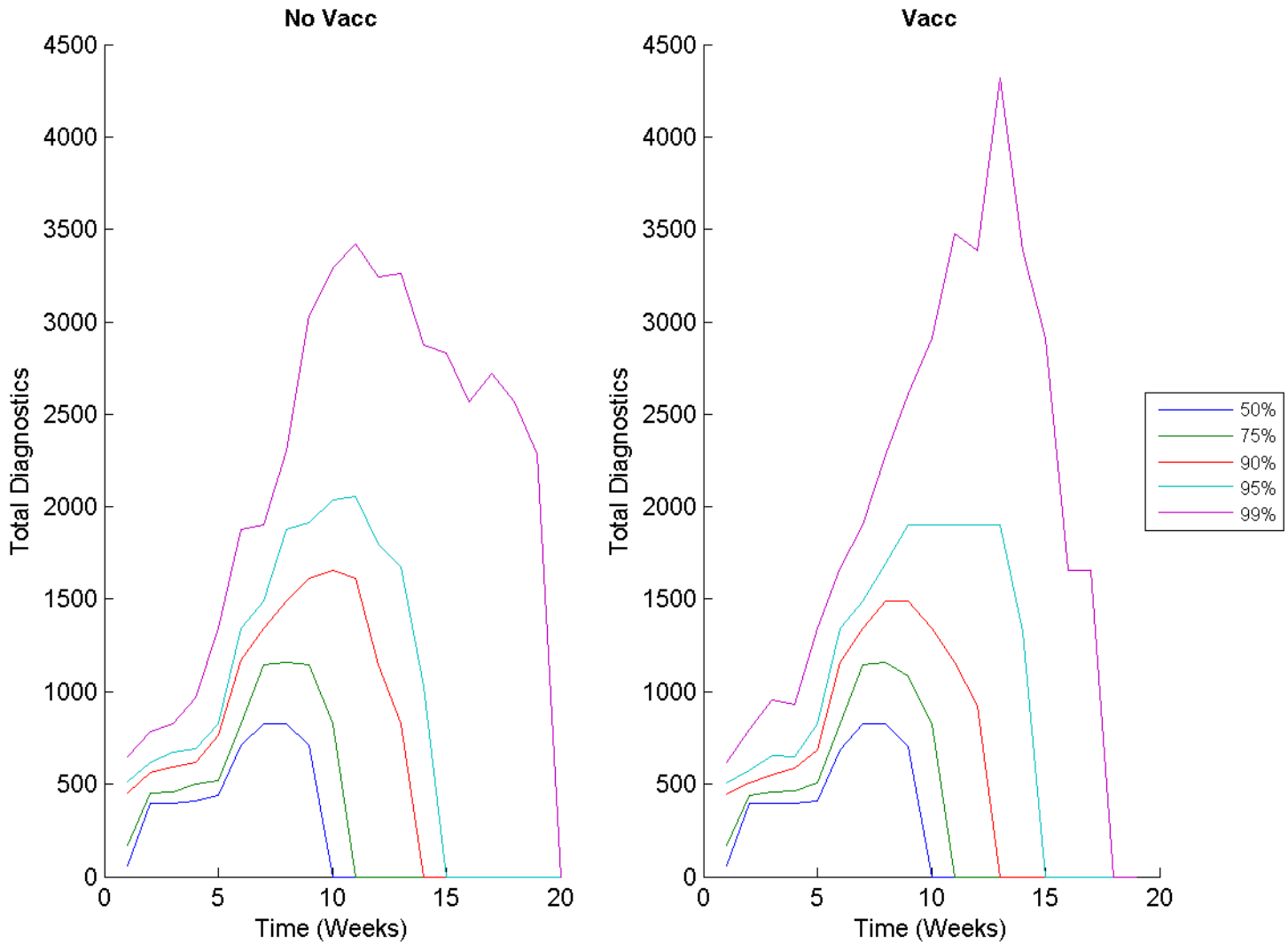
GA: Total Diagnostics over Time for the Largest 5% of Outbreaks



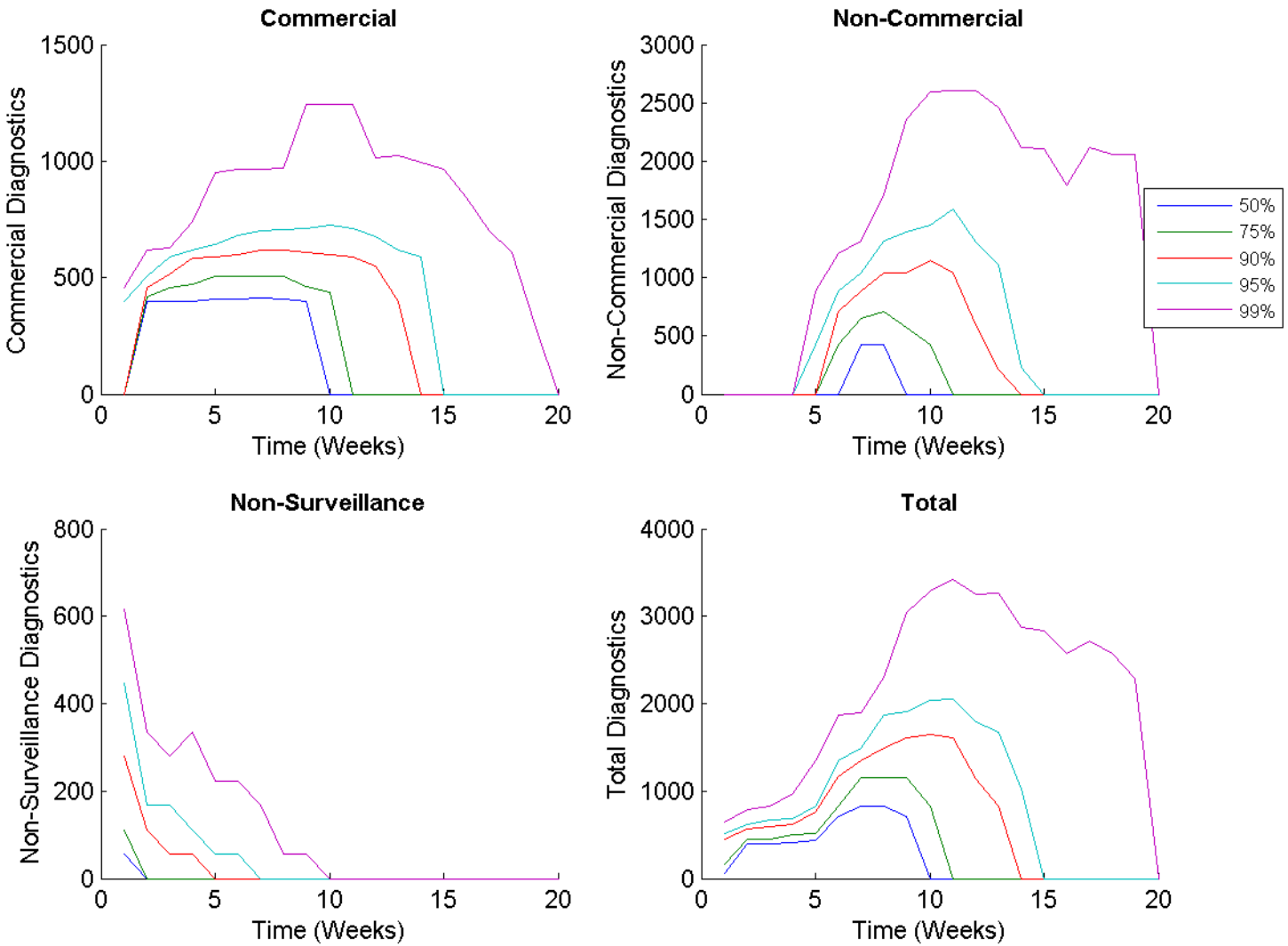
GA: Vaccinations



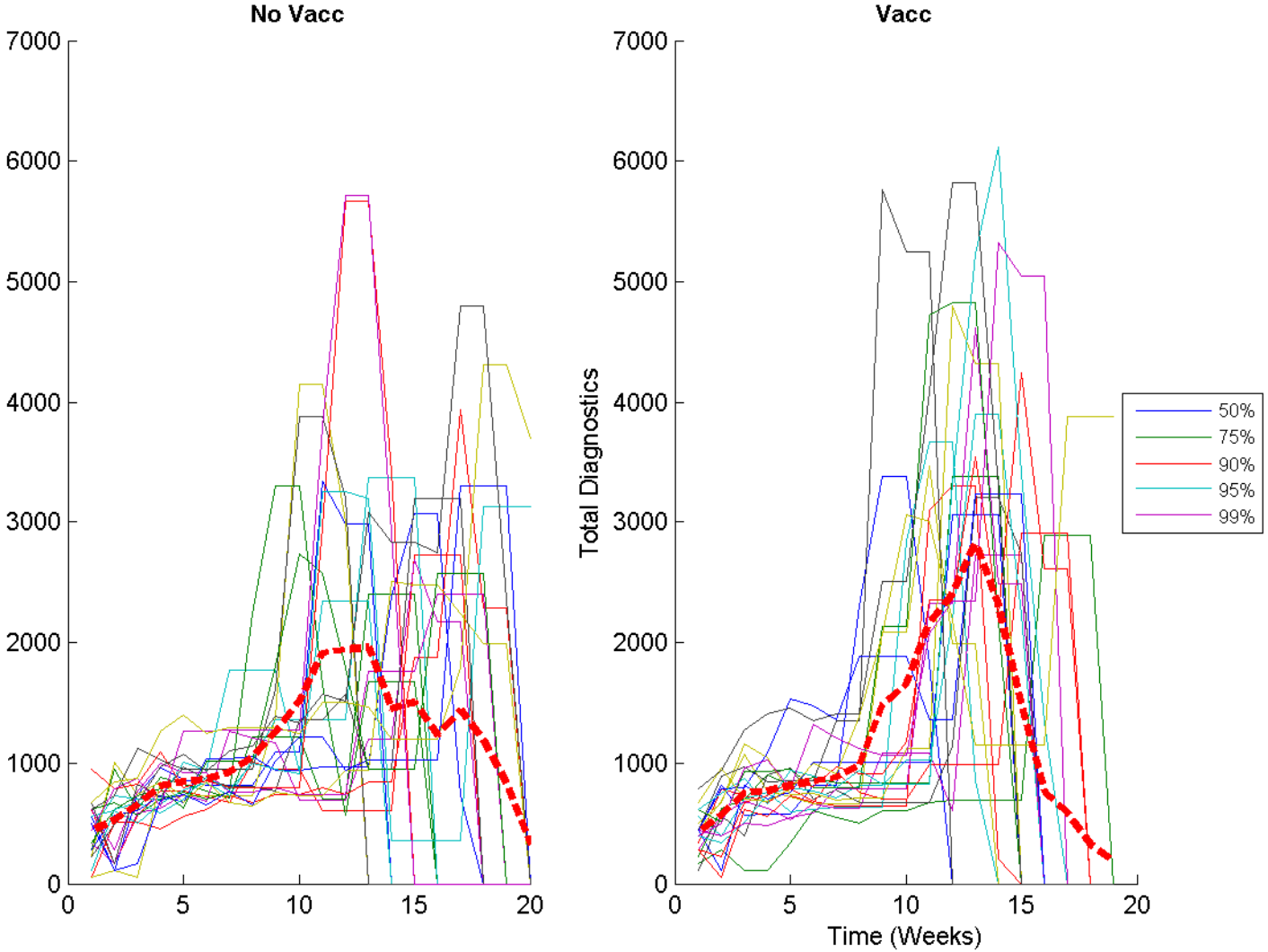
IA: Total Diagnostics



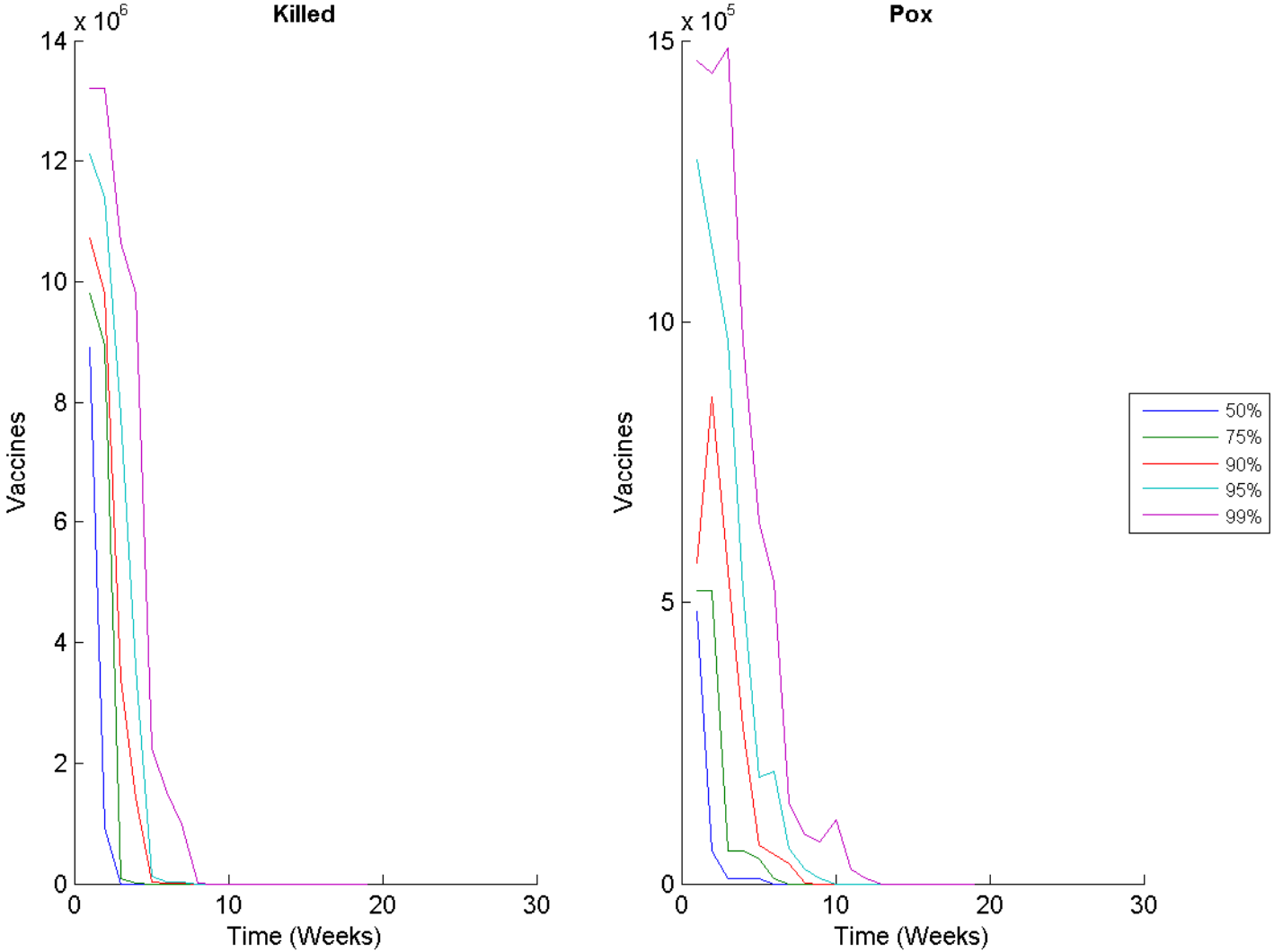
IA: Components vs. Total Diagnostics



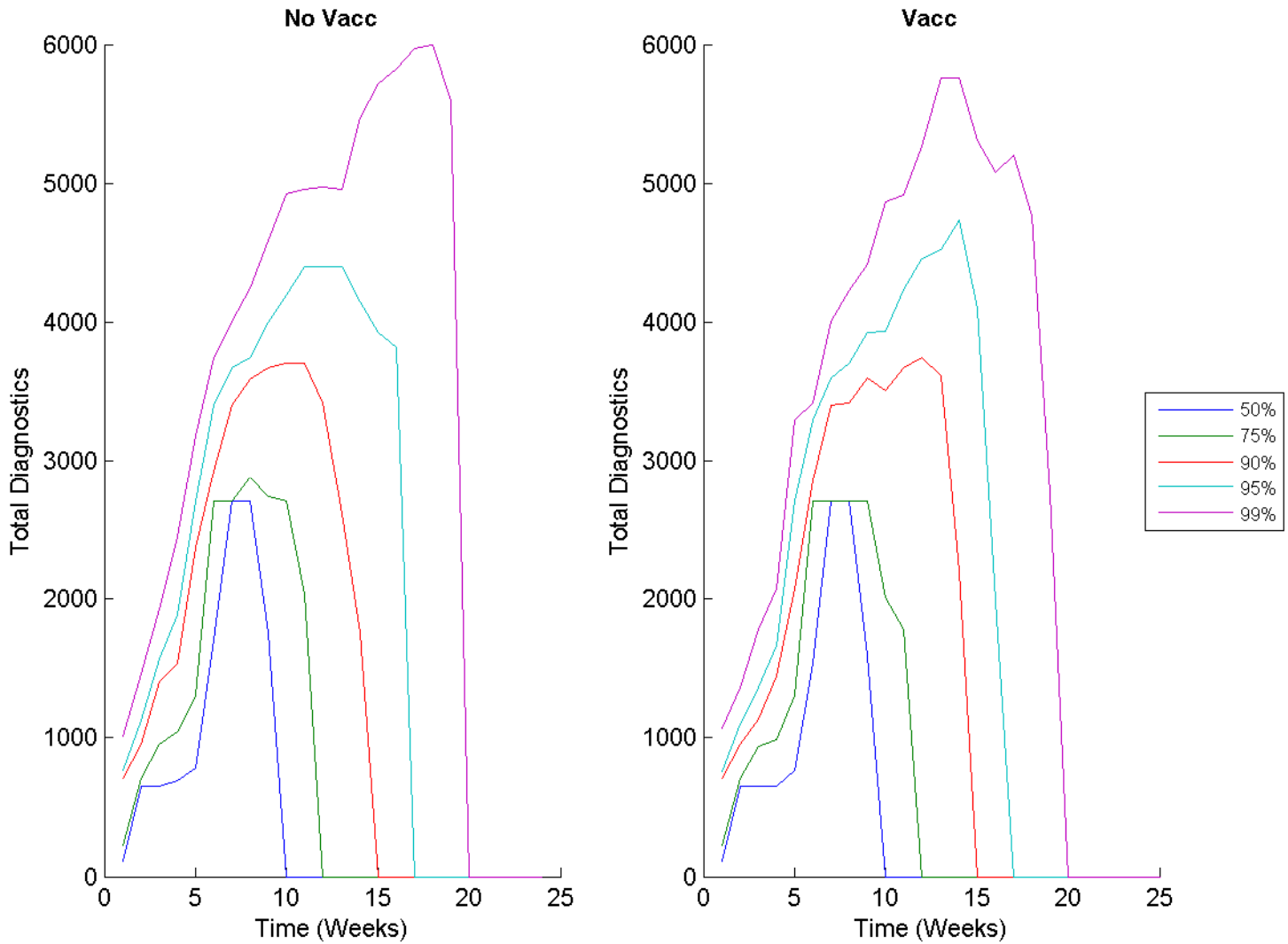
IA: Total Diagnostics over Time for the Largest 5% of Outbreaks



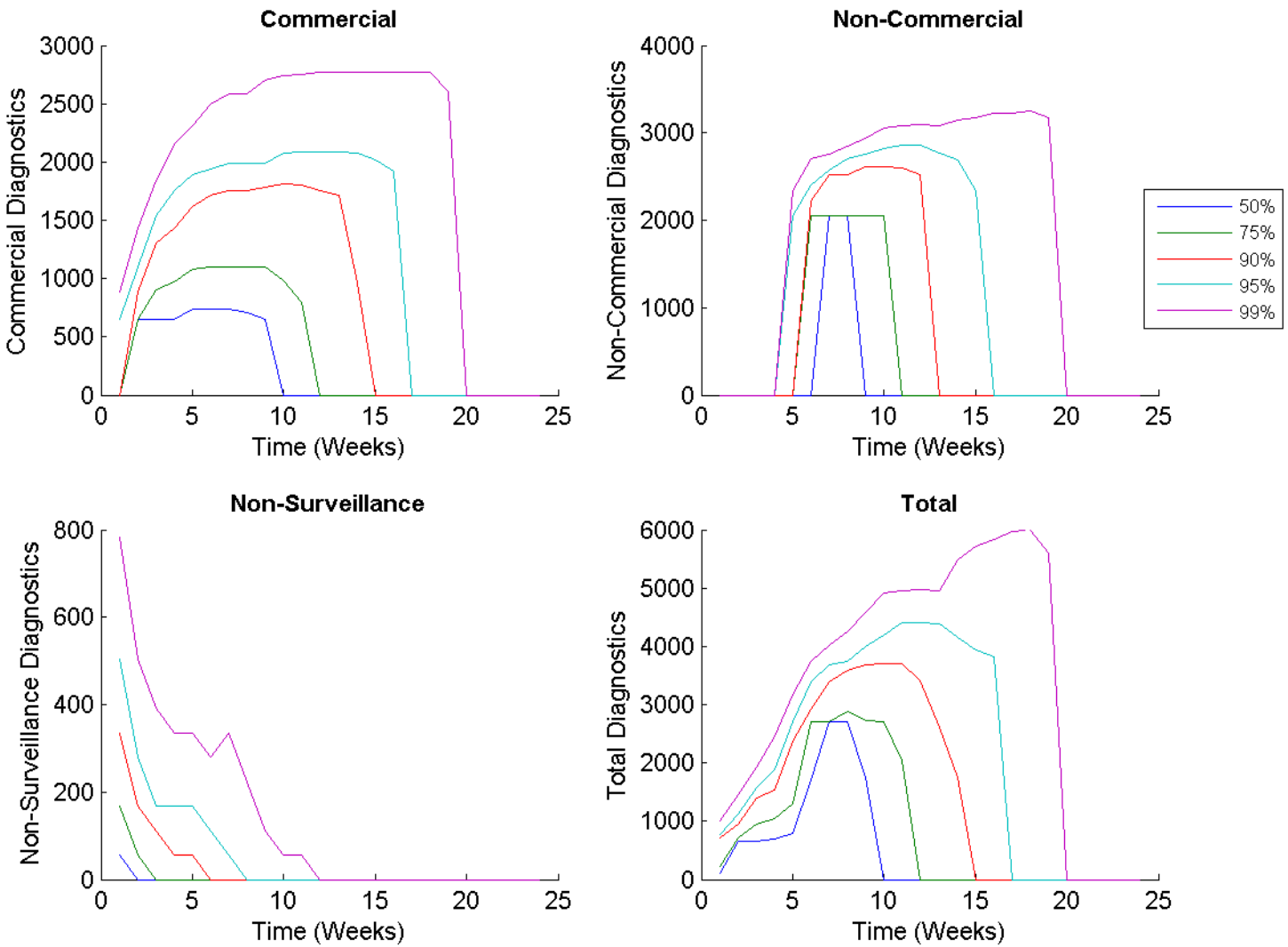
IA: Vaccinations



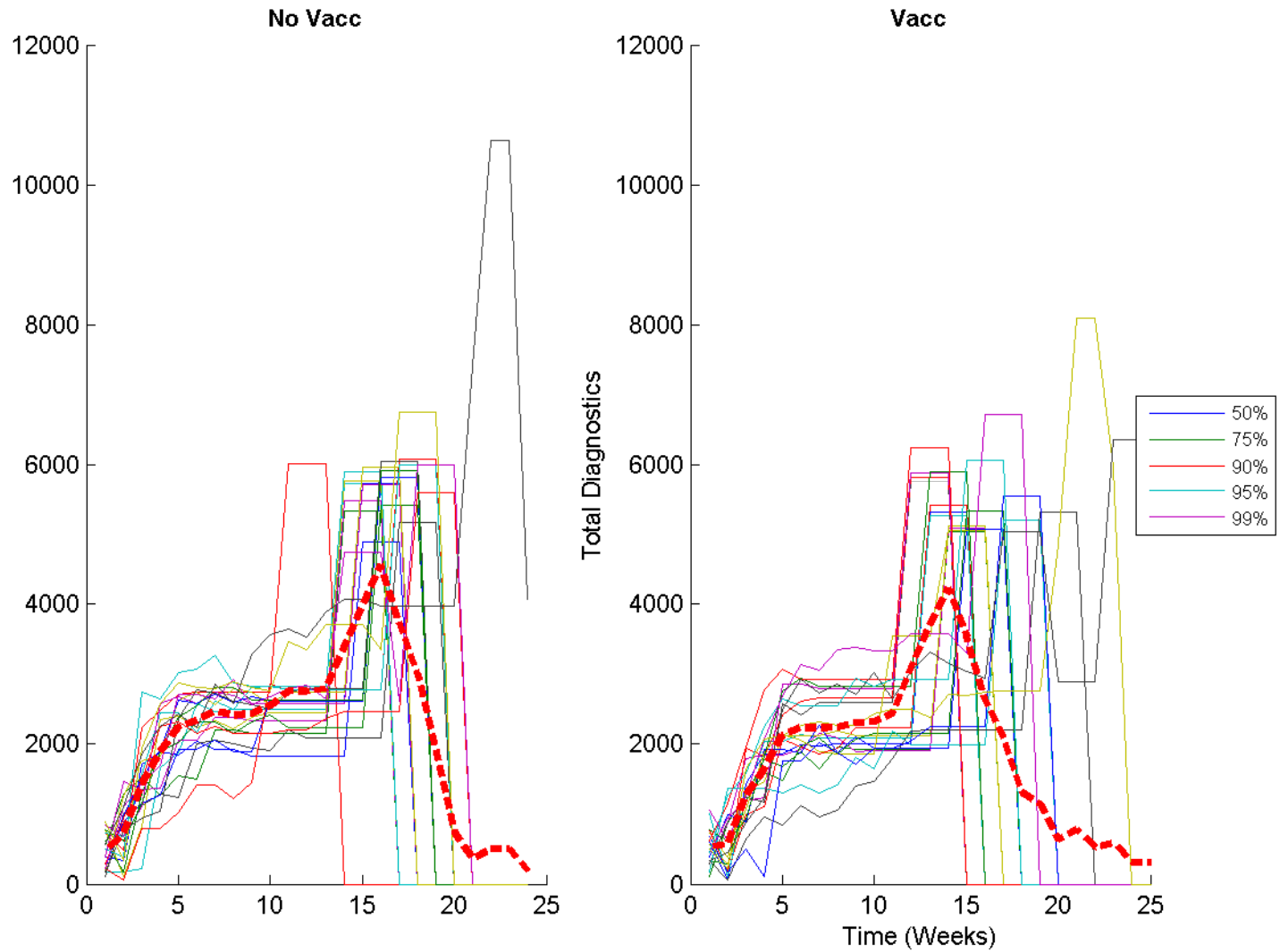
MN: Total Diagnostics



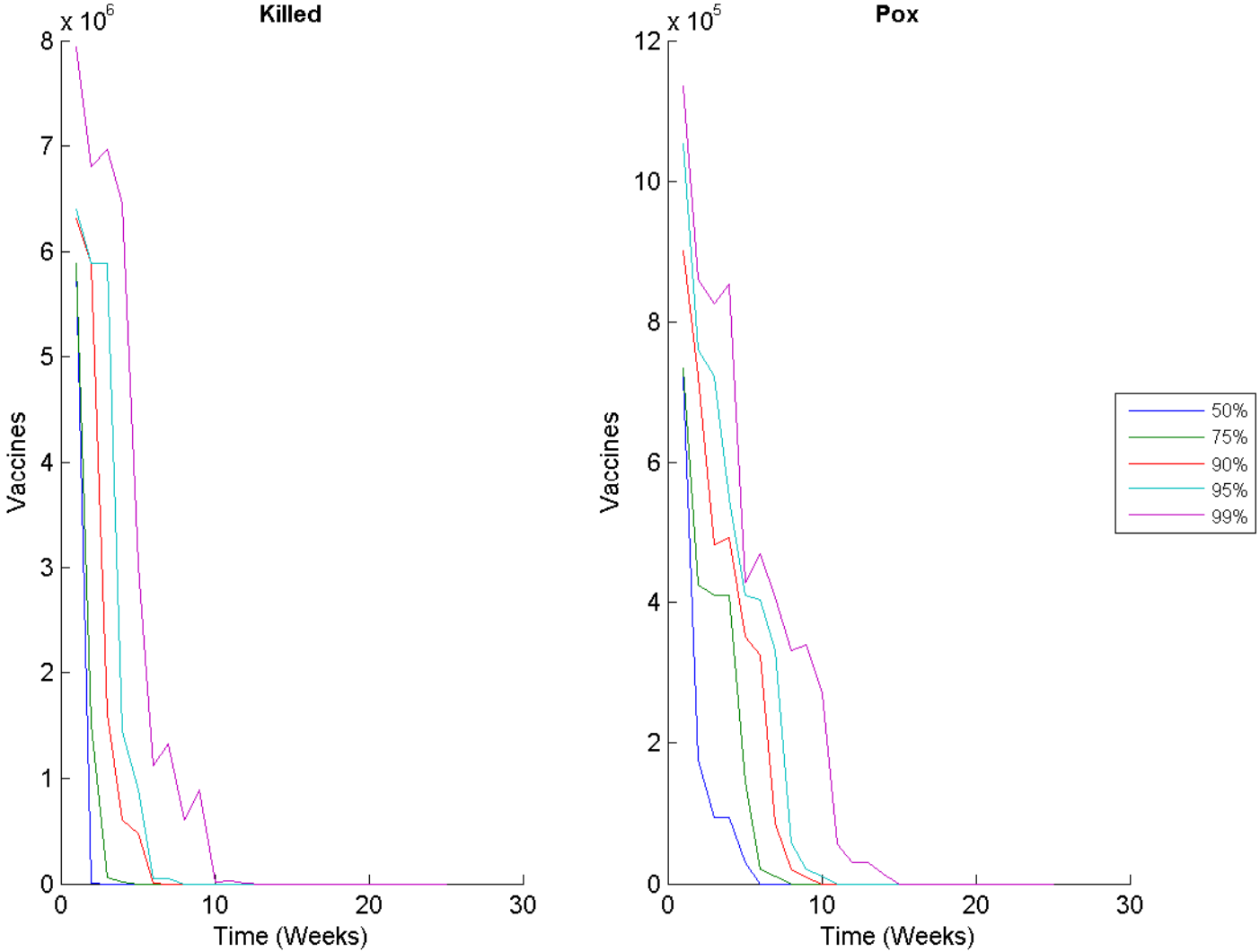
MN: Commercial vs. Total Diagnostics



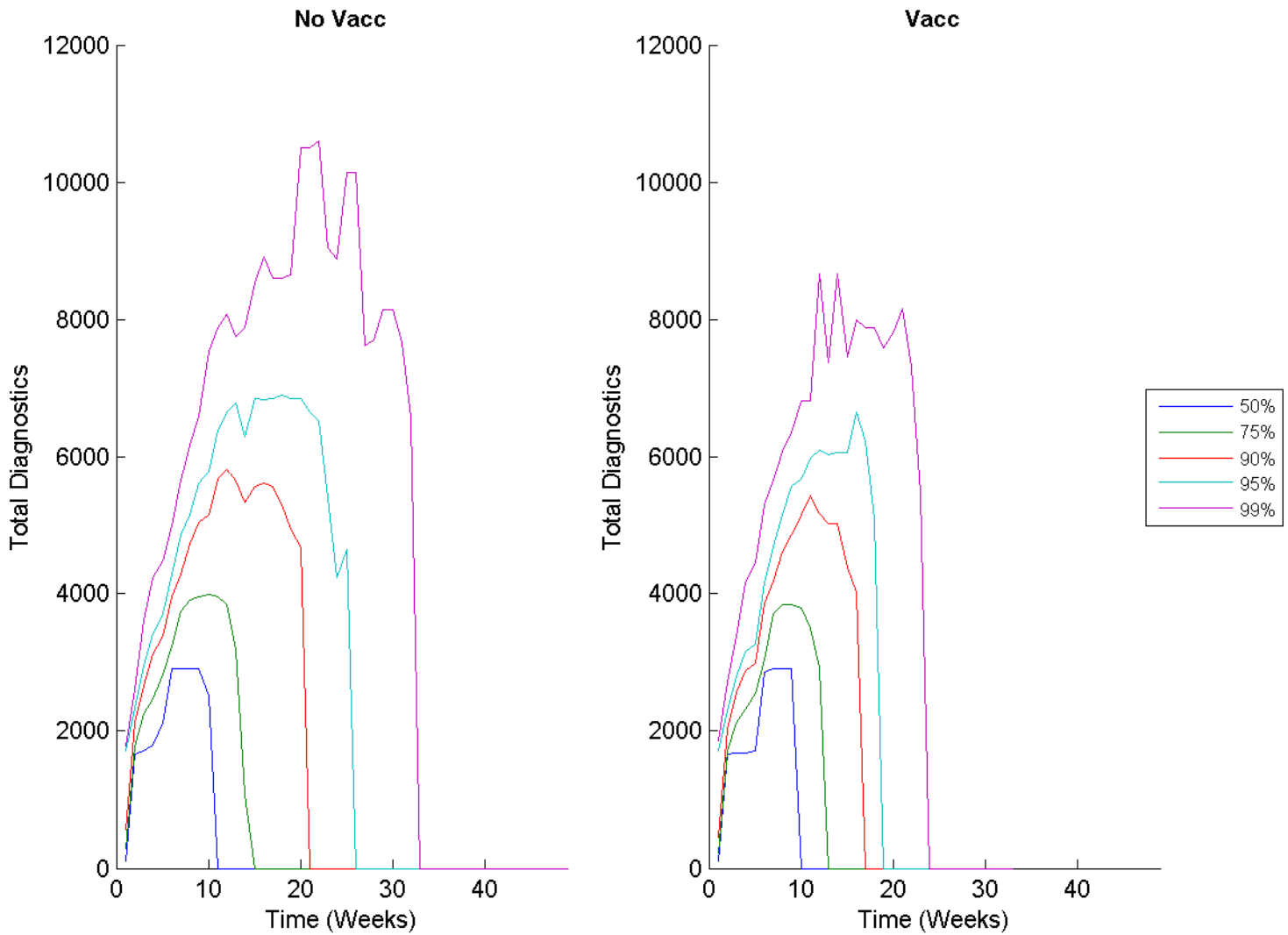
MN: Total Diagnostics over Time for the Largest 5% of Outbreaks



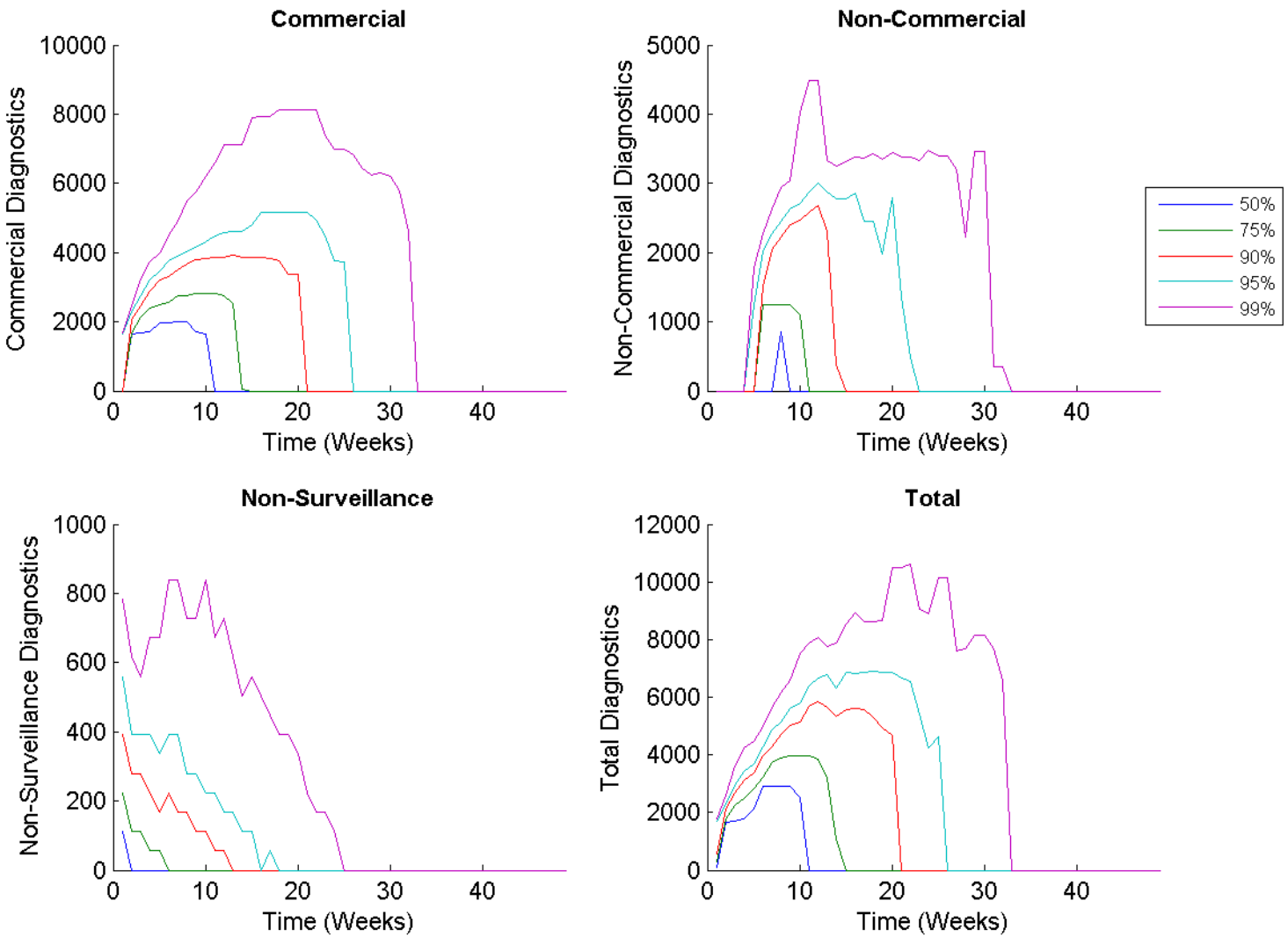
MN: Vaccinations



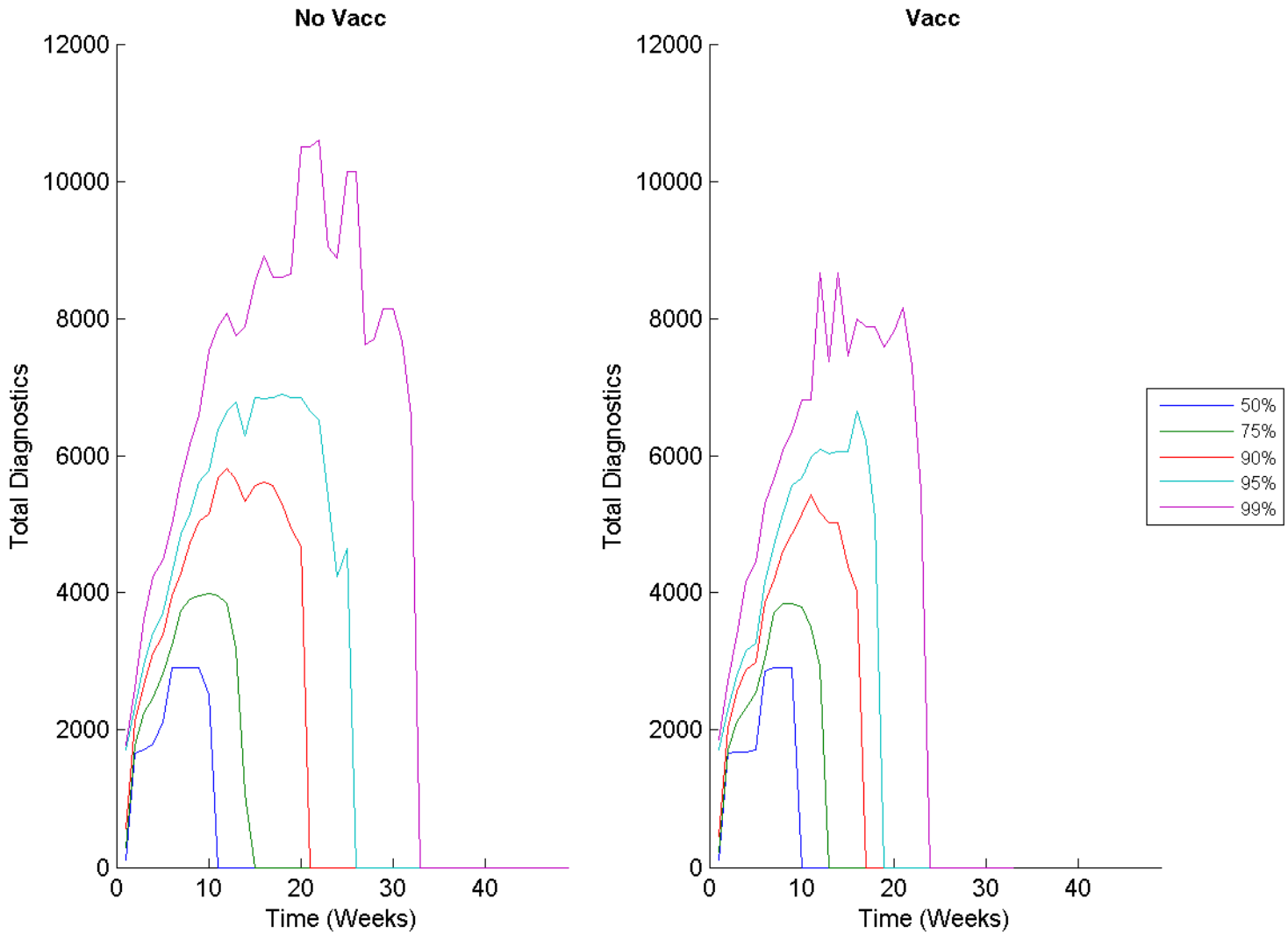
NC (b): Total Diagnostics



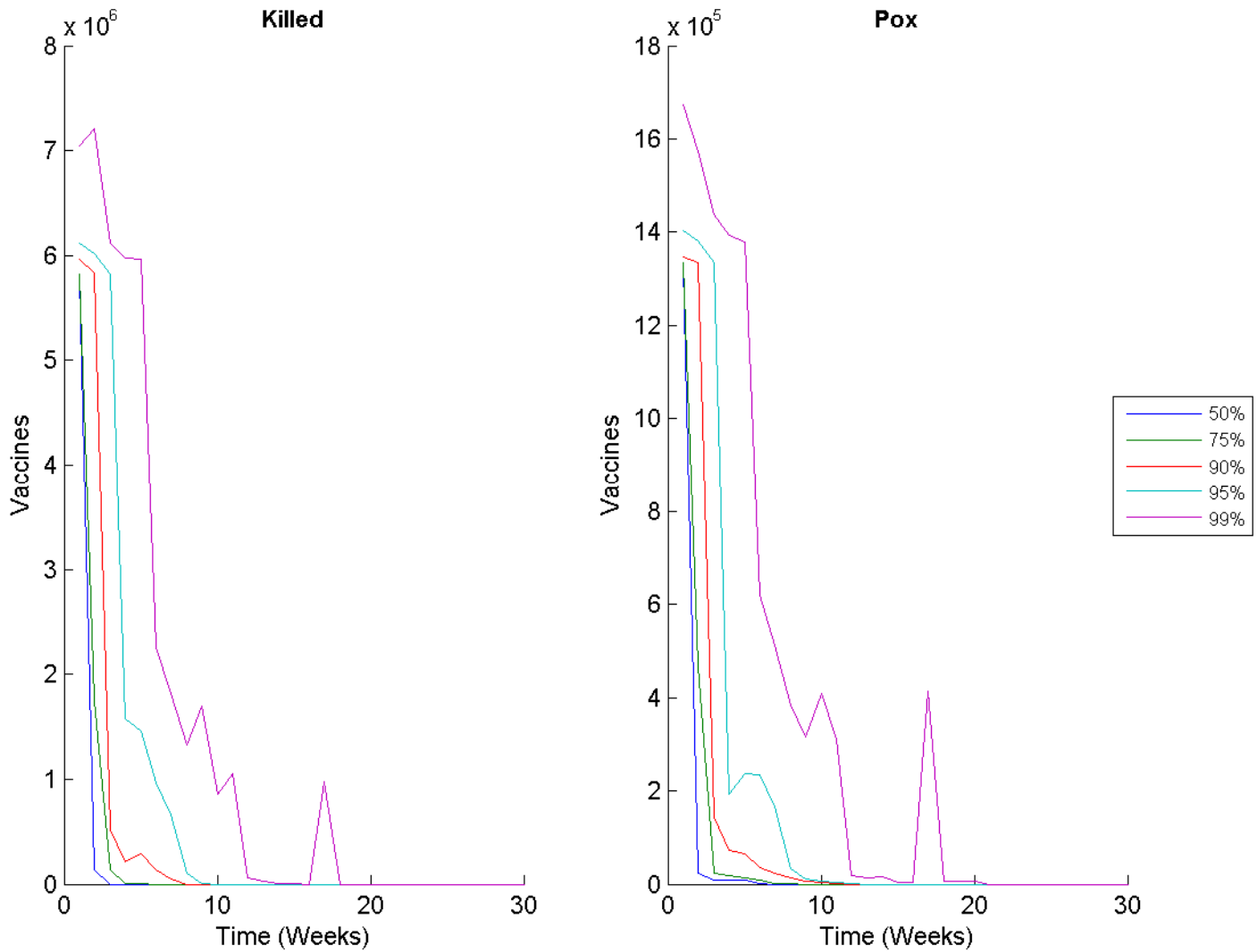
NC (b): Components vs. Total Diagnostics



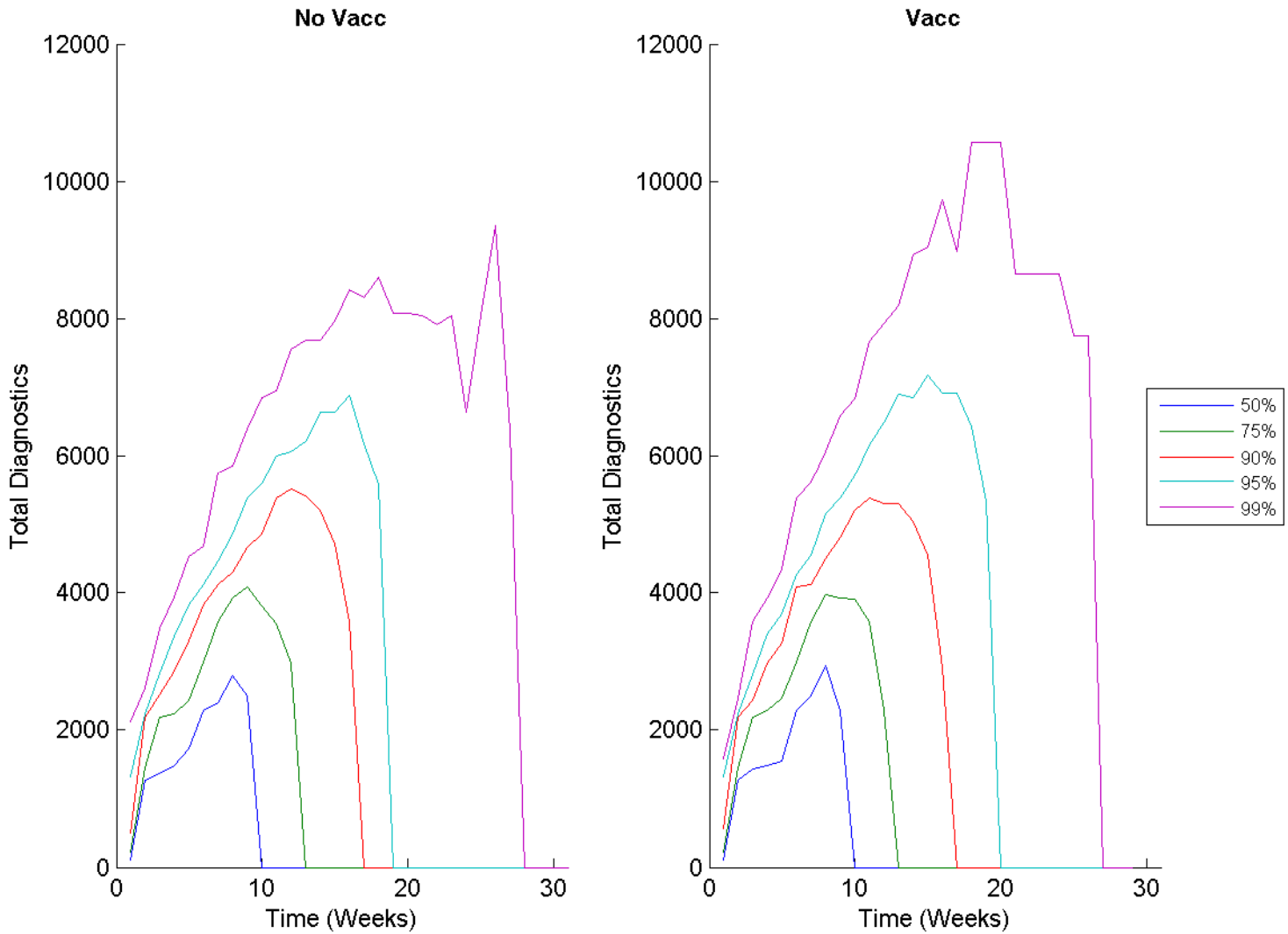
NC (b): Total Diagnostics over Time for the Largest 5% of Outbreaks



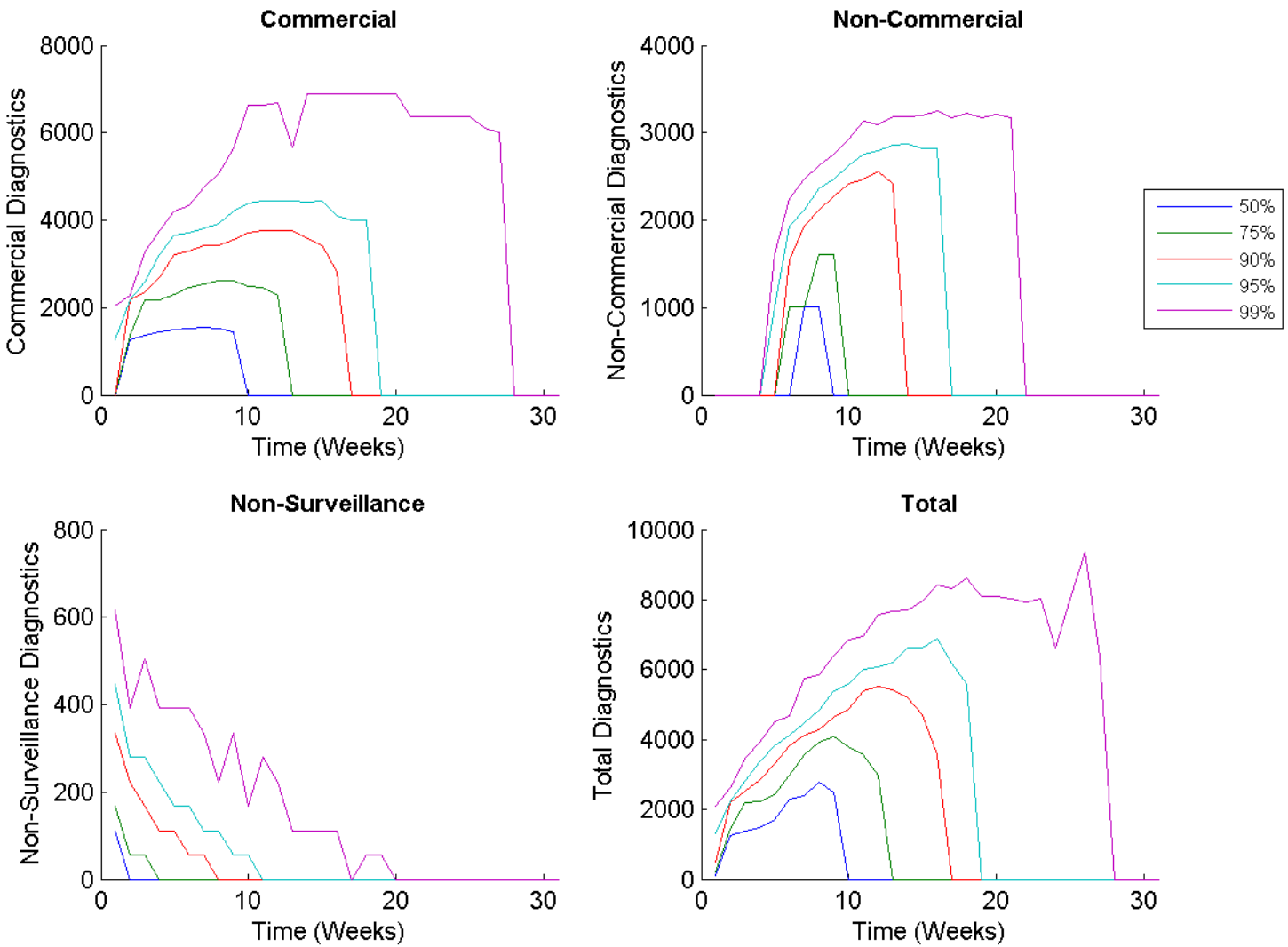
NC (b): Vaccinations



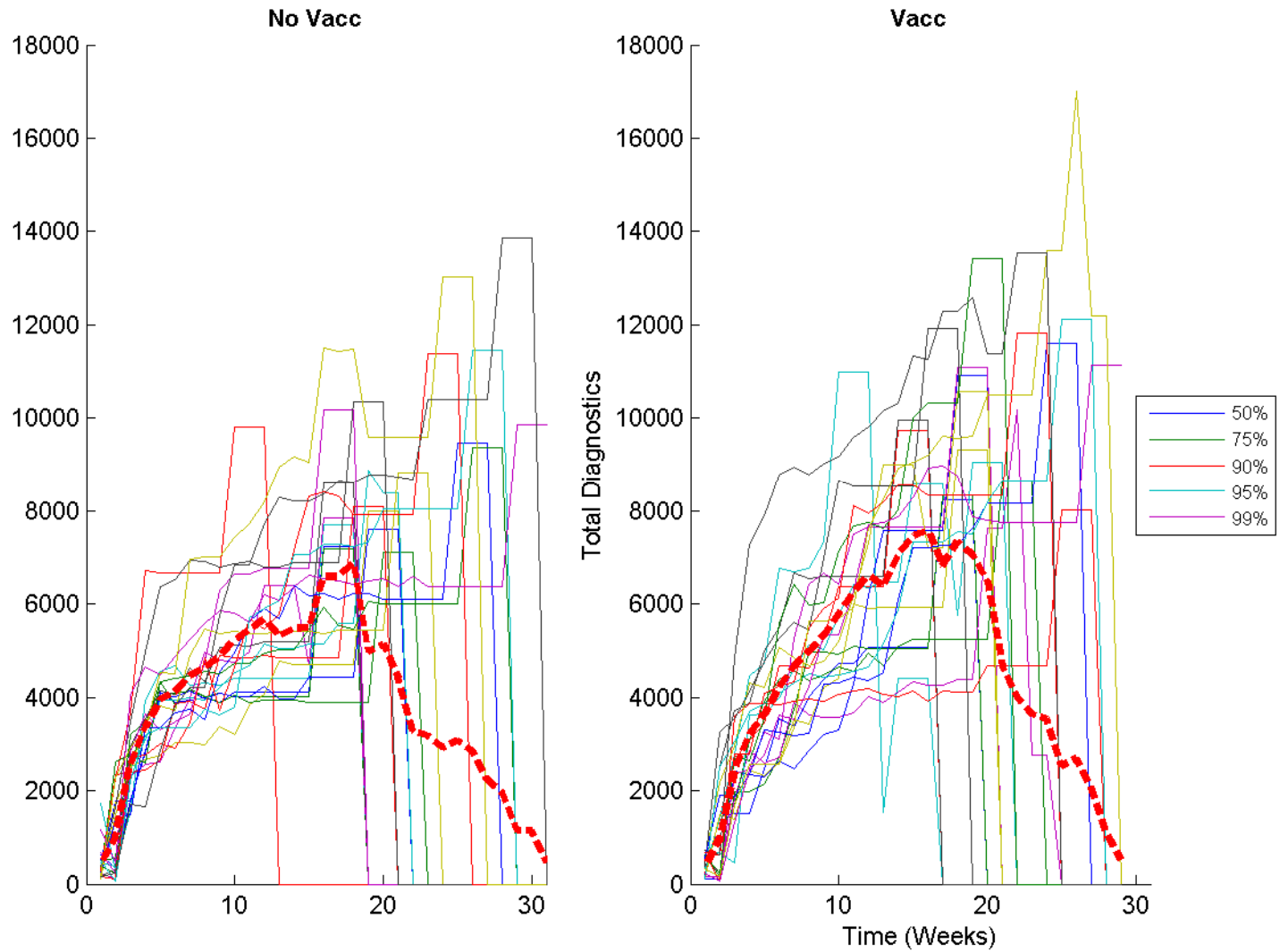
NC (t): Total Diagnostics



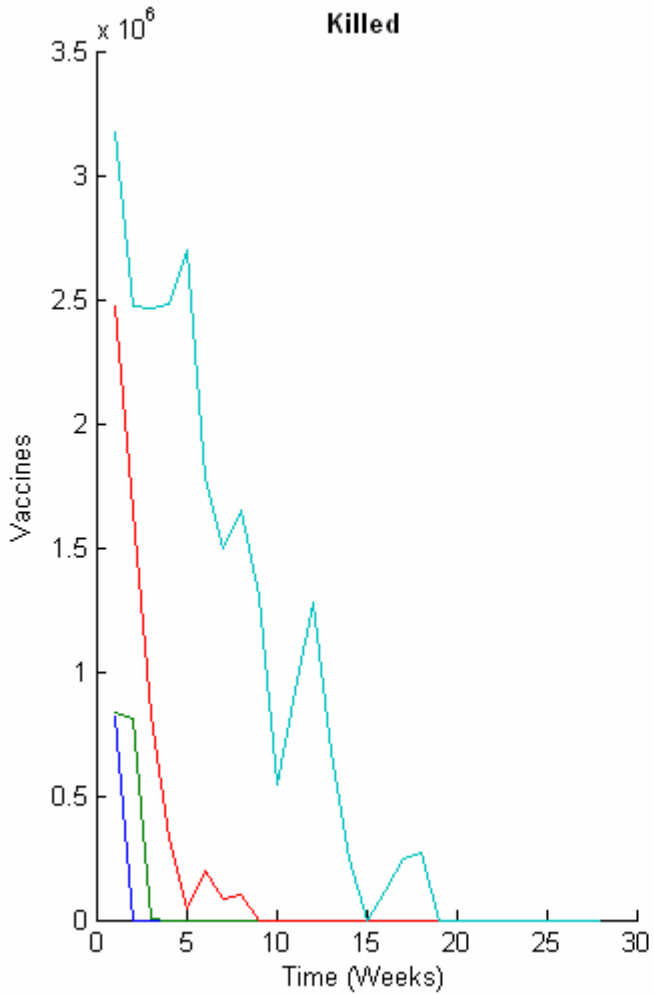
NC (t): Components vs. Total Diagnostics

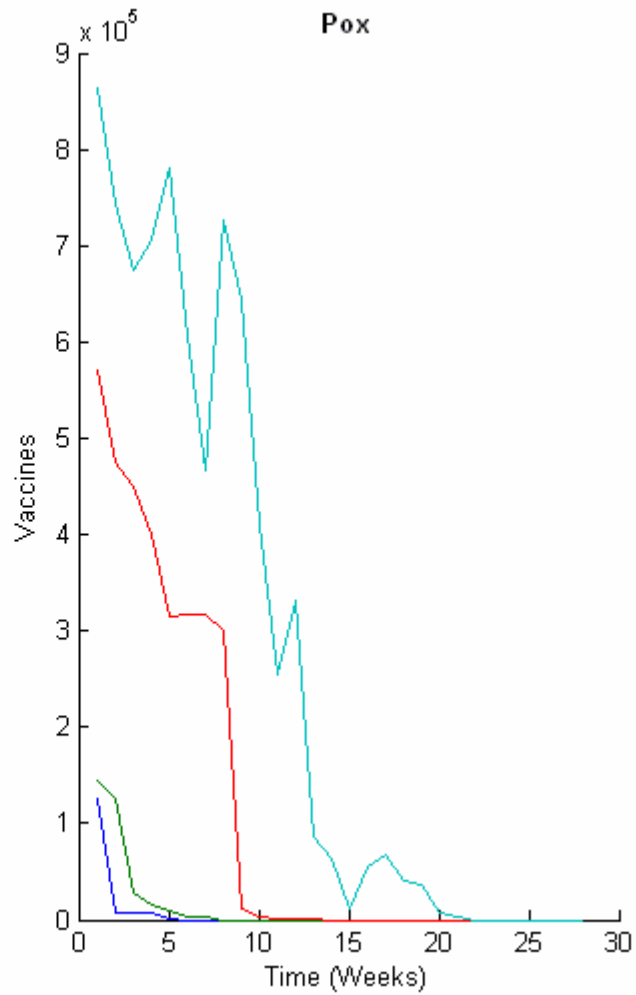


NC (t): Total Diagnostics over Time for the Largest 5% of Outbreaks

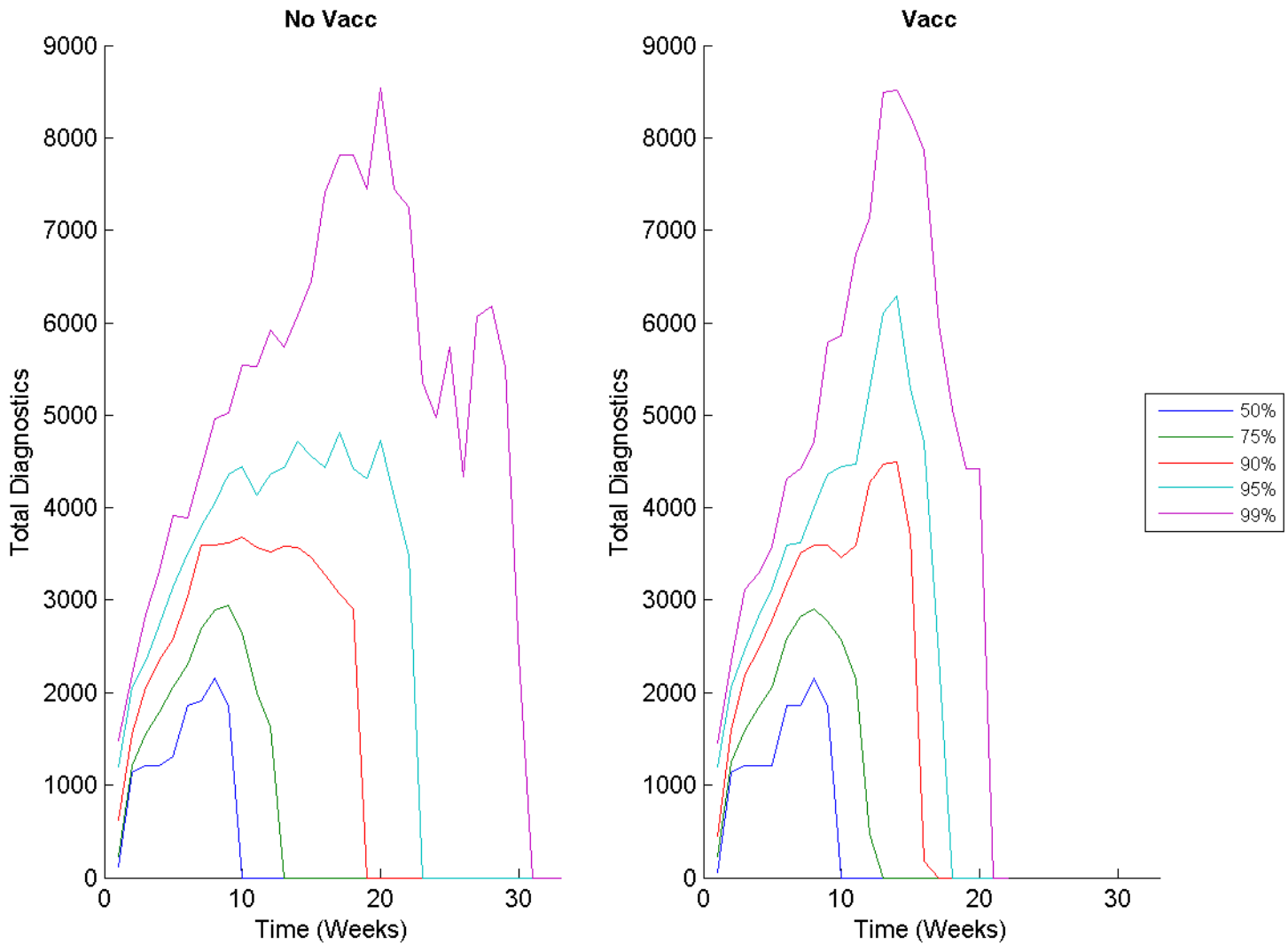


NC (t): Vaccinations

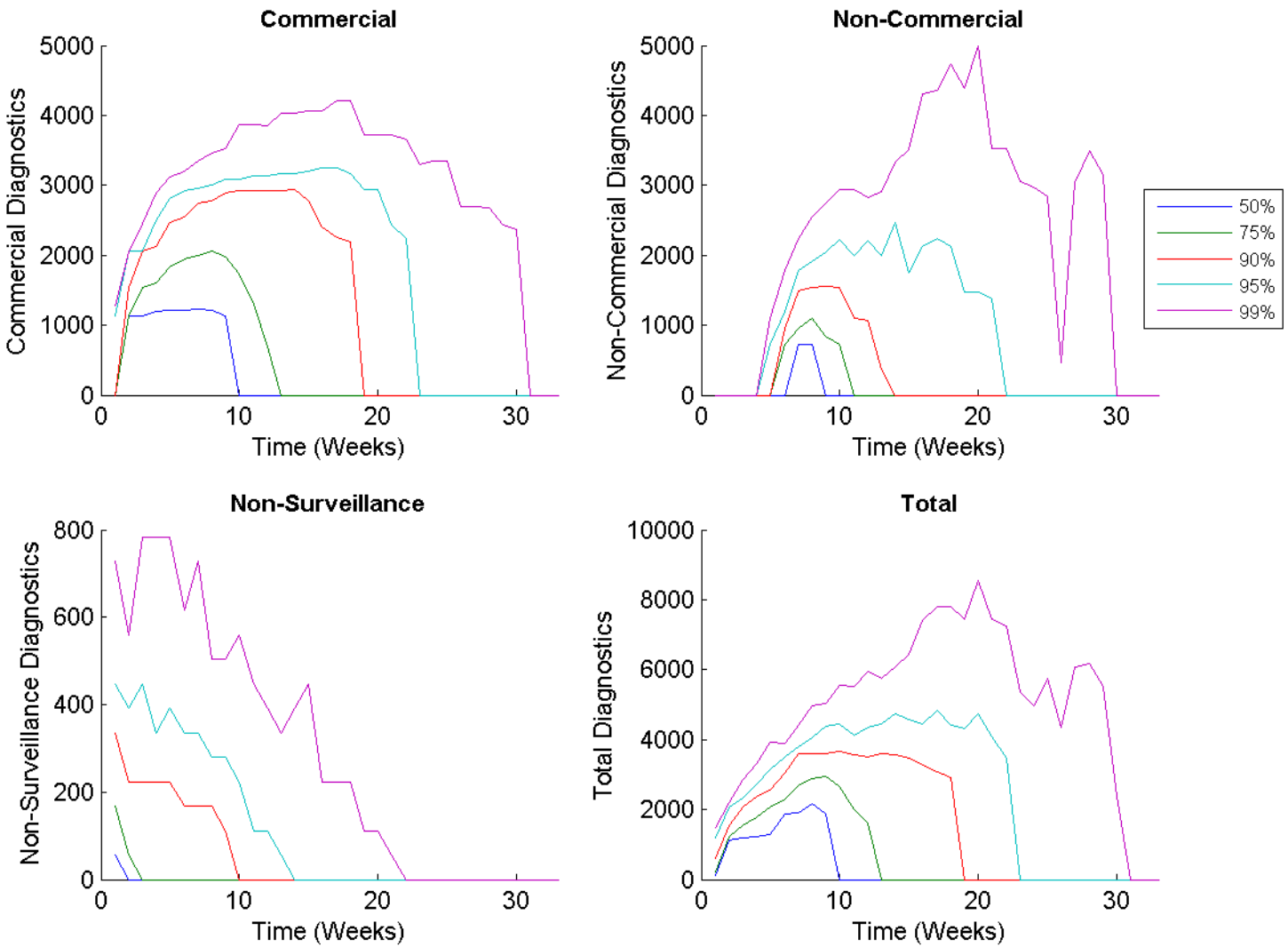




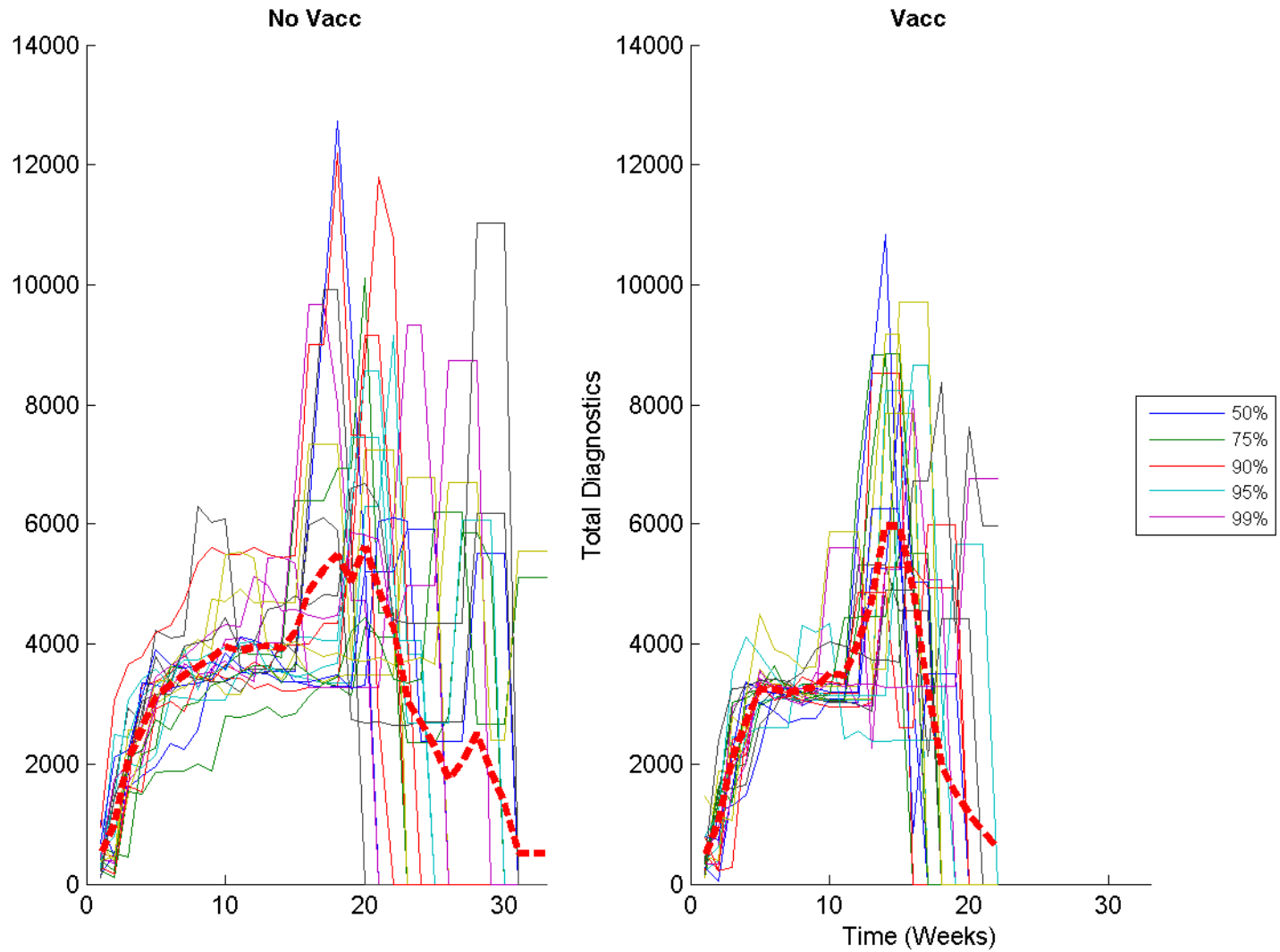
OH: Total Diagnostics



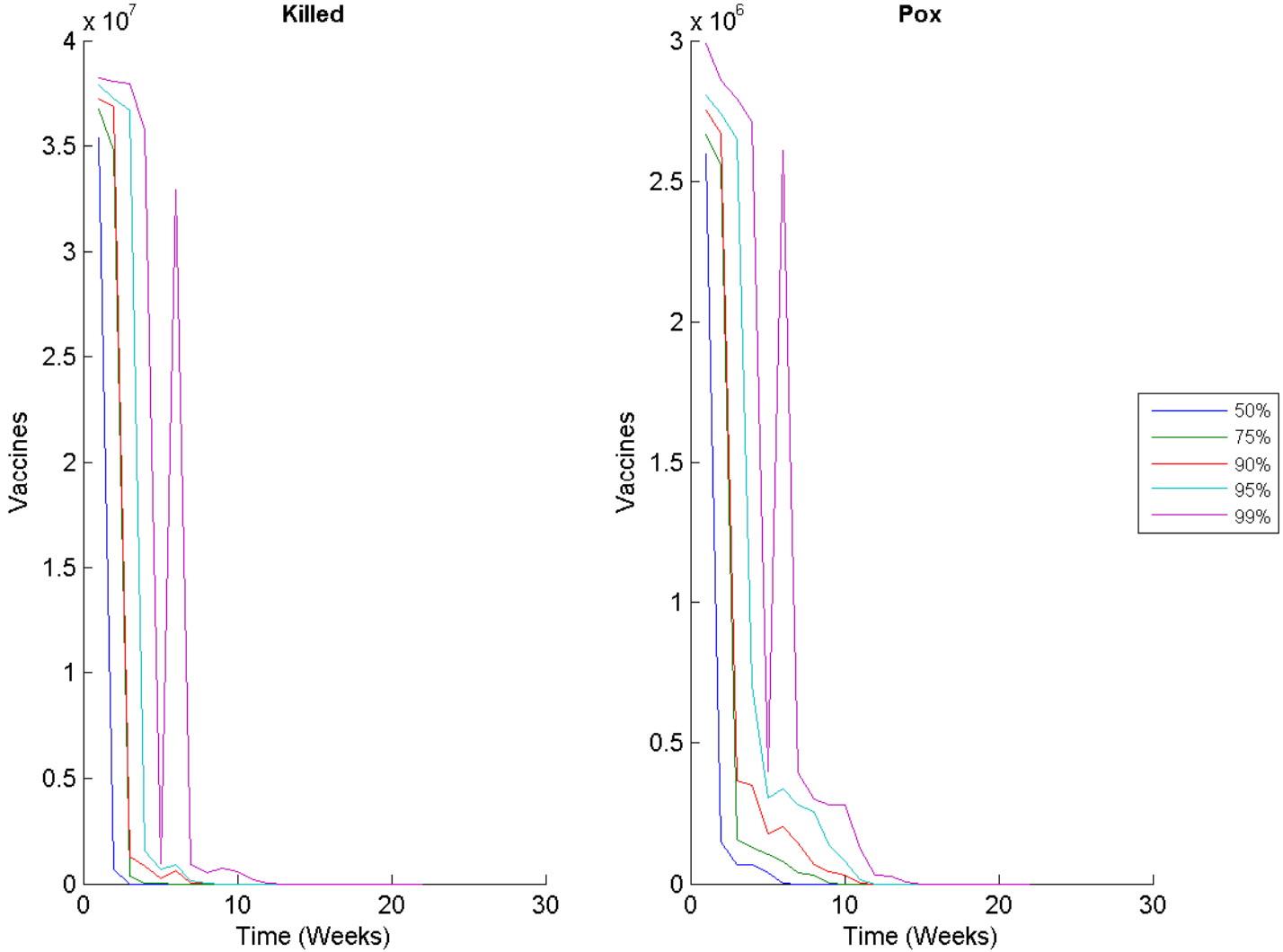
OH: Components vs. Total Diagnostics



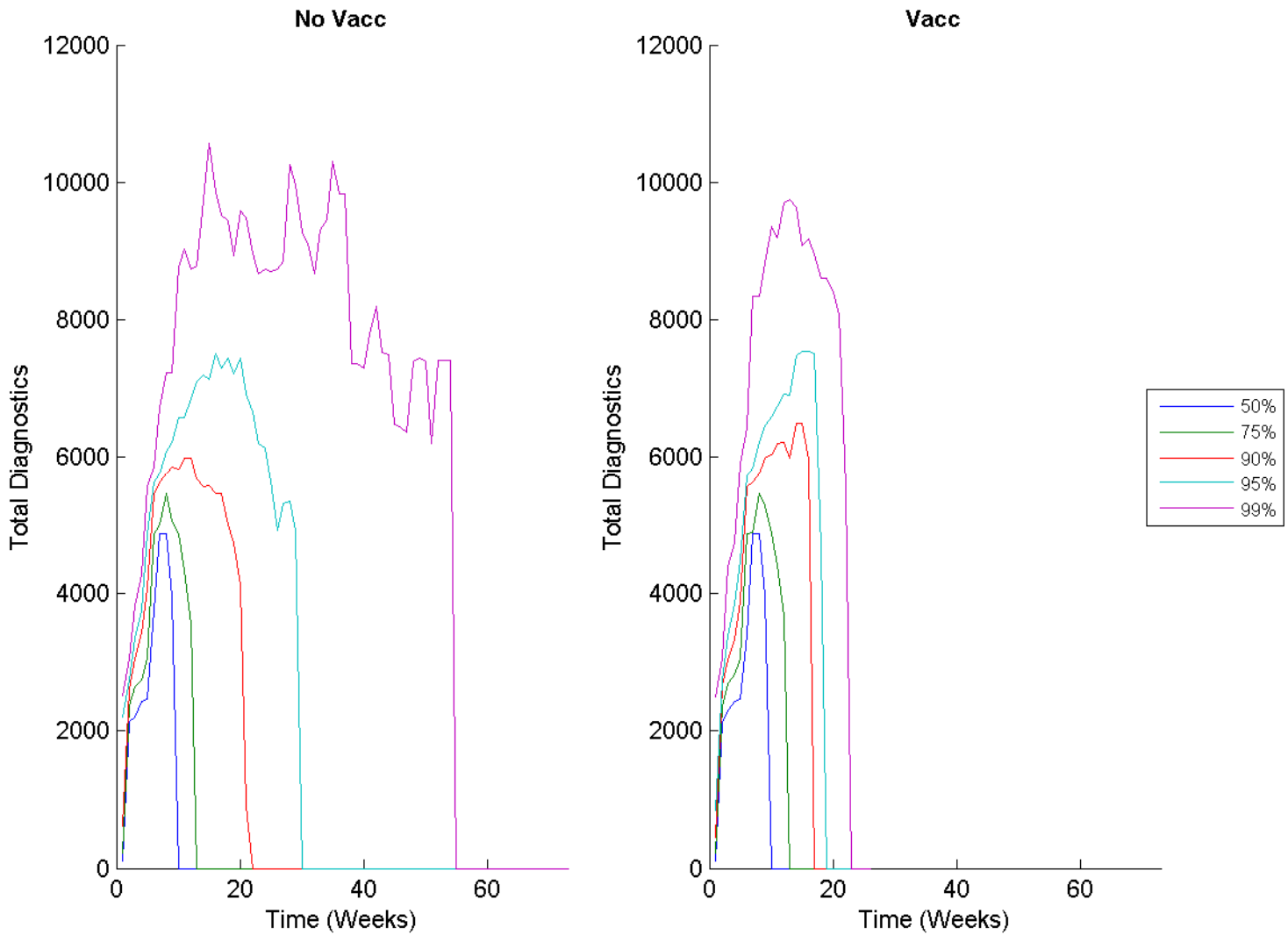
OH: Total Diagnostics over Time for the Largest 5% of Outbreaks



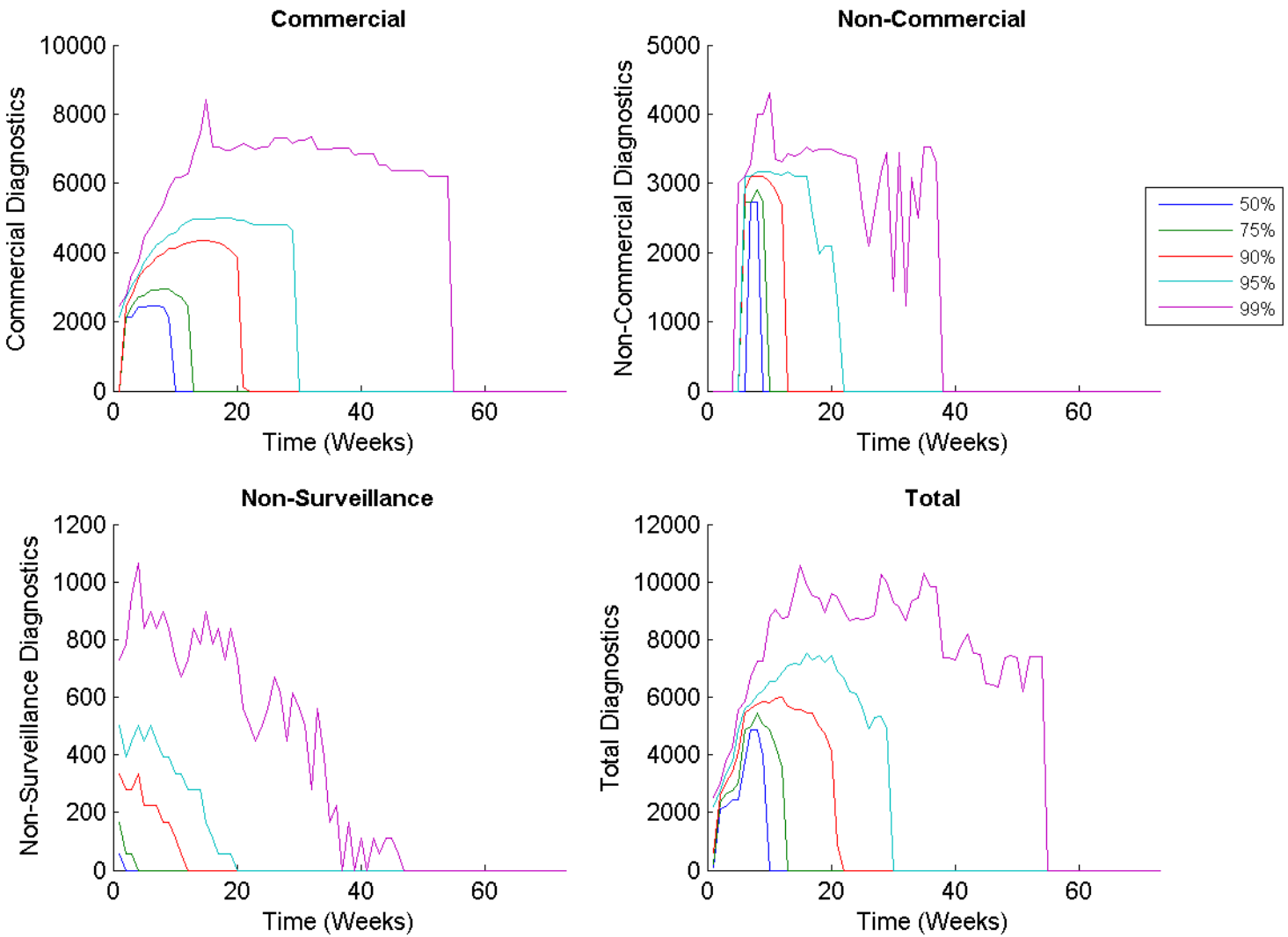
OH: Vaccinations



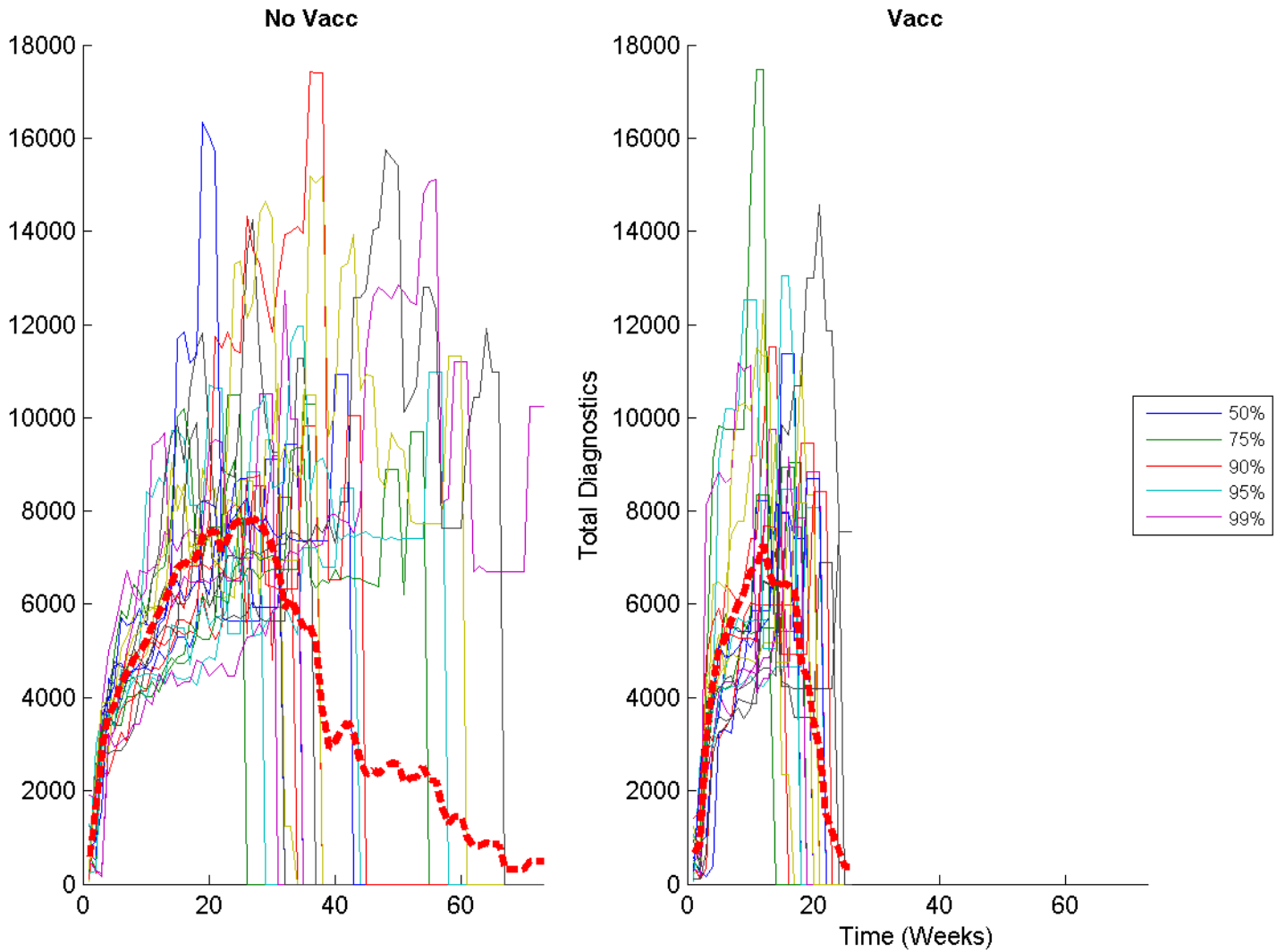
PA: Total Diagnostics



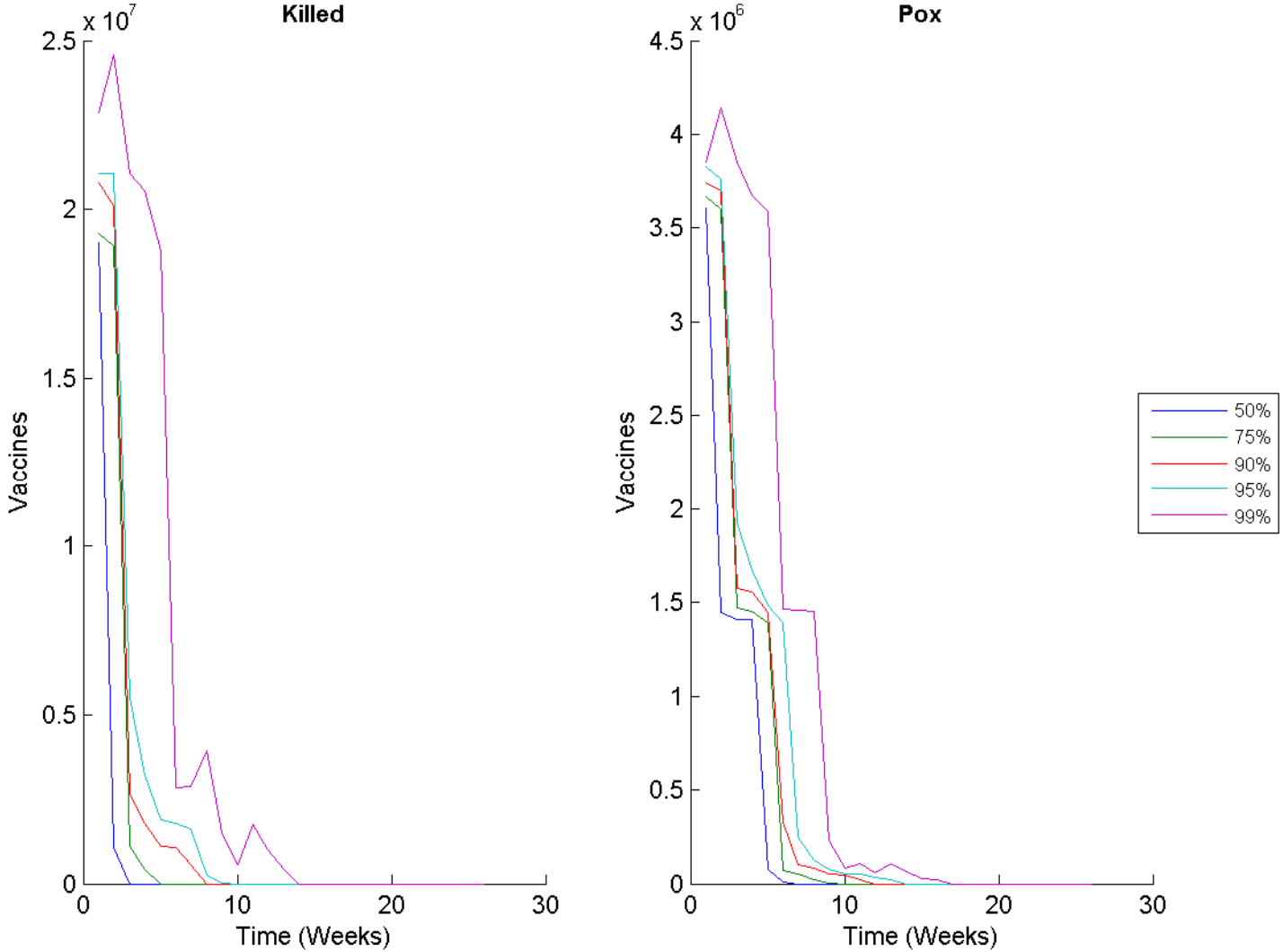
PA: Components vs. Total Diagnostics



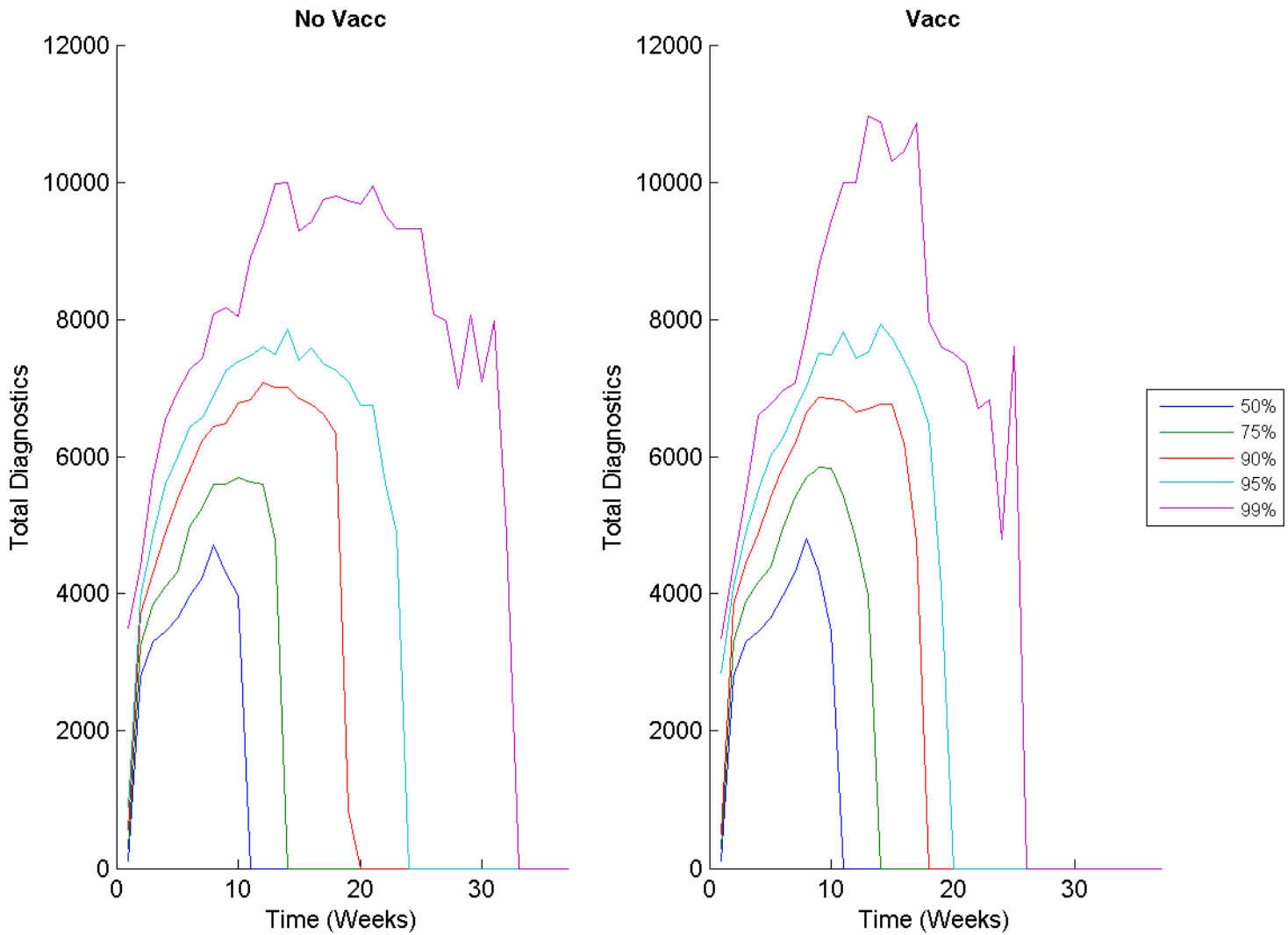
PA: Total Diagnostics over Time for the Largest 5% of Outbreaks



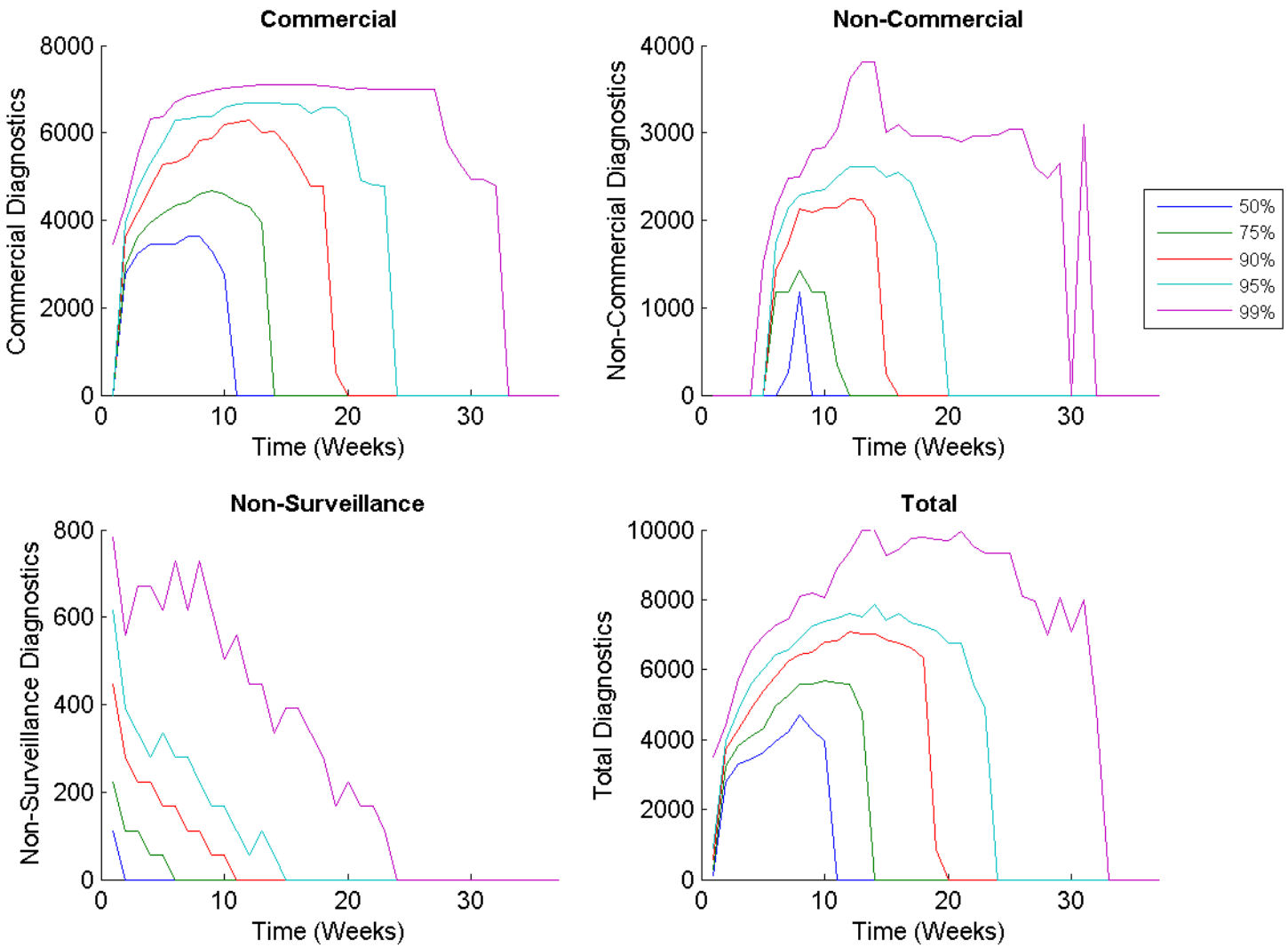
PA: Vaccinations



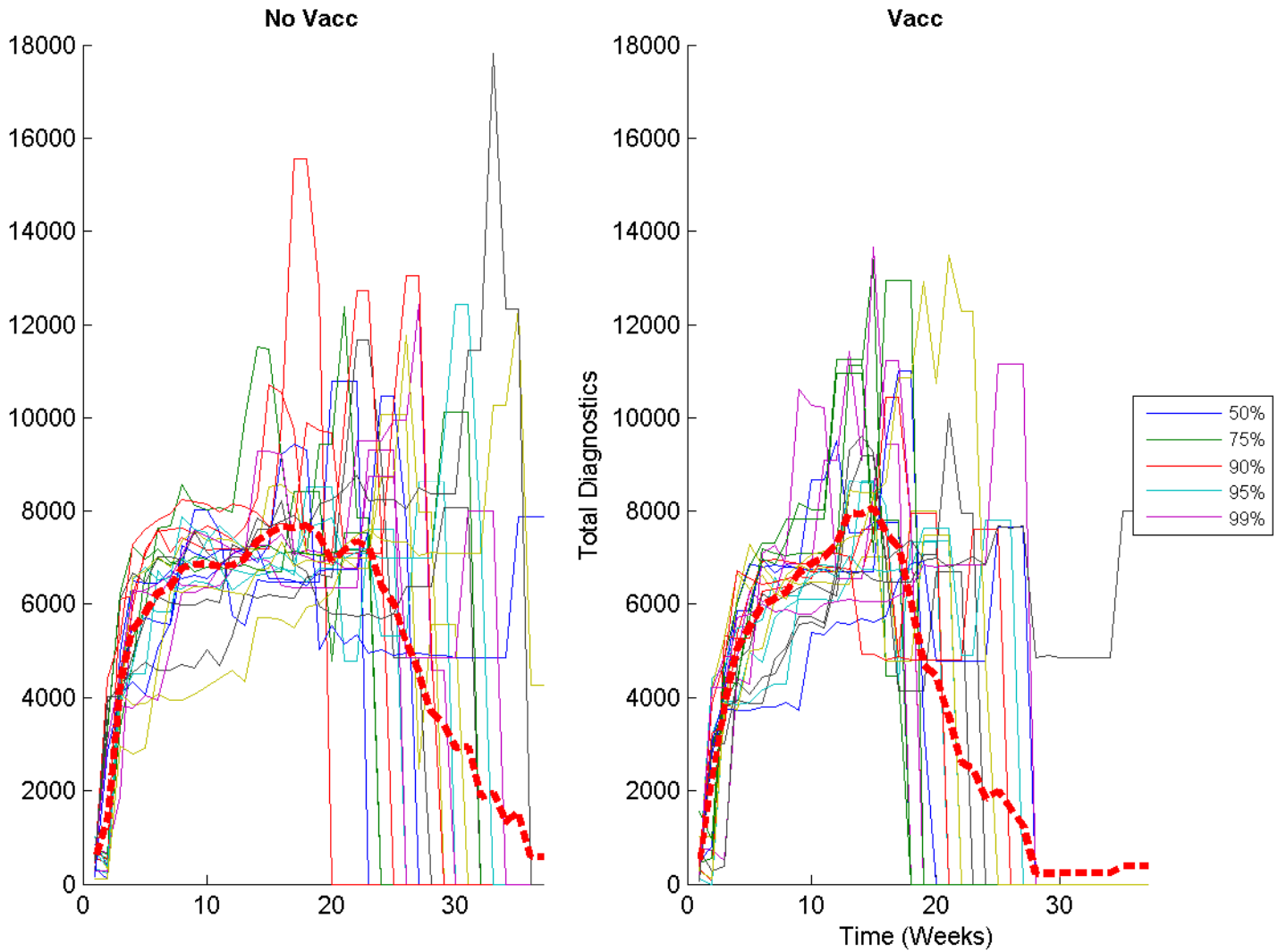
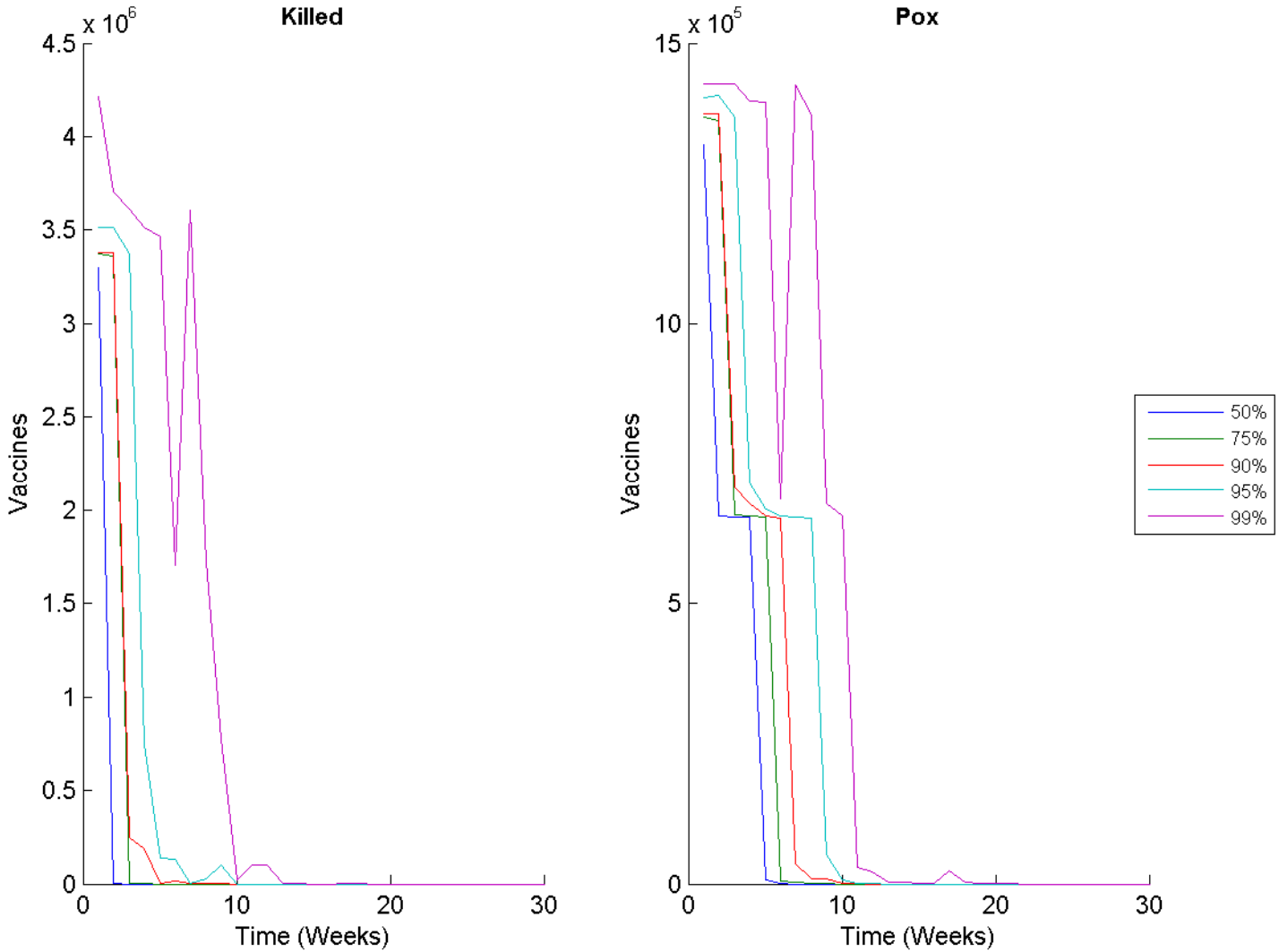
VA: Total Diagnostics



VA: Commercial vs. Total Diagnostics



VA: Total Diagnostics over Time for the Largest 5% of Outbreaks



VA: Vaccinations