

Agent-based models for free-range White-tailed deer and Chronic Wasting Disease



May 11, 2023

Presented by Mauri Liberati



Agent-based Modeling

(also called Individual-based Modeling)

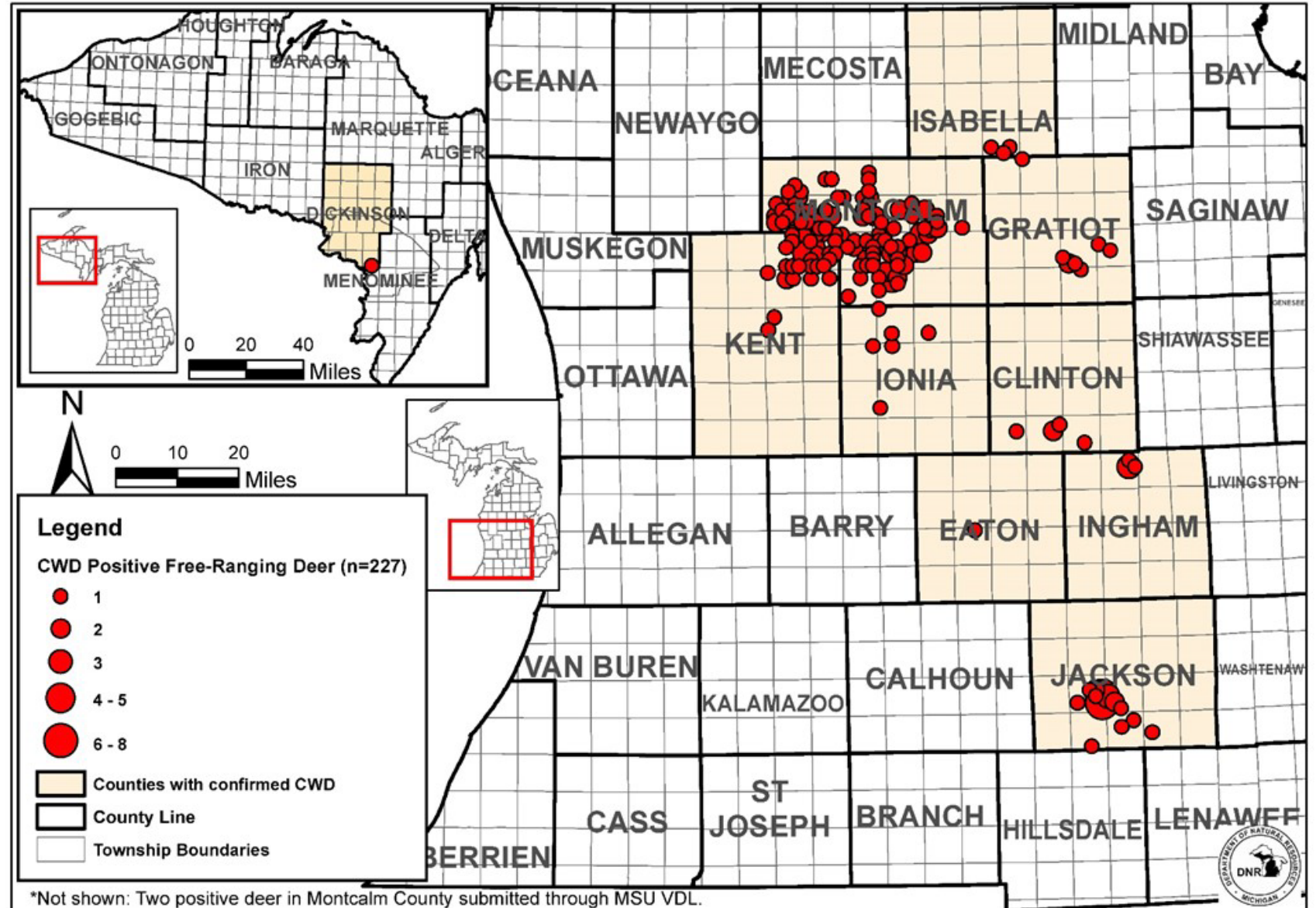
Attempts to recreate and predict the appearance of complex phenomena.

Computer-based model for simulating actions and interactions of autonomous agents.

Process of “emergence” – how do changes in individual behaviors impact the behavior or outcomes for the full system?

CWD in Michigan free-range white-tailed deer

Free-ranging White-tailed Deer Positive for Chronic Wasting Disease (CWD) Michigan as of March 15, 2022



Version: March 15, 2022

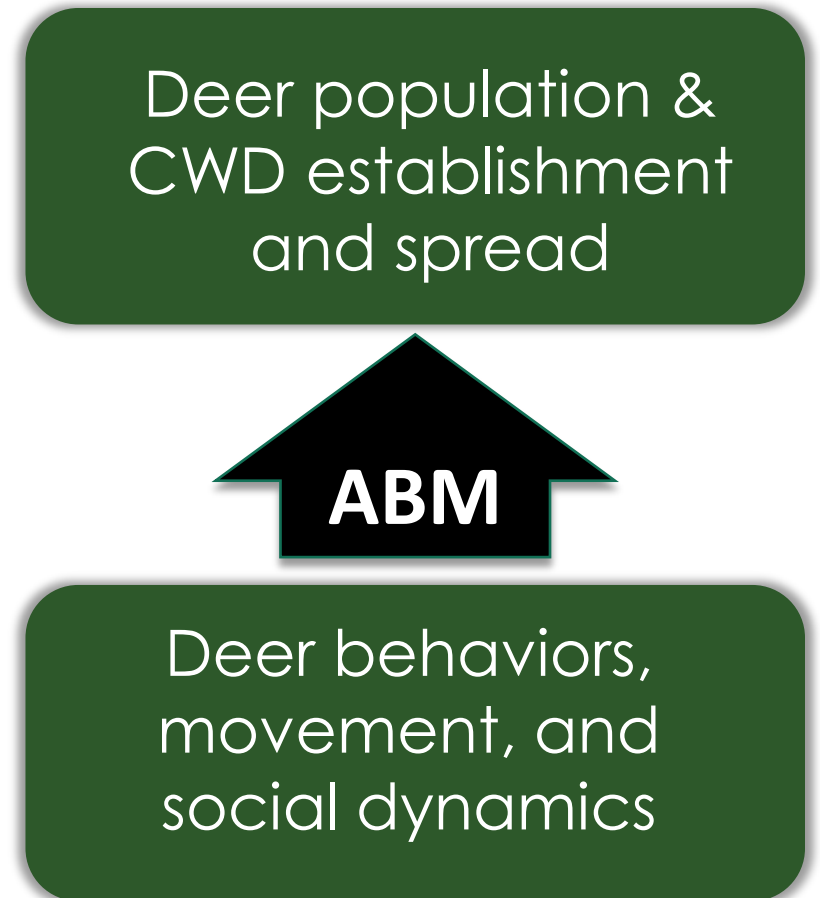
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(also called Individual-based Modeling)

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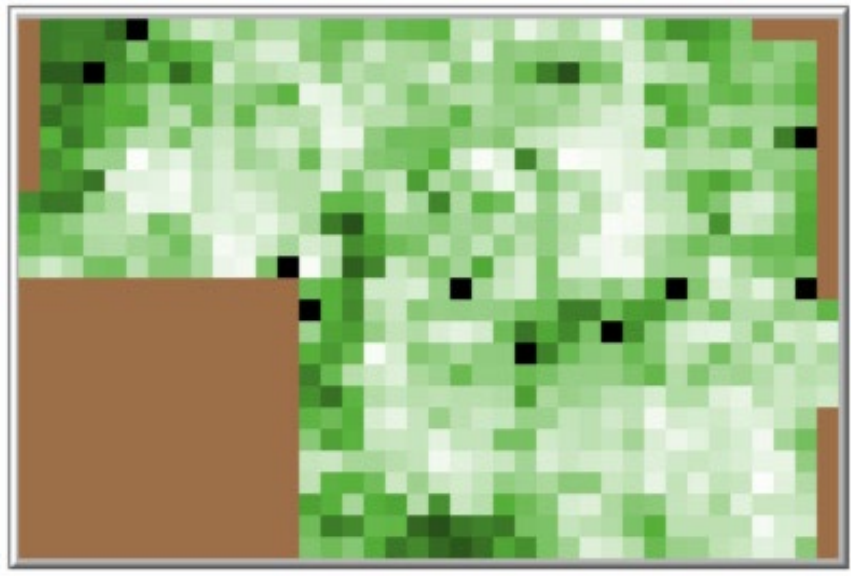
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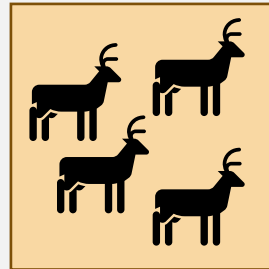


Agent-based Modeling

Landscape



Individuals
(Agents)



Decision-making Rules
(Procedures)

Aging
Reproduction
Dispersal
Natural mortality
Hunter harvest
Disease transmission
Etc.

Agent-based Modeling:

2020 O_vCWD Framework

MIOvPOP

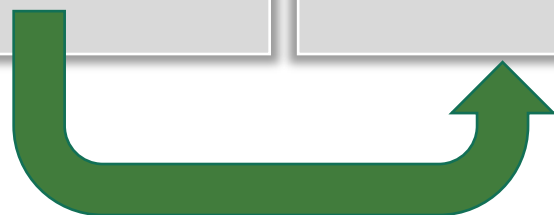
(VERSION 1.1.0)

Simulate white-tailed deer
population
dynamics

MIOvCWD

(VERSION 1.0.0)

Simulate spread
of CWD in
population of
white-tailed deer



Aniruddha Belsare
Michigan State University

Updated Deer-CWD Agent-based Model

Simulate deer
population dynamics

Optional switch to
introduce CWD

Integrate new data
and understanding of
deer-CWD dynamics
for Michigan

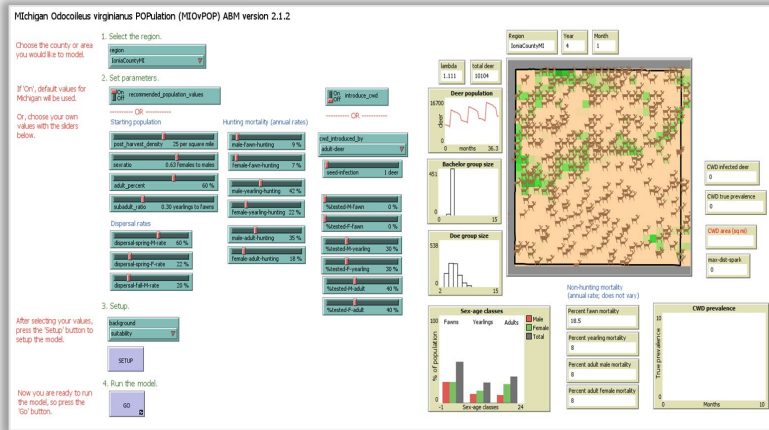
Amplify understanding
and usability of the
model for DNR staff

What does it mean to “run” an ABM?

5. Run the model.

Go

Run Replicates

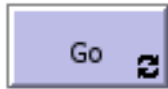


Stochasticity

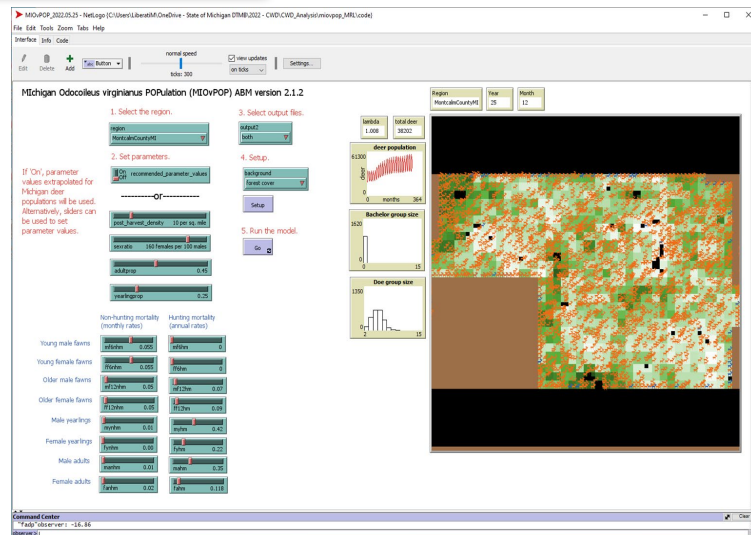


What does it mean to “run” an ABM?

5. Run the model.



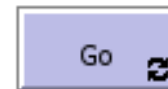
Run
Replicates



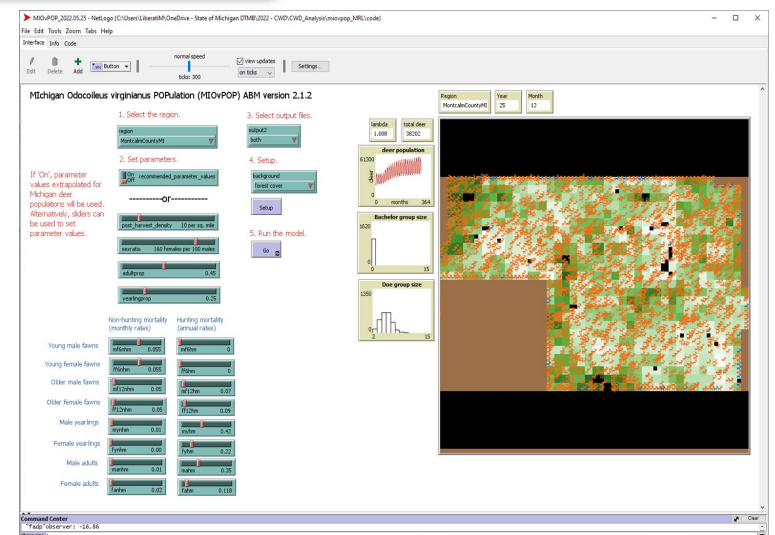
Scenario A
harvest levels

vs.

5. Run the model.



Run
Replicates



Scenario B
harvest levels

Choose the county or area you would like to model.

If 'On', default values for Michigan will be used.

Or, choose your own values with the sliders below.

1. Select the region.

region
IoniaCountyMI

2. Set parameters.

☒ On recommended_population_values

----- OR -----
Starting population

post_harvest_density 25 per square mile
sexratio 0.63 females to males
adult_percent 60 %
subadult_ratio 0.30 yearlings to fawns

Dispersal rates

dispersal-spring-M-rate 60 %
dispersal-spring-F-rate 22 %
dispersal-fall-M-rate 20 %

Hunting mortality (annual rates)

male-fawn-hunting 9 %
female-fawn-hunting 7 %
male-yearling-hunting 42 %
female-yearling-hunting 22 %
male-adult-hunting 35 %
female-adult-hunting 18 %

☒ On introduce_cwd

----- OR -----

cwd_introduced_by
adult-deer
seed-infection 1 deer
%tested-M-fawn 0 %
%tested-F-fawn 0 %
%tested-M-yearling 30 %
%tested-F-yearling 30 %
%tested-M-adult 40 %
%tested-F-adult 40 %

3. Setup.

background
suitability

SETUP

4. Run the model.

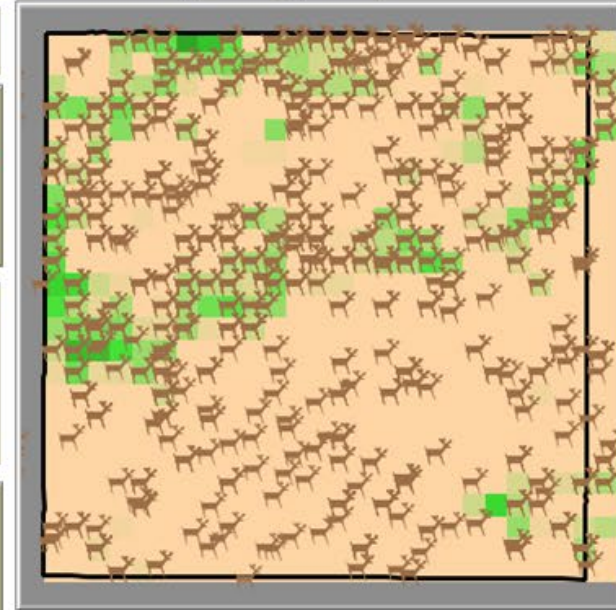
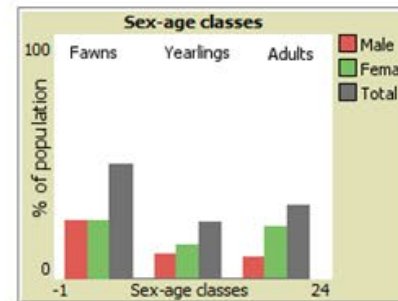
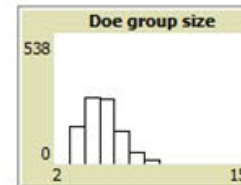
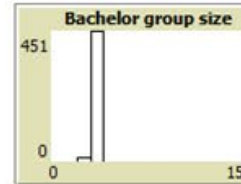
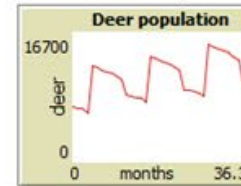
GO

After selecting your values, press the 'Setup' button to setup the model.

Now you are ready to run the model, so press the 'Go' button.

Region
IoniaCountyMI
Year
4
Month
1

lambda
1.111
total deer
10104



CWD infected deer
0

CWD true prevalence
0

CWD area (sq mi)
0

max-dist-spark
0

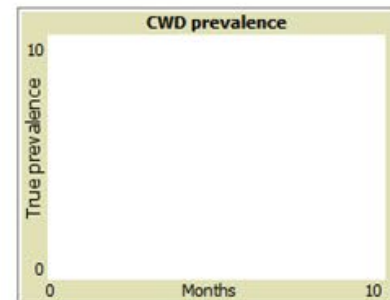
Non-hunting mortality
(annual rate; does not vary)

Percent fawn mortality
18.5

Percent yearling mortality
8

Percent adult male mortality
8

Percent adult female mortality
8



File Edit Tools Zoom

Interface

Info

Code

Population

- Procedures ▾
- ☒ Indent automaticall
- setup

setup-landscape

min-forestcover-percent

max-forestcover-percent

doe-group-size-regulator

juvenile-pregnancy-rate

adult-pregnancy-rate

yearling-male-dispersal-rate

yearling-female-dispersal-rate

mean-female-dispersal-distance

stddev-dispersal-distance

mean-bachelor-group-size

mad

fad

myd

fyd

mfd

ffd

mf

ff

my

fy

ma

fa

go

individual-growth

deer-reproduce

deer-mdisperse

deer-fdisperse

finalize-home-patch

new-group-formation

deer-die

hunting-mortality-mf12

hunting-mortality-ff12

hunting-mortality-my

hunting-mortality-fy

hunting-mortality-ma

hunting-mortality-fa

deer-mating

review-group-dynamics

doe-group-size-regulator

juvenile-pregnancy-rate

adult-pregnancy-rate

yearling-male-dispersal-rate

yearling-female-dispersal-rate

mean-female-dispersal-distance

stddev-dispersal-distance

mean-bachelor-group-size

cwd_area

mf

my

ma

ff

fy

fa

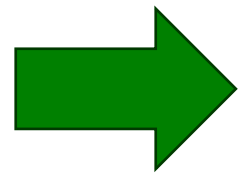
transmission-prob

mcwd

mycwd

CWD

setup	fyd	a1314ffsf	a15mgrb
setup-landscape	ffcwd	a1314fnsmy	a15msb
go	totcwwd	a1314fnsfy	
individual-growth	a3mom	a1314fgrf	
cwd-progression	a3fs	a1314fof	
deer-die-CWD	a3grf	a15fmom	
deer-die	a456mmom	a15fof	
new-group-leader	a456mfs	a15ffsf	
review-bachelor-group	a456mnsmf	a15fgrf	
form-bachelor-groups	a456mnsff	a15fngrf	
deer-mdisperse	a456mgrf	a1618fmom	
deer-fdisperse	a456fmom	a1618fofm	
finalize-home-patch	a456ffs	a1618foff	
fawning	a456fnsmf	a1618ffsf	
deer-reproduce	a456fnsff	a1618fgrf	
new-group-formation	a456fgrf	a1618fngrf	
distance-to-farthest-spark	a78mmom	a1920fmom	
hunting-mortality	a78mfsm	a1920fofm	
hunting-mortality-mf12	a78mfsf	a1920foff	
hunting-mortality-ff12	a78mnsmf	a1920ffsf	
hunting-mortality-my	a78mnsff	a1920fgrf	
hunting-mortality-fy	a78mgrf	a1920fngrf	
hunting-mortality-ma	a78fmom	a2124fmom	
hunting-mortality-fa	a78ffsm	a2124fofm	
deer-mating	a78ffsf	a2124foff	
review-group-dynamics	a78fnsmf	a2124ffsf	
doe-group-size-regulator	a78fnsff	a2124fgrf	
juvenile-pregnancy-rate	a78fgrf	a2124fngrf	
adult-pregnancy-rate	a912mmom	a2526ffsf	
yearling-male-dispersal-rate	a912mfsm	a2526fgrf	
yearling-female-dispersal-rate	a912mfsf	a2526fmy	
mean-female-dispersal-distance	a912mnsmf	a2526fof	
stddev-dispersal-distance	a912mnsff	a27fd4mom	
mean-bachelor-group-size	a912mgrf	a27fd10mom	
cwd_area	a912fmom	a27fd12mom	
mf	a912ffsm	a27fd4ofm	
my	a912ffsf	a27fd7ofm	
ma	a912fnsmf	a27fd10ofm	
ff	a912fnsff	a27fd12ofm	
fy	a912fgrf	a27fd4off	
fa	a912fngrf	a27fd7off	
transmission-prob	a1314mfsm	a27fd10off	
mcwd	a1314mfsf	a27fd12off	
mycwd	a1314mnsmy	a27fd10grf	
	a1314mnsfy	a27fd12grf	



- Procedures ▾
- ☒ Indent automaticall
- setup-model-parameters

setup-landscape

setup-deer-population

setup-files

setup

go

individual-growth

nonhunting-mortality

hunting-mortality

deer-reproduce

fawns-per-doe

dispersal-spring

dispersal-fall

emigrate

update-doe-group-info

doe-group-leader

form-bachelor-groups

census

lambda-output

groupedbarplot

cwd-introduced

cwd-transmission

interact-mom

interact-siblings

interact-cohort

interact-group.members.female

interact-group.members.male

interact-neighbors

interact-my.fawns

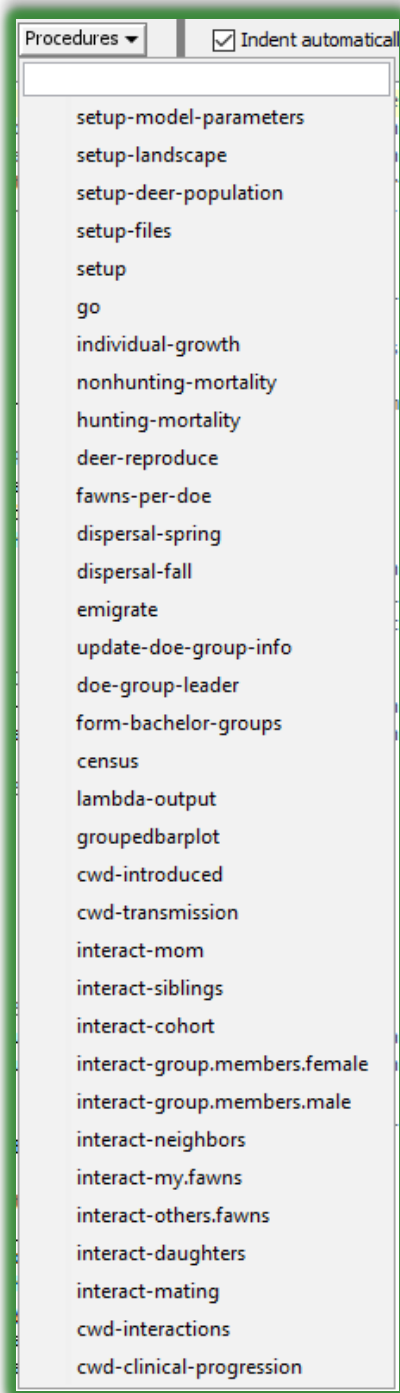
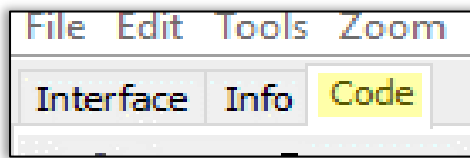
interact-others.fawns

interact-daughters

interact-mating

cwd-interactions

cwd-clinical-progression



Remove redundancies

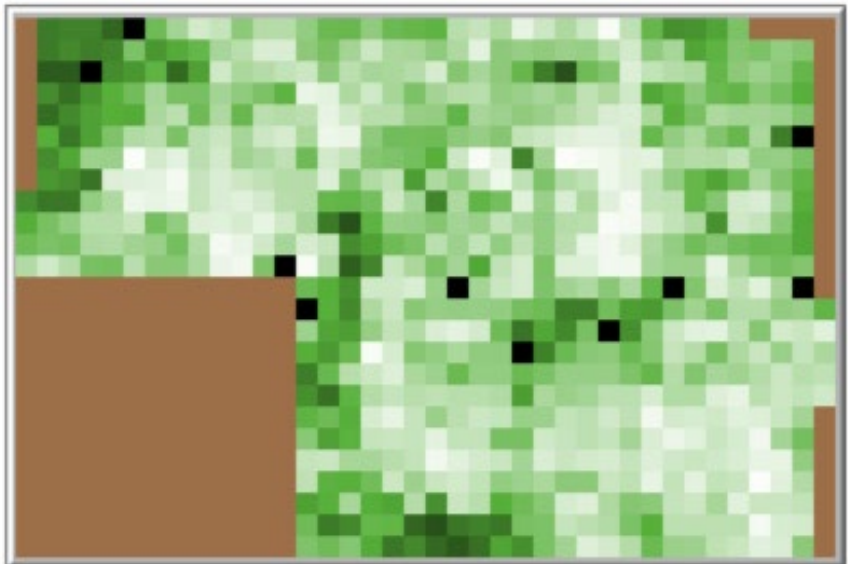
**Simplified workflow
reduces possible bugs**

New decision-rules:

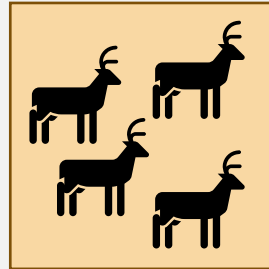
Environmental transmission

All potential deer
interactions that could lead
to disease transmission

Landscape



Individuals (Agents)

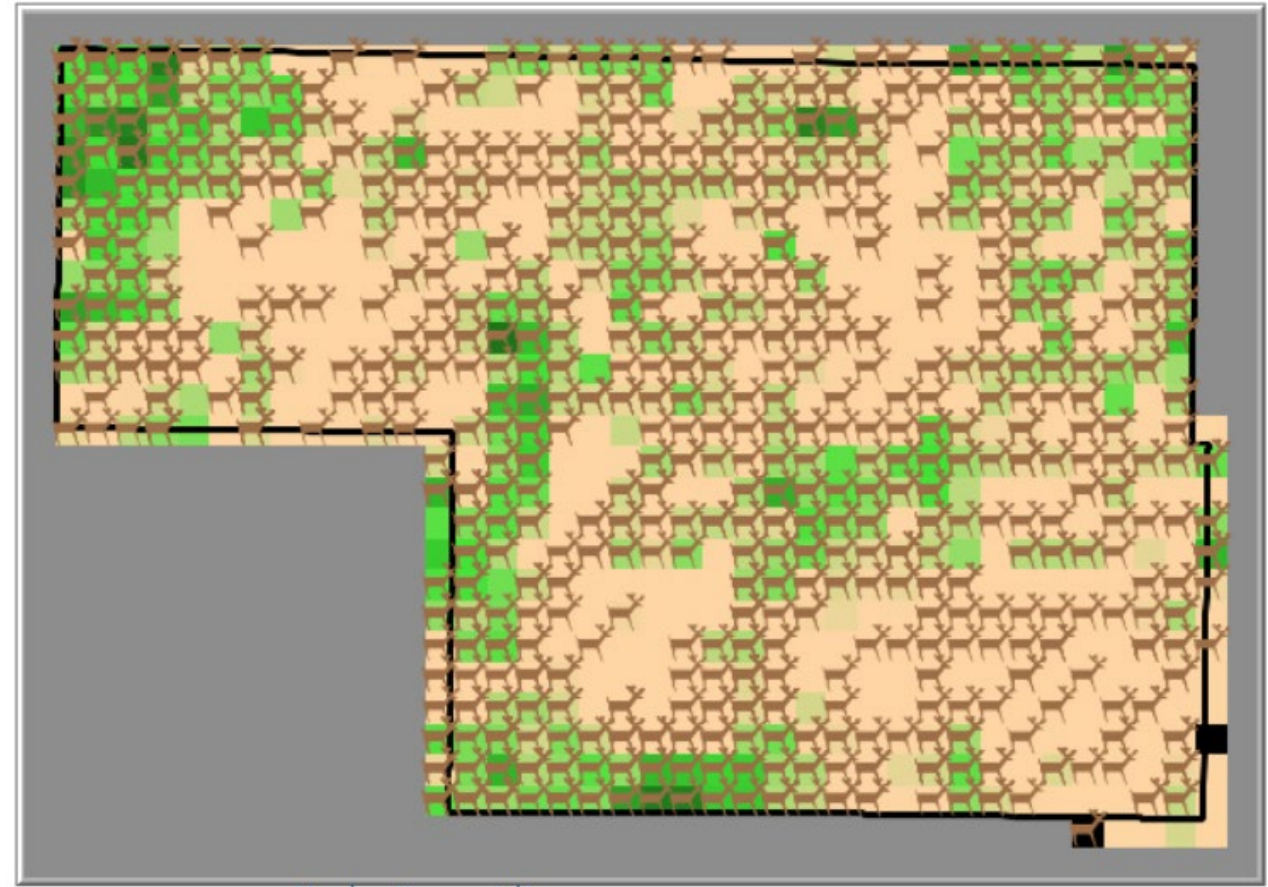


Decision-making Rules (Procedures)

Aging
Reproduction
Dispersal
Natural mortality
Hunter harvest
Disease transmission
Etc.

Landscape

- 2016 National Land Cover Database (NLCD) Tree Canopy
- 1 pixel (patch) = 1 sq mile
- Habitat suitability
 - Ideal habitat = 25-100% forest cover
 - Darker squares = Higher % forest cover

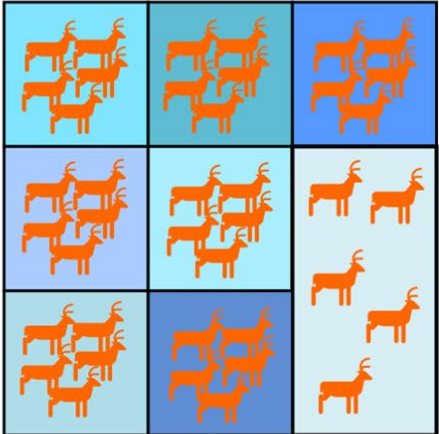
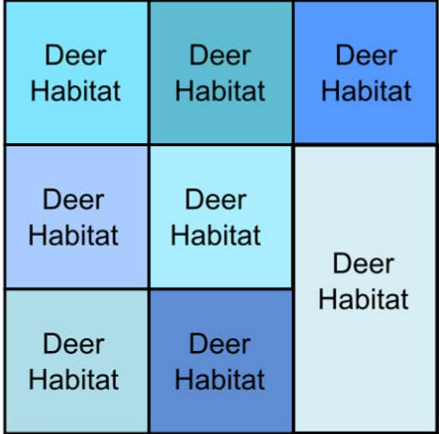
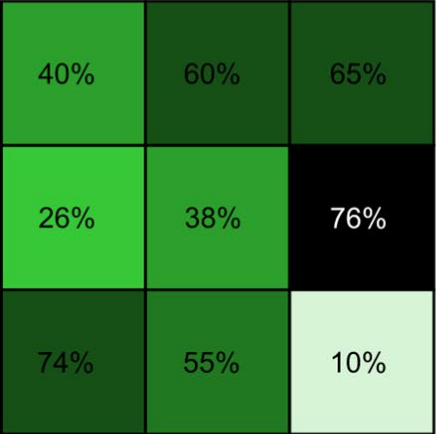


Adding Individual Agents

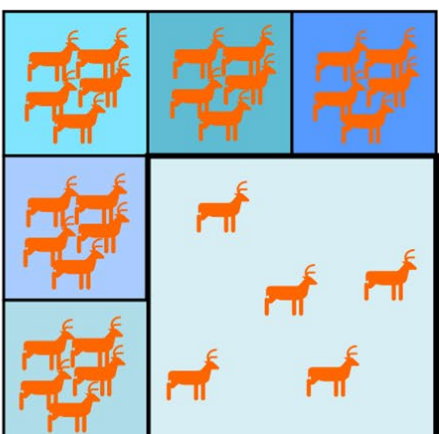
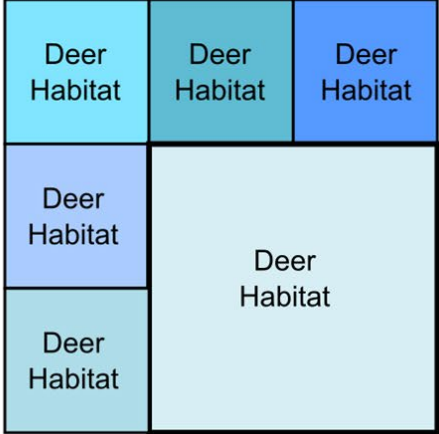
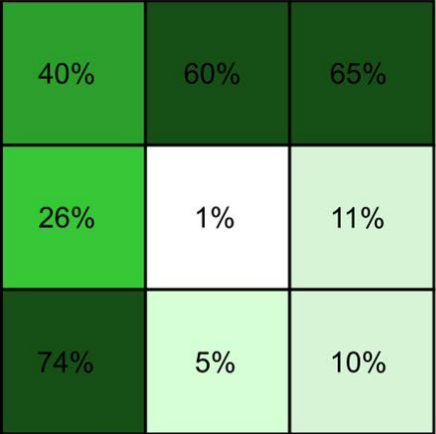
Deer added to habitat patches based on:

- 1. Percent forest cover
- 2. User-defined deer density

Percent Forest Cover



Percent Forest Cover



Decision Making Rules

(Procedures)

- County/Region of interest
- Starting population
 - Deer density
 - Sex ratio (females:male)
 - Adult proportion
 - Sub-adult proportion
- Dispersal rates
- Hunting mortality (sex-age specific)
- **CWD introduction**
 - **Number of deer initially infected**
 - **Sex-age of deer introducing CWD**
- **CWD testing rates**

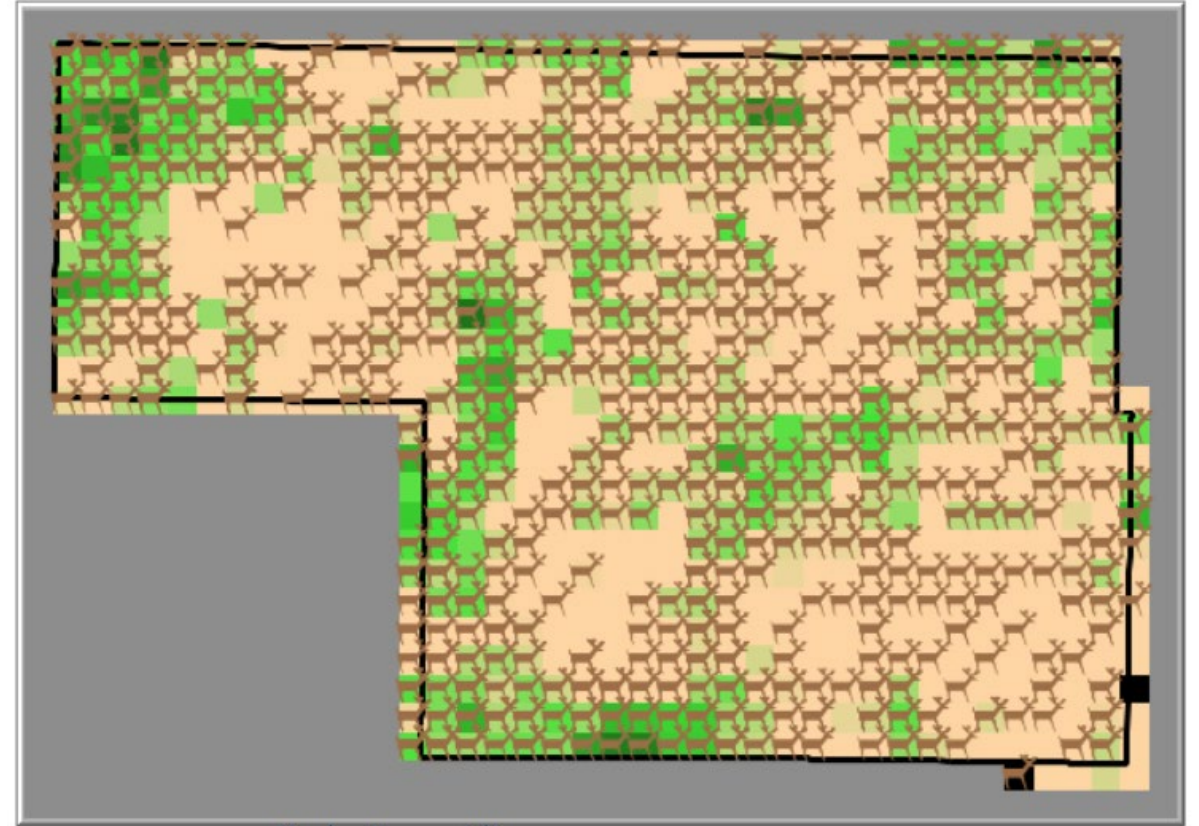
Specified in Interface

- Non-hunting mortality (sex-age specific)
- Doe and bachelor group dynamics
- Pregnancy rates (age specific)
- **CWD transmission probability**
- **Clinical disease progression**
- **Matrix the describes interactions between individuals (age-sex-group disease transmission)**

Specified in Code

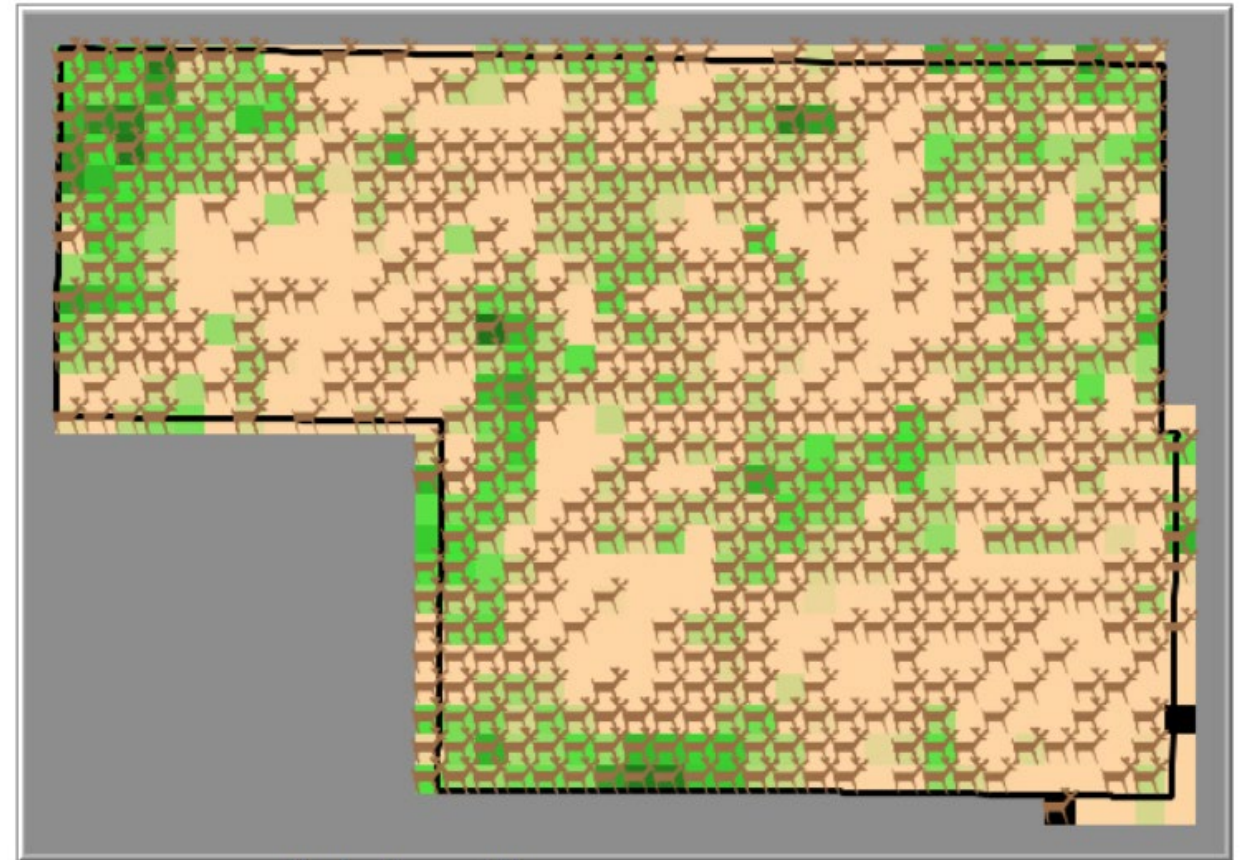
Decision-Rule Parameters

- Each parameter has a default, starting value
- Can adjust parameters
 - Reflect a landscape of interest
 - Explore how the system responds to different parameter levels
 - Test ecological expectations of the system



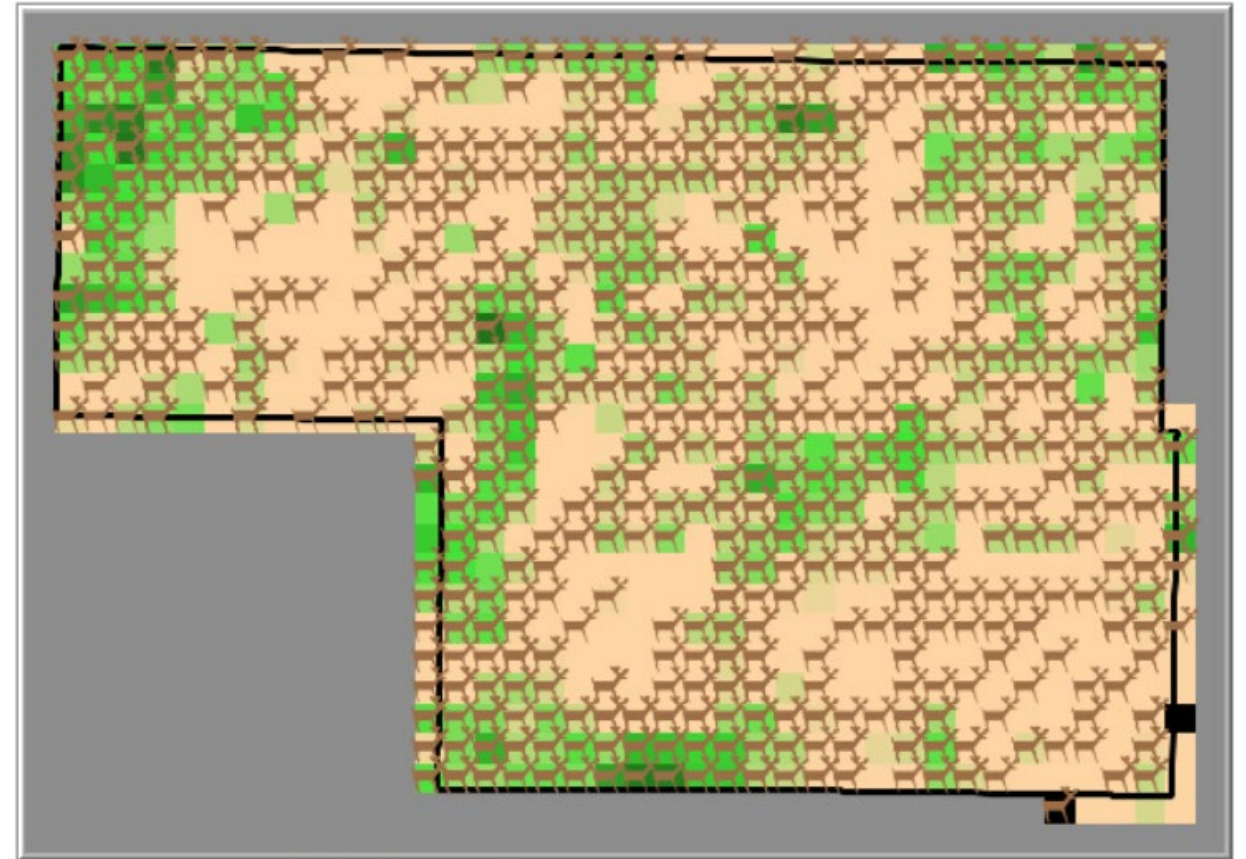
Decision-Rule Parameters: Deer Ecology

Variable	Default value
Post harvest density	25 per sqmi
Sex ratio (females to males)	0.63
Adult percentage	60%
Subadult-ratio (yearlings to fawns)	0.3
Spring yearling male dispersal rate	60%
Spring yearling female dispersal rate	22%
Fall yearling male dispersal rate	20%
Fawn, 0-6 mo	0.025
Fawn, 7-12 mo	0.02
Yearling, 12-24 mo	0.01
Adult male, >24 mo	0.01
Adult female, >24 mo	0.01



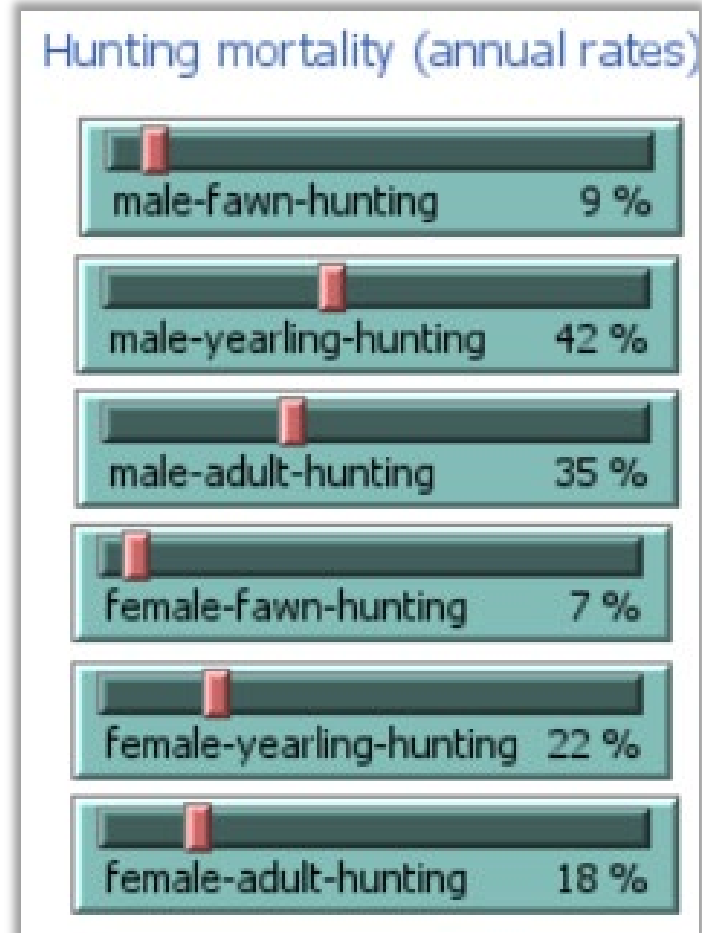
Decision-Rule Parameters: CWD

Variable	Default value
Transmission probability	0.0128 per interactions
Infectious stage maximum start	10 mo
Clinical stage minimum start	15 mo
Clinical stage maximum start	26 mo
Clinical phase length	2 mo
Male adult testing probability	41%
Female adult testing probability	37%



Decision-Rules Parameters: Harvest rates

Variable	Default harvest rates (% population harvested annually)
Male fawn, 1-12 mo	9%
Male yearling, 13-24 mo	42%
Male adult, >24 mo	35%
Female fawn, 1-12 mo	7%
Female yearling, 13-24 mo	22%
Female adult, >24 mo	18%



Model Scenarios

Harvest Examples

- Parameters
 - Adult male harvest – 25%, 30%, 35%
 - Yearling male harvest – 35%, 40%, 45%
 - Introduced CWD – Yes, No
- 18 Scenarios – every combination of parameter values
- Opportunities for future scenarios and parameter levels to incorporate data from ongoing studies (e.g., APR)

Adult harvest	Yearling harvest	CWD introduced	SCENARIO
A-25%	Y-35%	CWD-True	A25-Y35-cwdTRUE
A-25%	Y-35%	CWD-False	A25-Y35-cwdFALSE
A-25%	Y-40%	CWD-True	A25-Y40-cwdTRUE
A-25%	Y-40%	CWD-False	A25-Y40-cwdFALSE
A-25%	Y-45%	CWD-True	A25-Y45-cwdTRUE
A-25%	Y-45%	CWD-False	A25-Y45-cwdFALSE
A-30%	Y-35%	CWD-True	A30-Y35-cwdTRUE
A-30%	Y-35%	CWD-False	A30-Y35-cwdFALSE
A-30%	Y-40%	CWD-True	A30-Y40-cwdTRUE
A-30%	Y-40%	CWD-False	A30-Y40-cwdFALSE
A-30%	Y-45%	CWD-True	A30-Y45-cwdTRUE
A-30%	Y-45%	CWD-False	A30-Y45-cwdFALSE
A-35%	Y-35%	CWD-True	A35-Y35-cwdTRUE
A-35%	Y-35%	CWD-False	A35-Y35-cwdFALSE
A-35%	Y-40%	CWD-True	A35-Y40-cwdTRUE
A-35%	Y-40%	CWD-False	A35-Y40-cwdFALSE
A-35%	Y-45%	CWD-True	A35-Y45-cwdTRUE
A-35%	Y-45%	CWD-False	A35-Y45-cwdFALSE

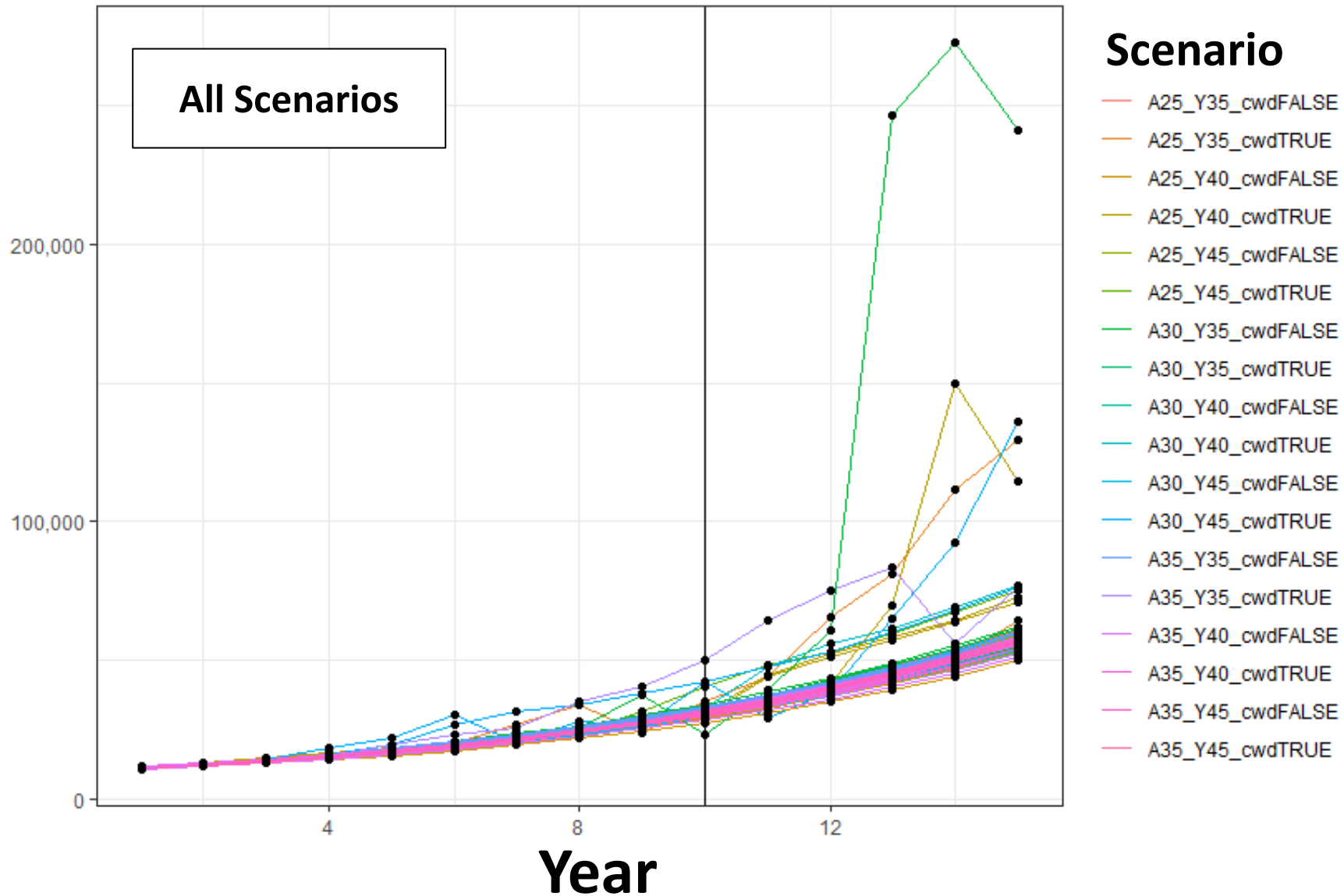
Model Runs

Harvest Examples

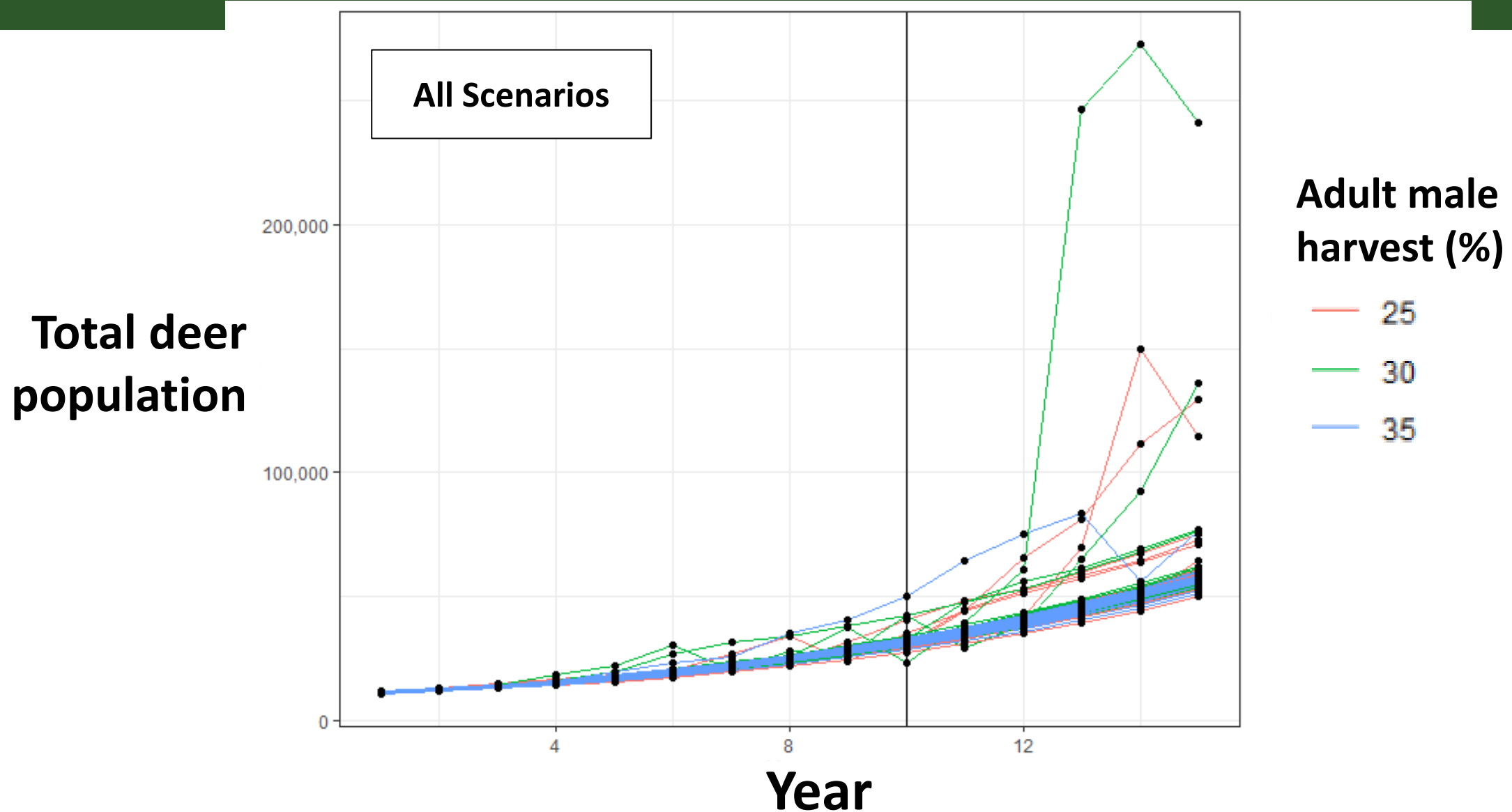
- Replicates = 10 per scenario
(NOTE: Need to increase the number of replicates given the complexity of this model)
- Model run for 15 years per replicate
 - Population simulated for 10 years before CWD introduced
 - Model population with CWD for 5 years

Adult harvest	Yearling harvest	CWD introduced	SCENARIO
A-25%	Y-35%	CWD-True	A25-Y35-cwdTRUE
A-25%	Y-35%	CWD-False	A25-Y35-cwdFALSE
A-25%	Y-40%	CWD-True	A25-Y40-cwdTRUE
A-25%	Y-40%	CWD-False	A25-Y40-cwdFALSE
A-25%	Y-45%	CWD-True	A25-Y45-cwdTRUE
A-25%	Y-45%	CWD-False	A25-Y45-cwdFALSE
A-30%	Y-35%	CWD-True	A30-Y35-cwdTRUE
A-30%	Y-35%	CWD-False	A30-Y35-cwdFALSE
A-30%	Y-40%	CWD-True	A30-Y40-cwdTRUE
A-30%	Y-40%	CWD-False	A30-Y40-cwdFALSE
A-30%	Y-45%	CWD-True	A30-Y45-cwdTRUE
A-30%	Y-45%	CWD-False	A30-Y45-cwdFALSE
A-35%	Y-35%	CWD-True	A35-Y35-cwdTRUE
A-35%	Y-35%	CWD-False	A35-Y35-cwdFALSE
A-35%	Y-40%	CWD-True	A35-Y40-cwdTRUE
A-35%	Y-40%	CWD-False	A35-Y40-cwdFALSE
A-35%	Y-45%	CWD-True	A35-Y45-cwdTRUE
A-35%	Y-45%	CWD-False	A35-Y45-cwdFALSE

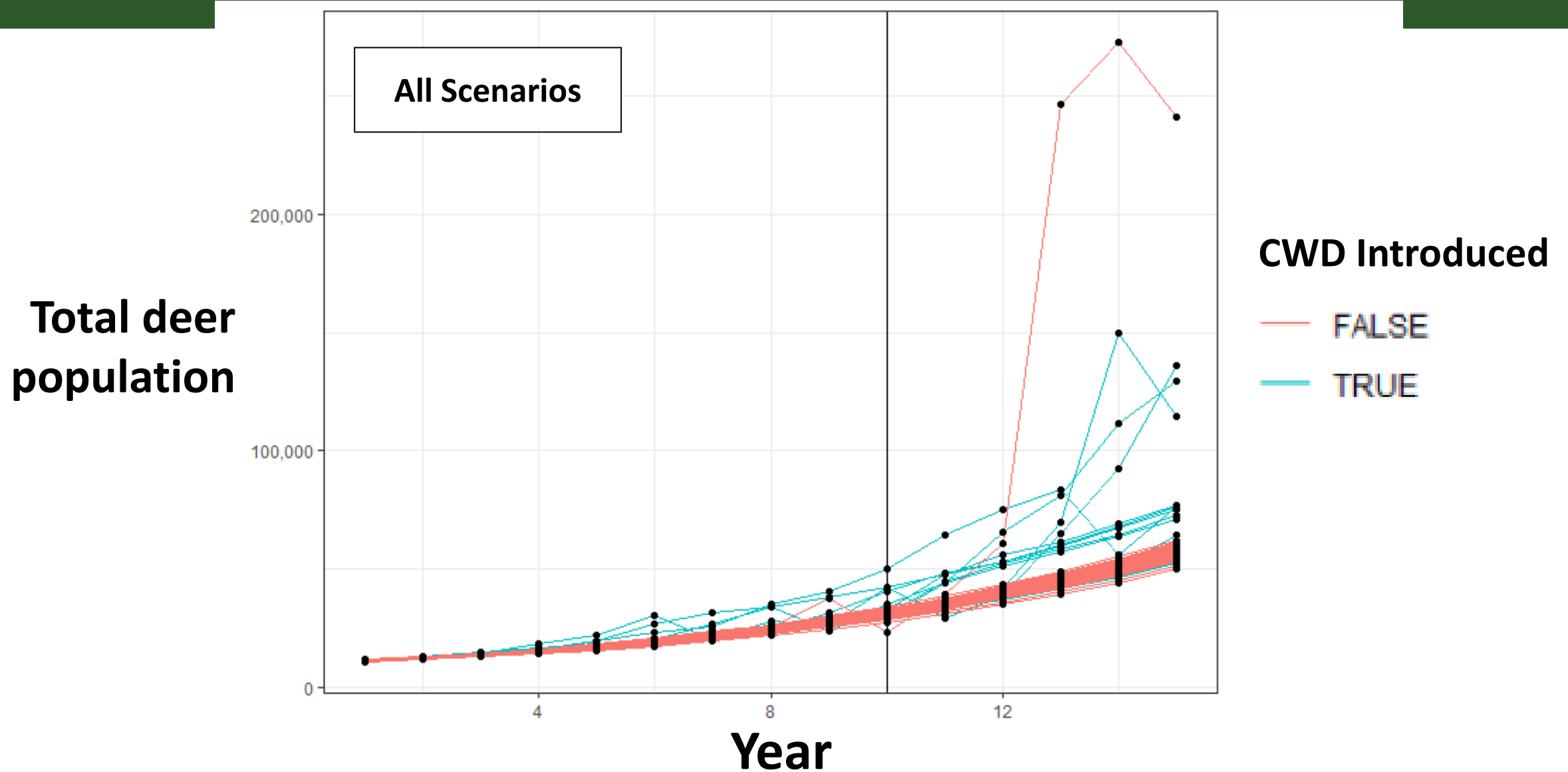
Preliminary Simulations: Deer population



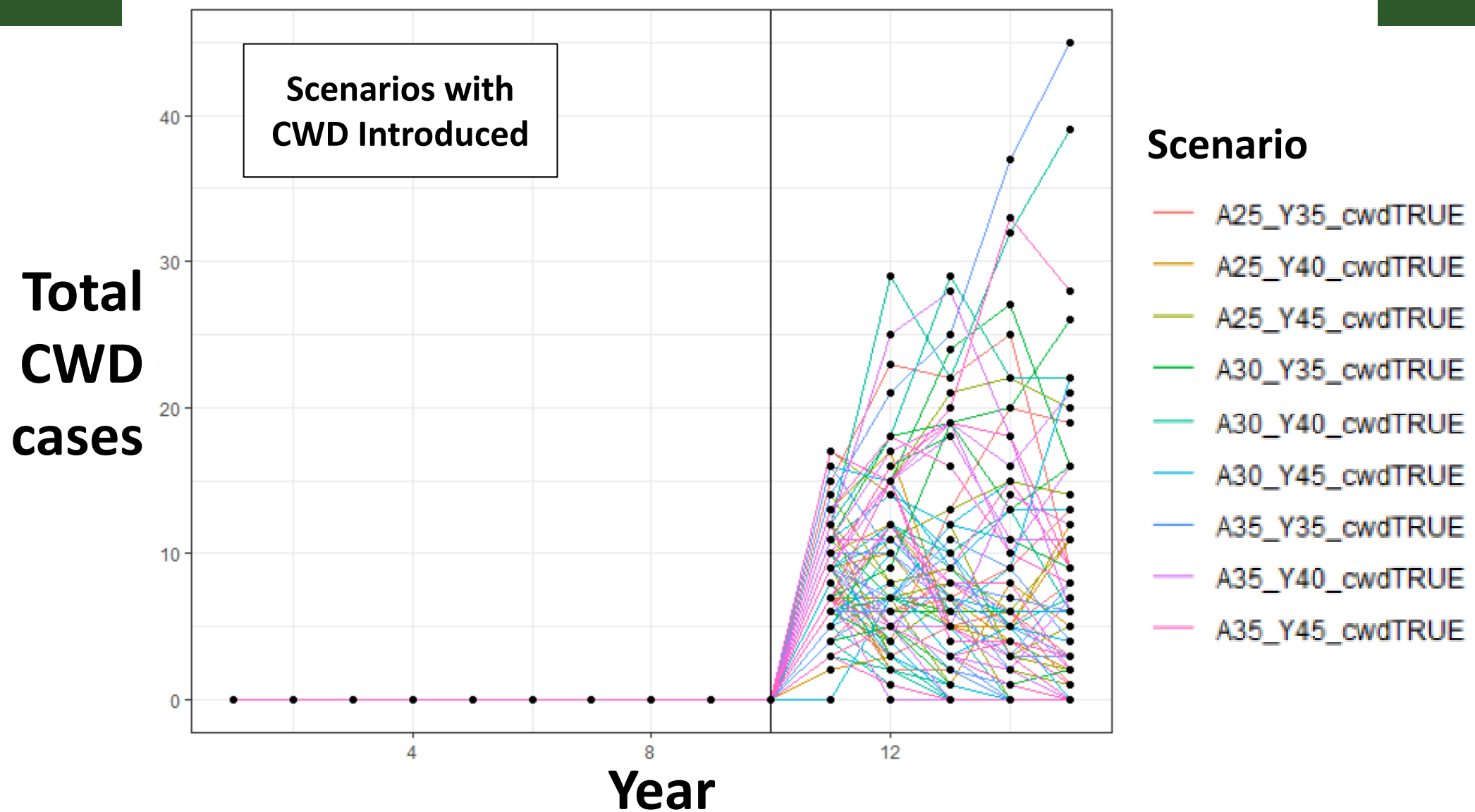
Preliminary Simulations: Deer population



Preliminary Simulations: Deer population

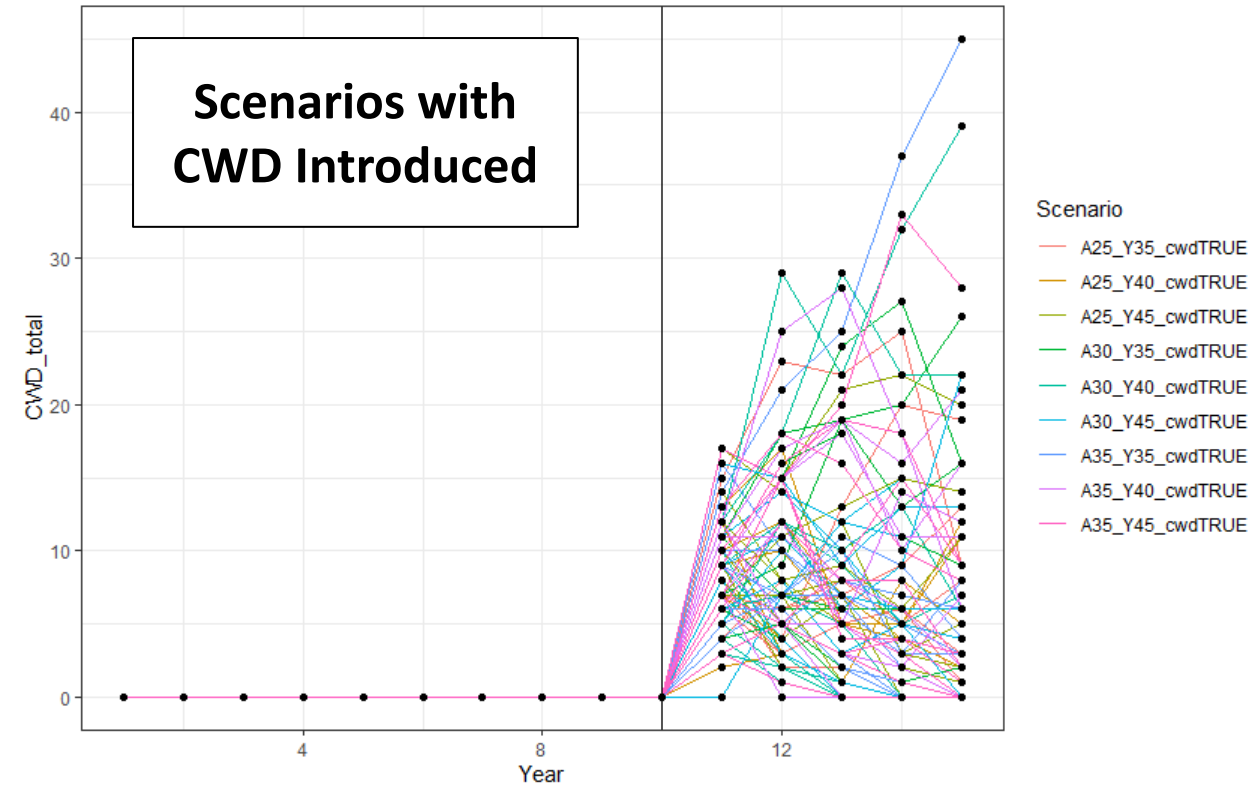


Preliminary Simulations: CWD cases



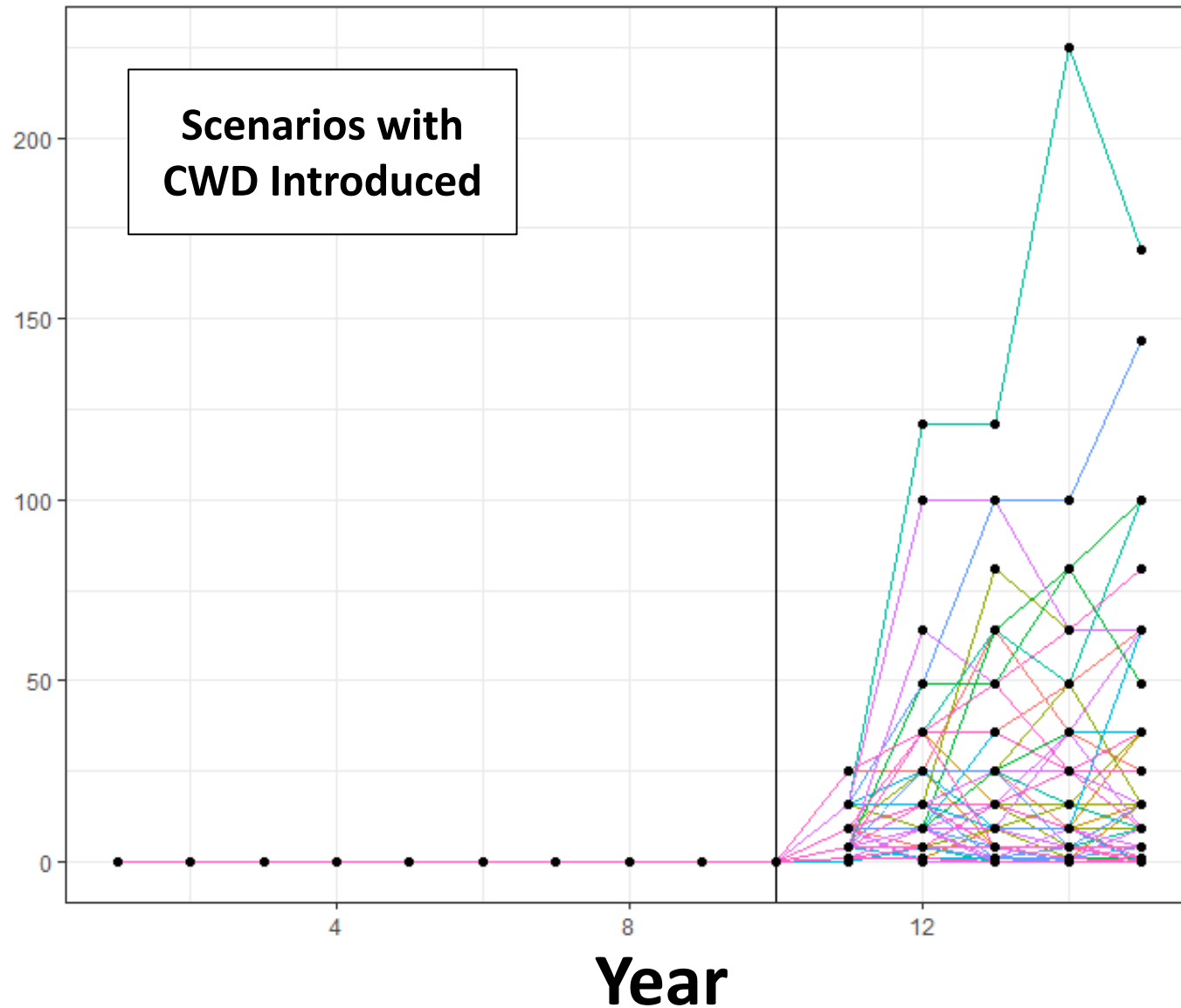
Preliminary Simulations: CWD cases

Scenario (CWD introduced)	Min CWD+ cases	Max CWD+ cases	Median CWD+ cases
Adult 25%, Yearling 35%	0	19	3
Adult 25%, Yearling 40%	0	12	1
Adult 25%, Yearling 45%	0	20	3.5
Adult 30%, Yearling 35%	0	26	2.5
Adult 30%, Yearling 40%	0	39	0
Adult 30%, Yearling 45%	0	22	5
Adult 35%, Yearling 35%	0	45	3
Adult 35%, Yearling 40%	0	21	6.5
Adult 35%, Yearling 45%	0	28	2.5



Preliminary Simulations: CWD area

**CWD
area**

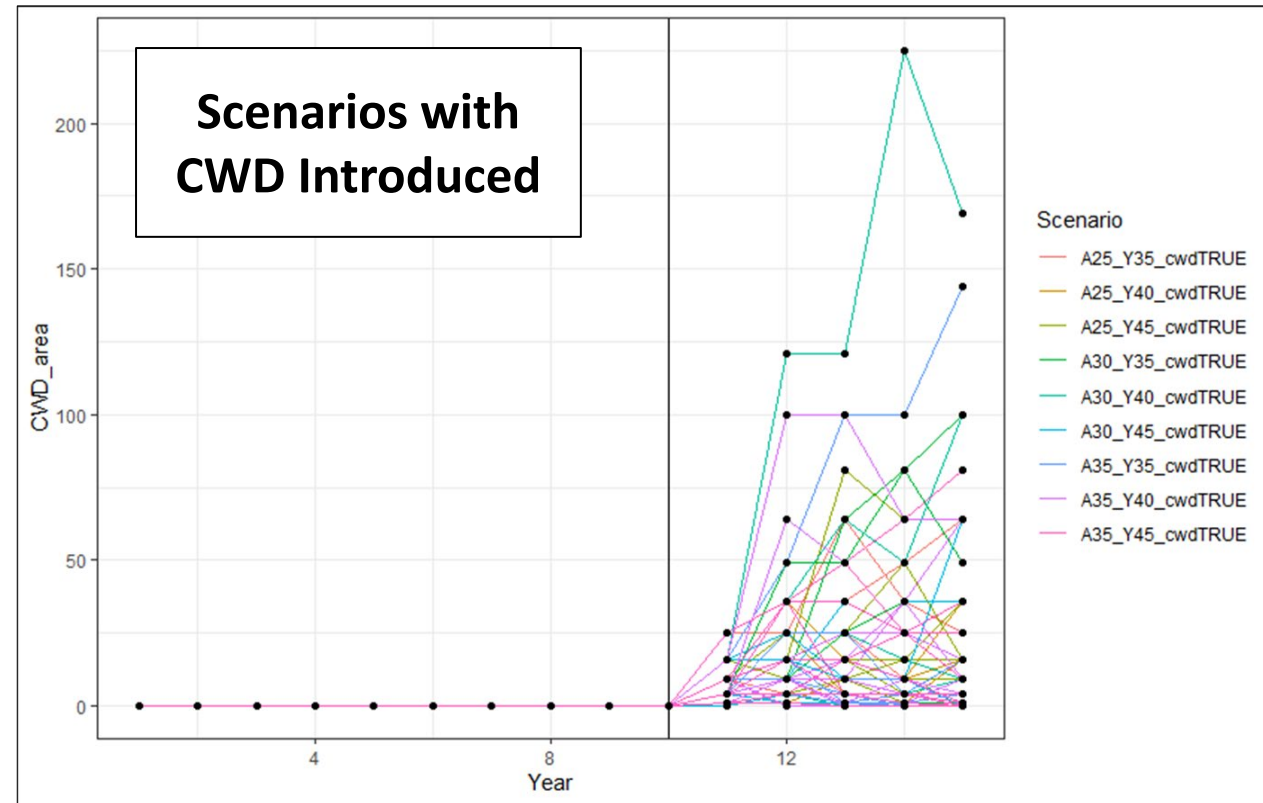


Scenario

- A25_Y35_cwdTRUE
- A25_Y40_cwdTRUE
- A25_Y45_cwdTRUE
- A30_Y35_cwdTRUE
- A30_Y40_cwdTRUE
- A30_Y45_cwdTRUE
- A35_Y35_cwdTRUE
- A35_Y40_cwdTRUE
- A35_Y45_cwdTRUE

Preliminary Simulations: CWD area

Scenario (CWD introduced)	Min area	Max area	Median area
Adult 25%, Yearling 35%	0	65	9
Adult 25%, Yearling 40%	0	36	2
Adult 25%, Yearling 45%	0	81	6.5
Adult 30%, Yearling 35%	0	100	4
Adult 30%, Yearling 40%	0	169	0
Adult 30%, Yearling 45%	0	64	4
Adult 35%, Yearling 35%	0	144	1
Adult 35%, Yearling 40%	0	64	9
Adult 35%, Yearling 45%	0	81	2.5



Model Scenario Opportunities

- Adjust parameters

- Reflect a landscape of interest
- Explore how the system responds to different parameter levels
- Test ecological expectations of the system



Integrate data and understanding gained from ongoing projects (e.g., APR study)



Test expectations under different harvest and deer management strategies