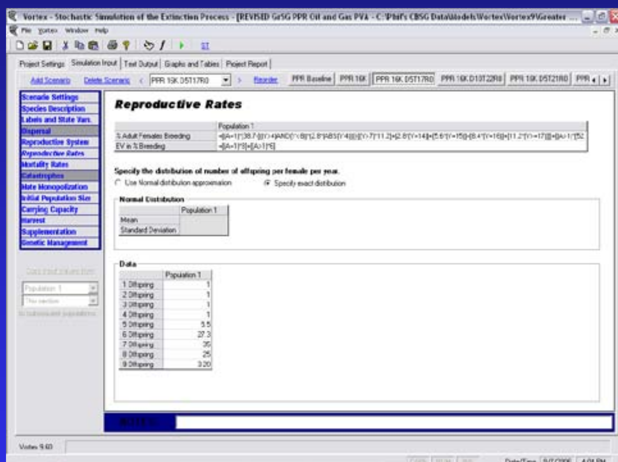
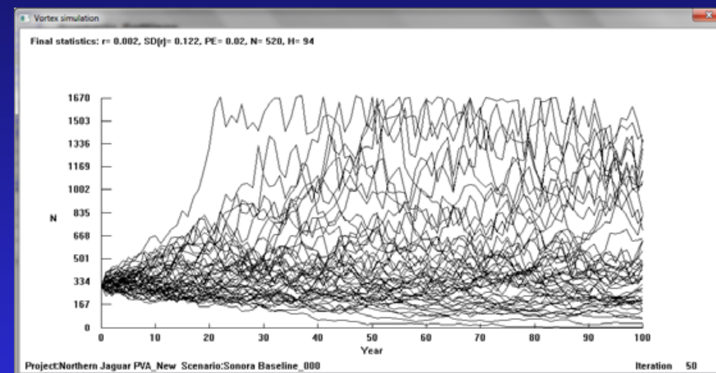
Computer Simulation as a Tool to Evaluate FRC Population Dynamics





Phil Miller

Conservation Breeding Specialist Group
(IUCN / SSC)
www.cbsg.org

Complexity in Endangered Species Management

- Can we identify optimal water management strategies throughout the Middle Rio Grande River so that local economic and social needs are met without further endangering the resident Rio Grande silvery minnow and Southwest Willow Flycatcher?

Complexity in Endangered Species Management

- Can we identify appropriate strategies for reintroducing viable populations of scimitar-horned oryx across multiple countries throughout Sahelo-Saharan Africa, where habitat quality has been degraded through intensive agricultural activity?

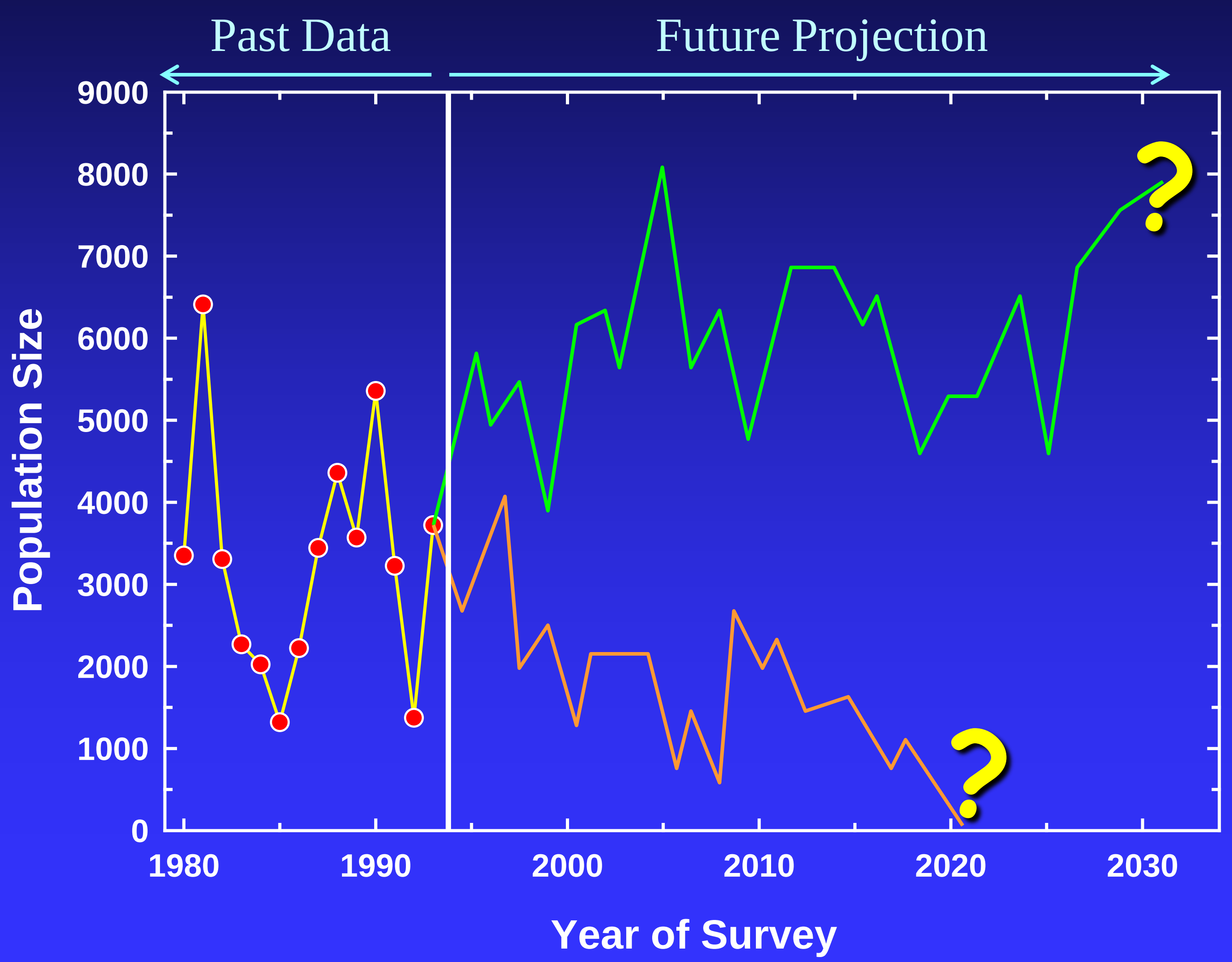
Complexity in Endangered Species Management

- How do we reconstruct a functional network of small, isolated populations of African wild dogs across a human-dominated landscape?

Complexity in Endangered Species Management

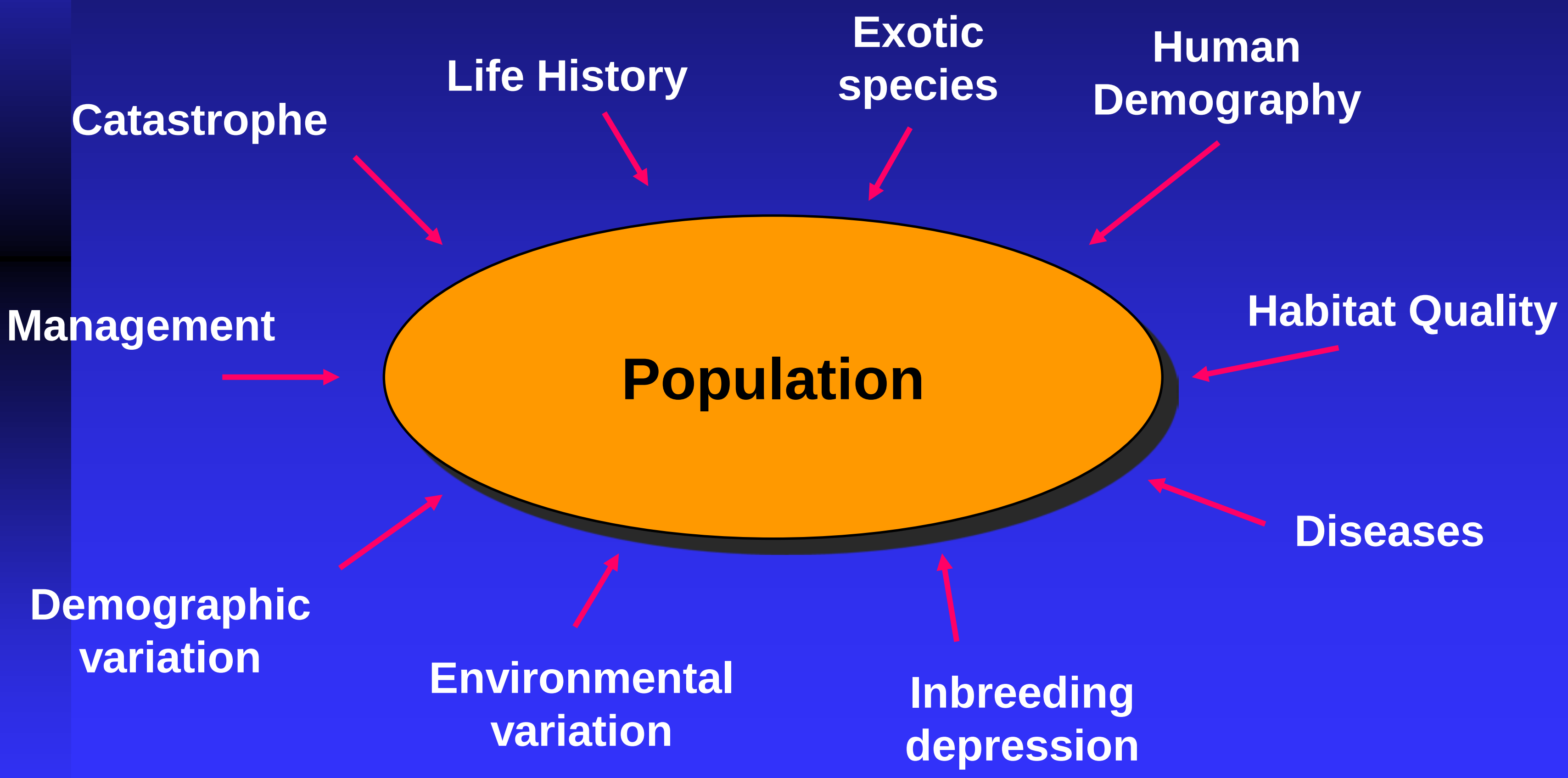
- How does sustained hunting pressure by local human populations impact long-term viability of North American polar bear populations in the face of increased climatic instability?

What Might the Future Bring?

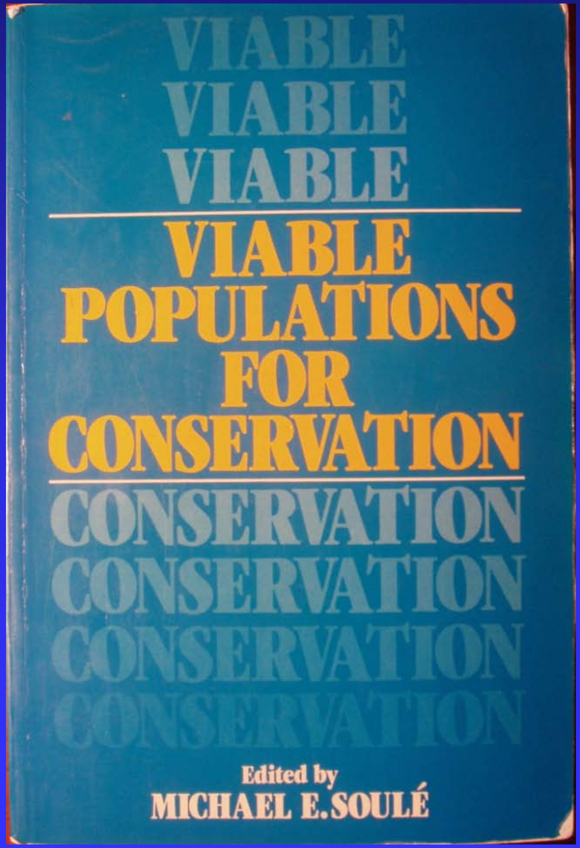


Population Viability Analysis – PVA

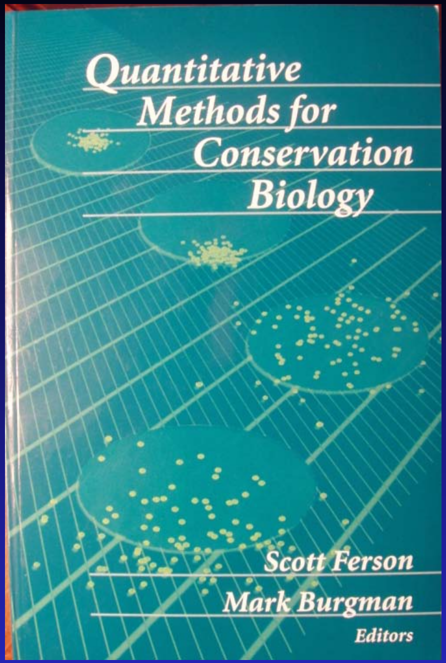
The Process of Evaluating the Interacting Factors Affecting Population Extinction Risk



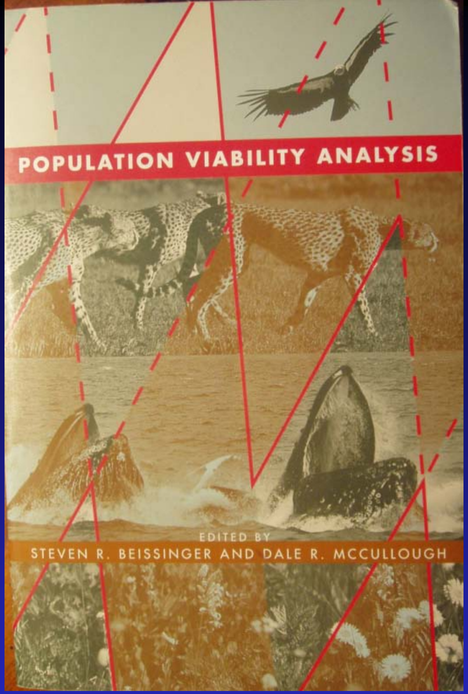
The Science of PVA



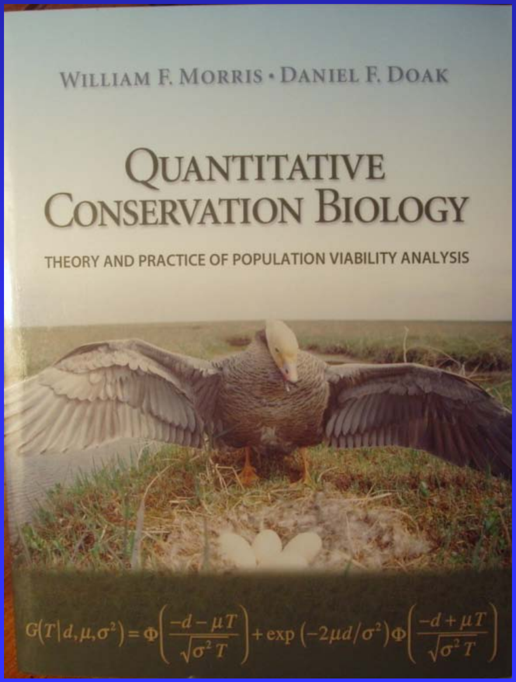
1987



2000



2002



2002

An Analytical Approach to PVA

Mean Time to Extinction, MTE:

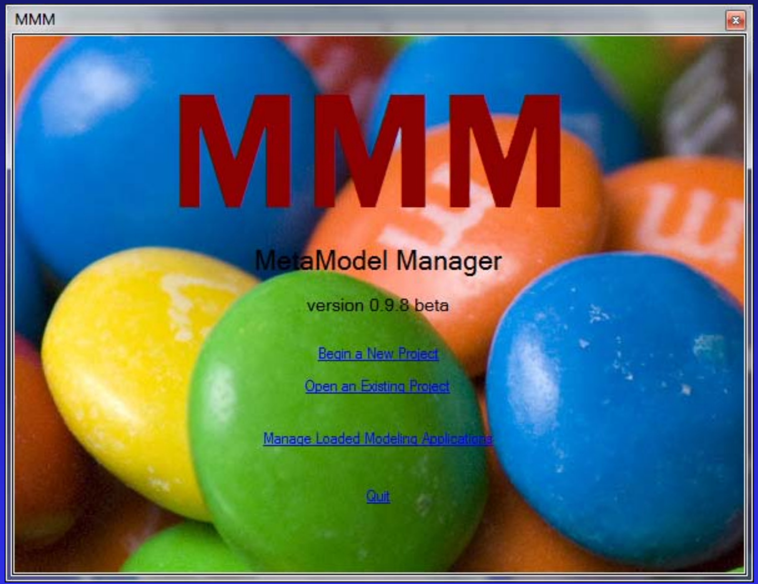
$$\text{MTE} = \sum_{x=1}^{N} \sum_{y=x}^{K} \frac{2}{y(yV_y - r_z)} \prod_{z=x}^{y-1} \frac{zV_z + r_z}{zV_z - r_z}$$

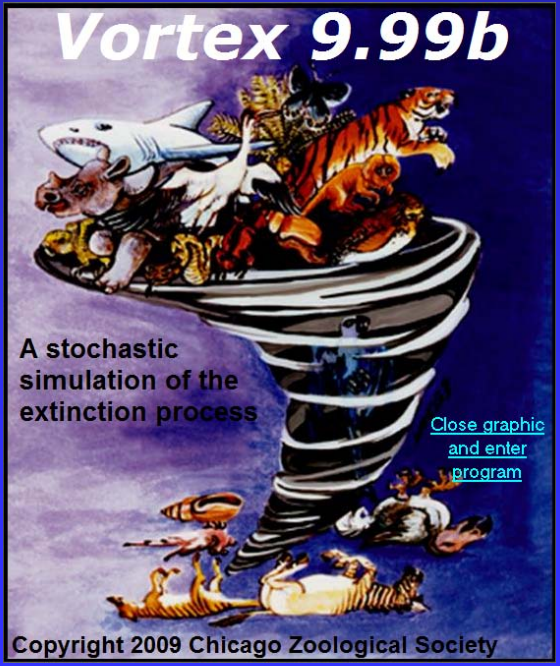
***From*: Goodman, 1987**

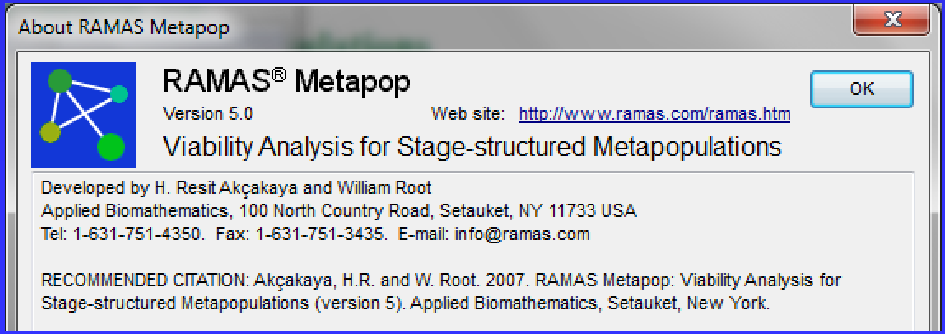
where
***r* = mean exponential growth rate**
V* = variance in *r
***N* = initial population size**
***K* = carrying capacity**

But this approach remains simplistic – little to no ability to tease apart the many factors that collectively determine and influence the population growth rate and its variability over time.

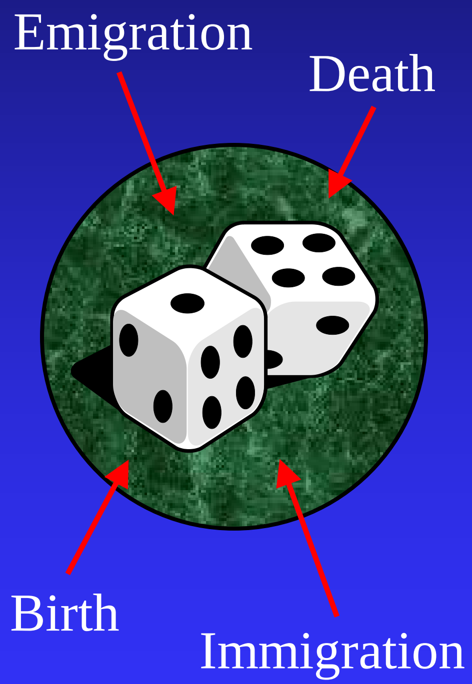
A Complementary Alternative: Computer Simulation







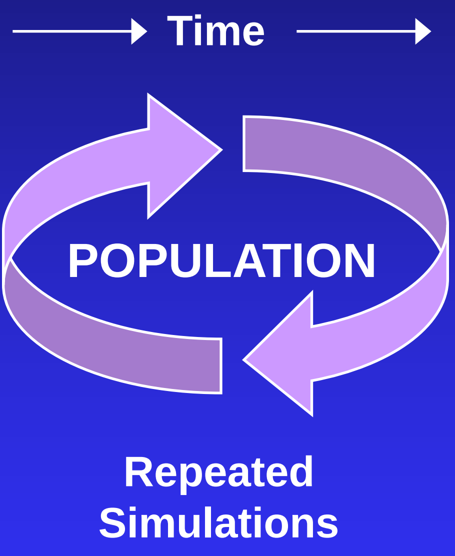
What is a Simulation Model?



- A simulation model is designed to follow, step by step, the essential elements of an animal population in the real world.
- A <u>stochastic</u> simulation incorporates the uncertainty and unpredictability of biological events in an attempt to recreate the natural world.

The Mechanics of Population Dynamics Simulation Models

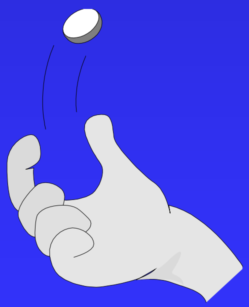
Life History
Age Structure
Inbreeding Depression
Environmental Variation
Carrying Capacity
Density Dependence
Catastrophes
Threats



Population Size
Growth Rate
Extinction Probability
Genetic Diversity

Stochastic Simulation Models

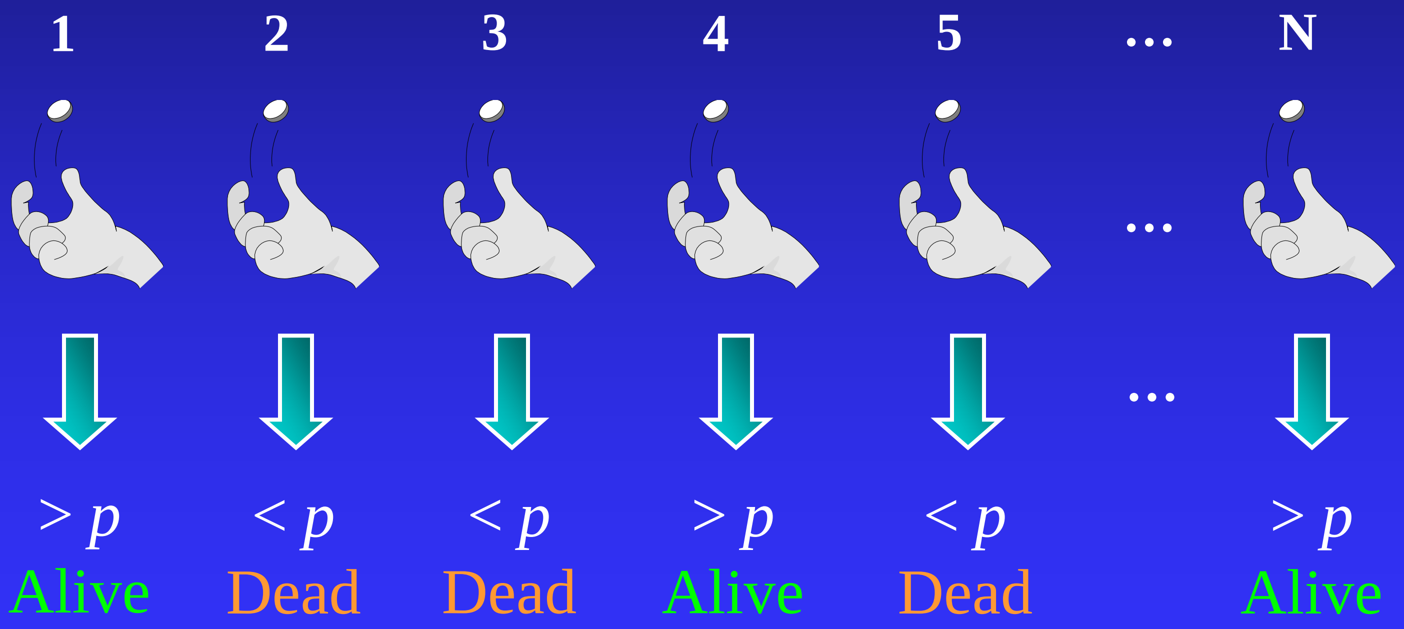
- Individual-based computer simulation uses a type of "coin-flipping" technique to determine the fate of individuals within populations at each time step (year, 6 months, day, etc.).
- Because of stochasticity in this process, different "runs" of the model will yield different results.



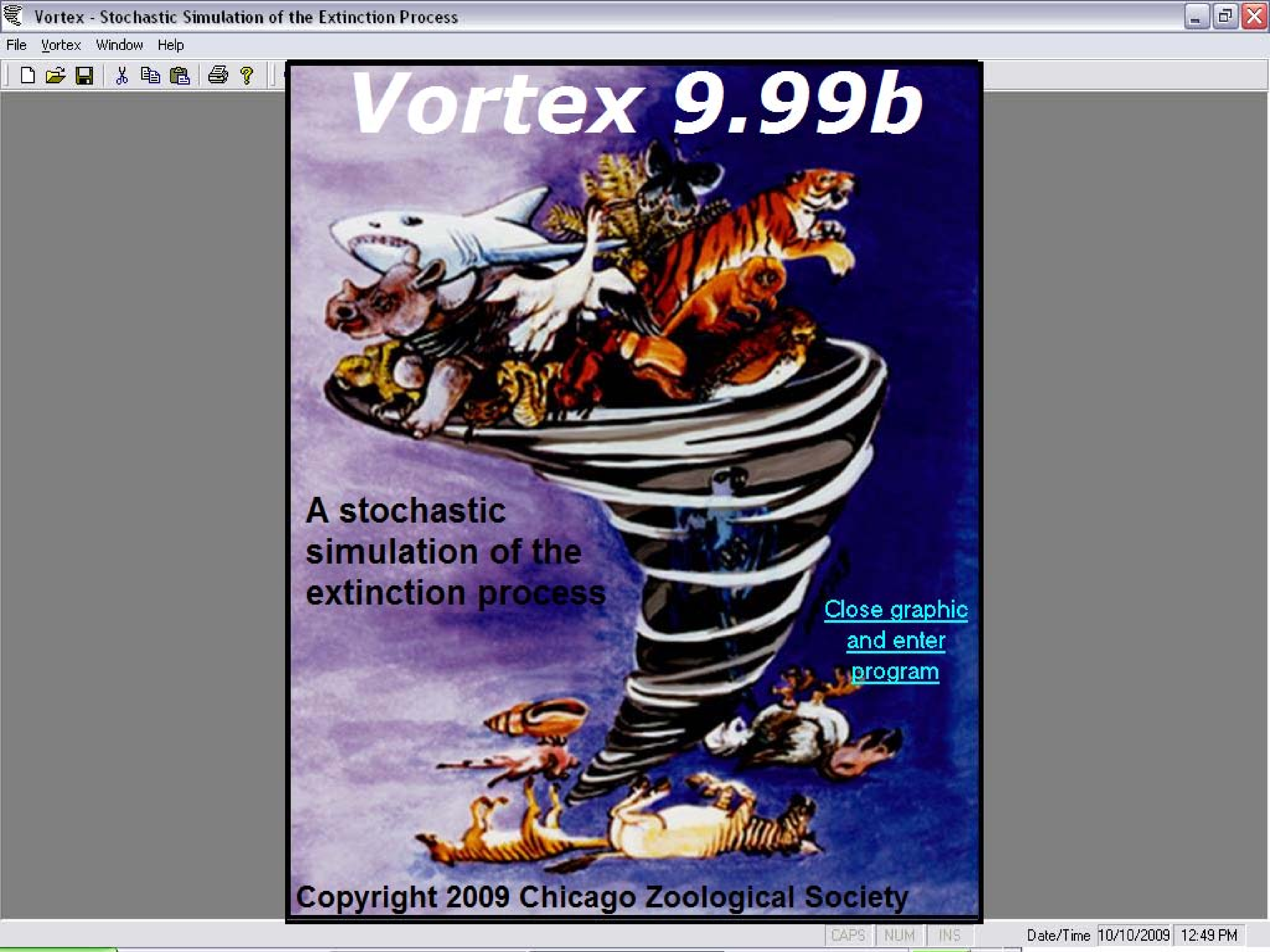
Stochastic Simulation Models

The Stochastic Nature of Mortality

Population size in year X = N_x; probability of death = p



Population size in year X + 1 = N_x – Dead = N_{X+1}


Vortex - Stochastic Simulation of the Extinction Process
File
Vortex
Window
Help
Vortex 9.99b
A stochastic simulation of the extinction process
Close graphic and enter program
Copyright 2009 Chicago Zoological Society
CAPS
NUM
INS
Date/Time
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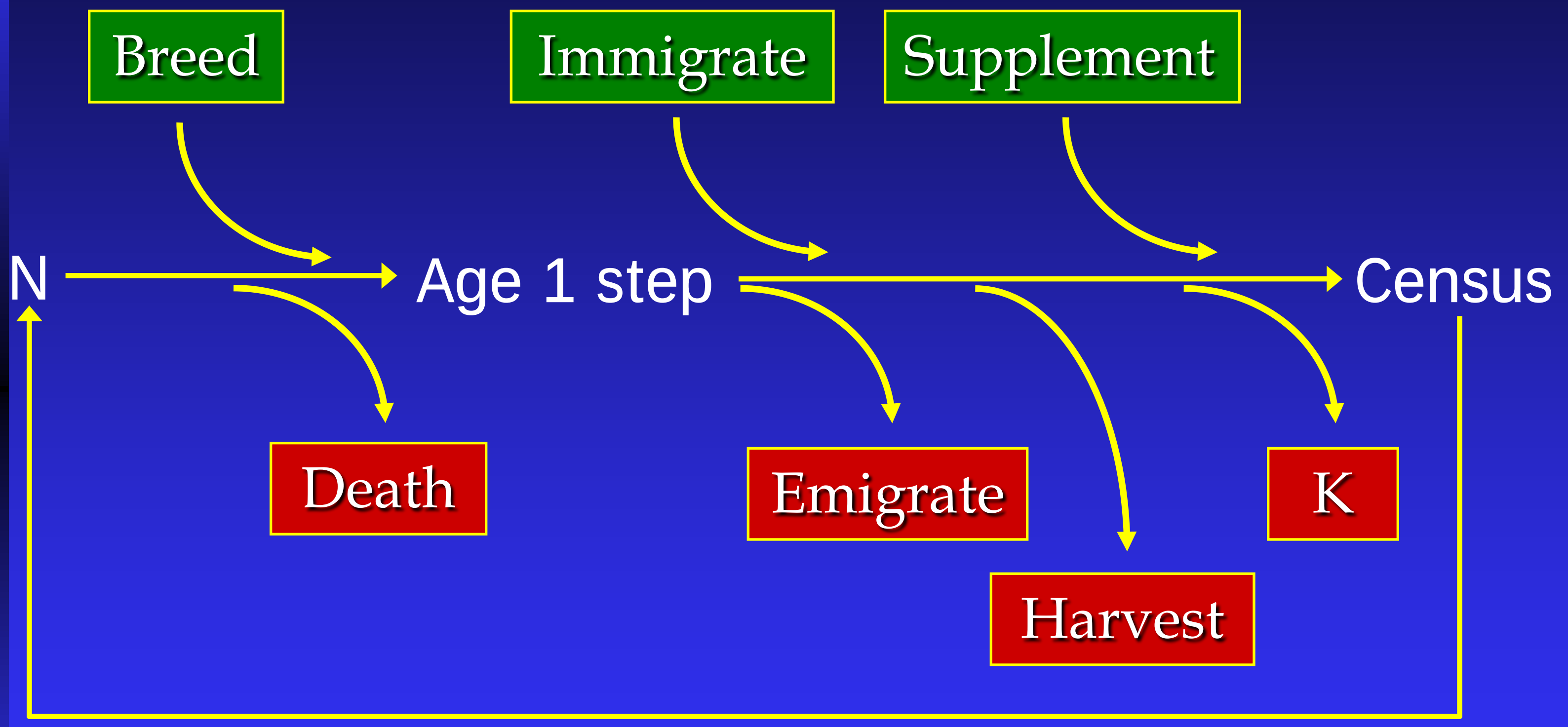
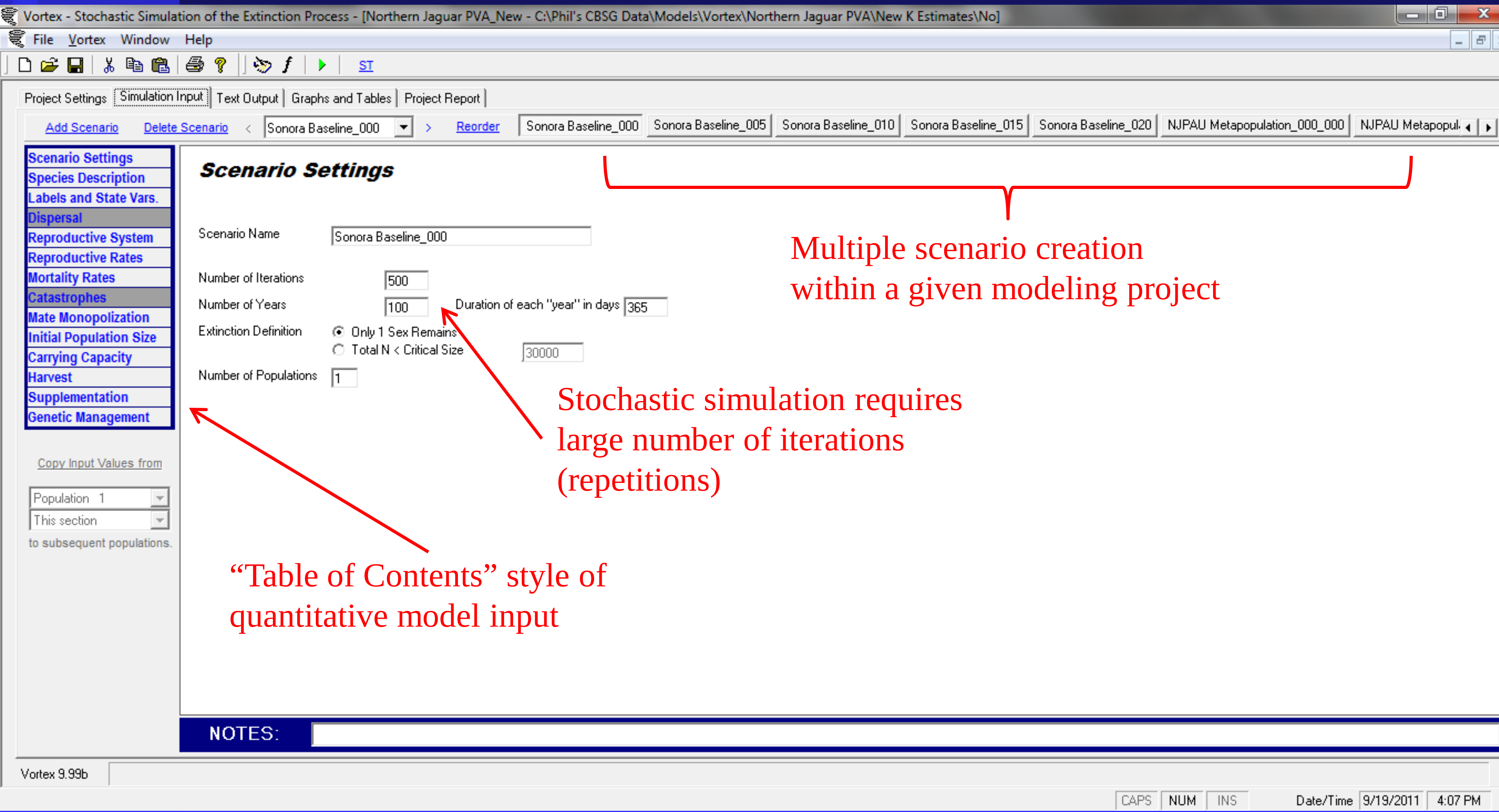
12:49 PM

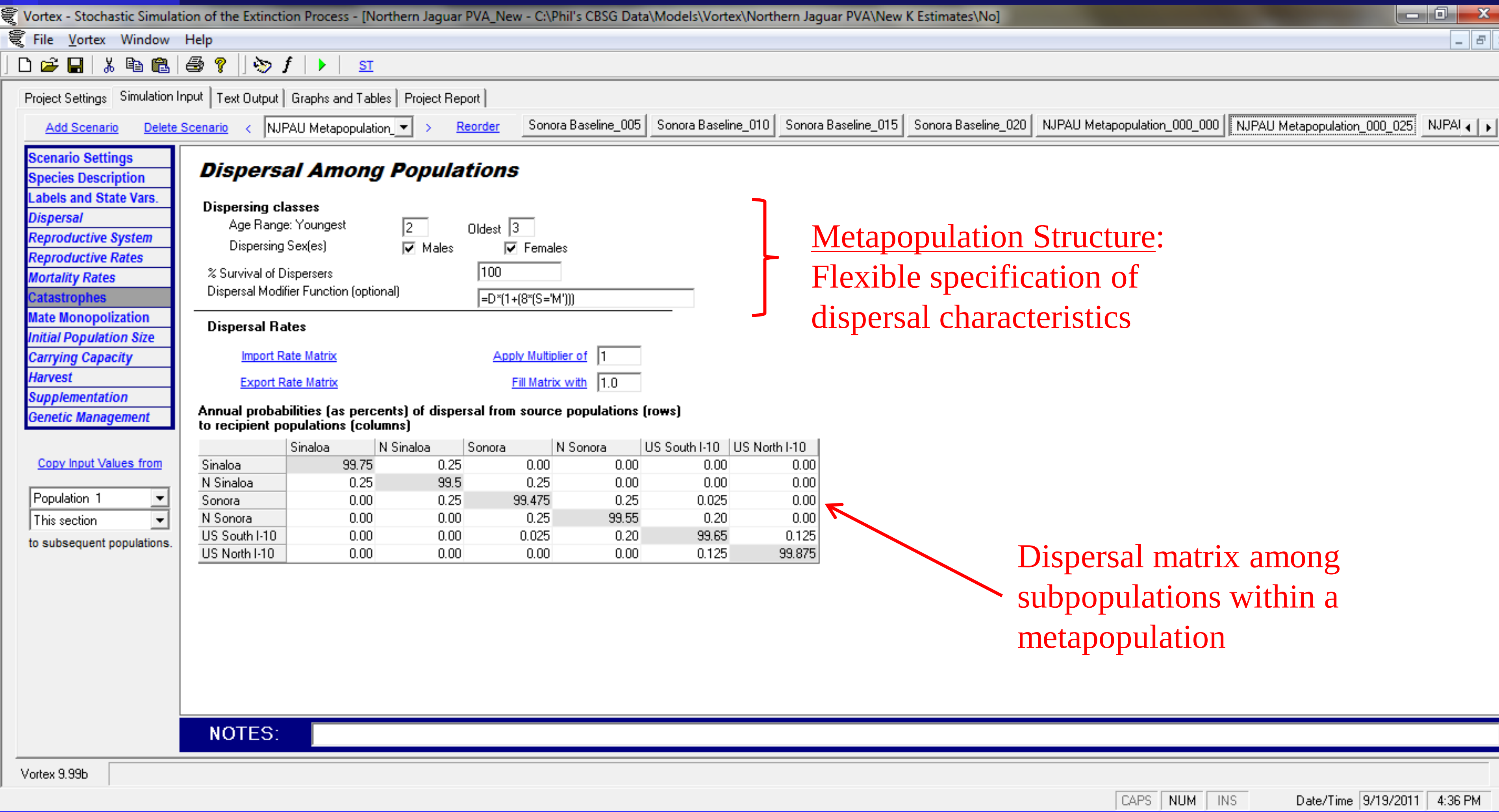
Vortex Simulation Model Timeline



VORTEX Model Input Process



VORTEX Model Input Process

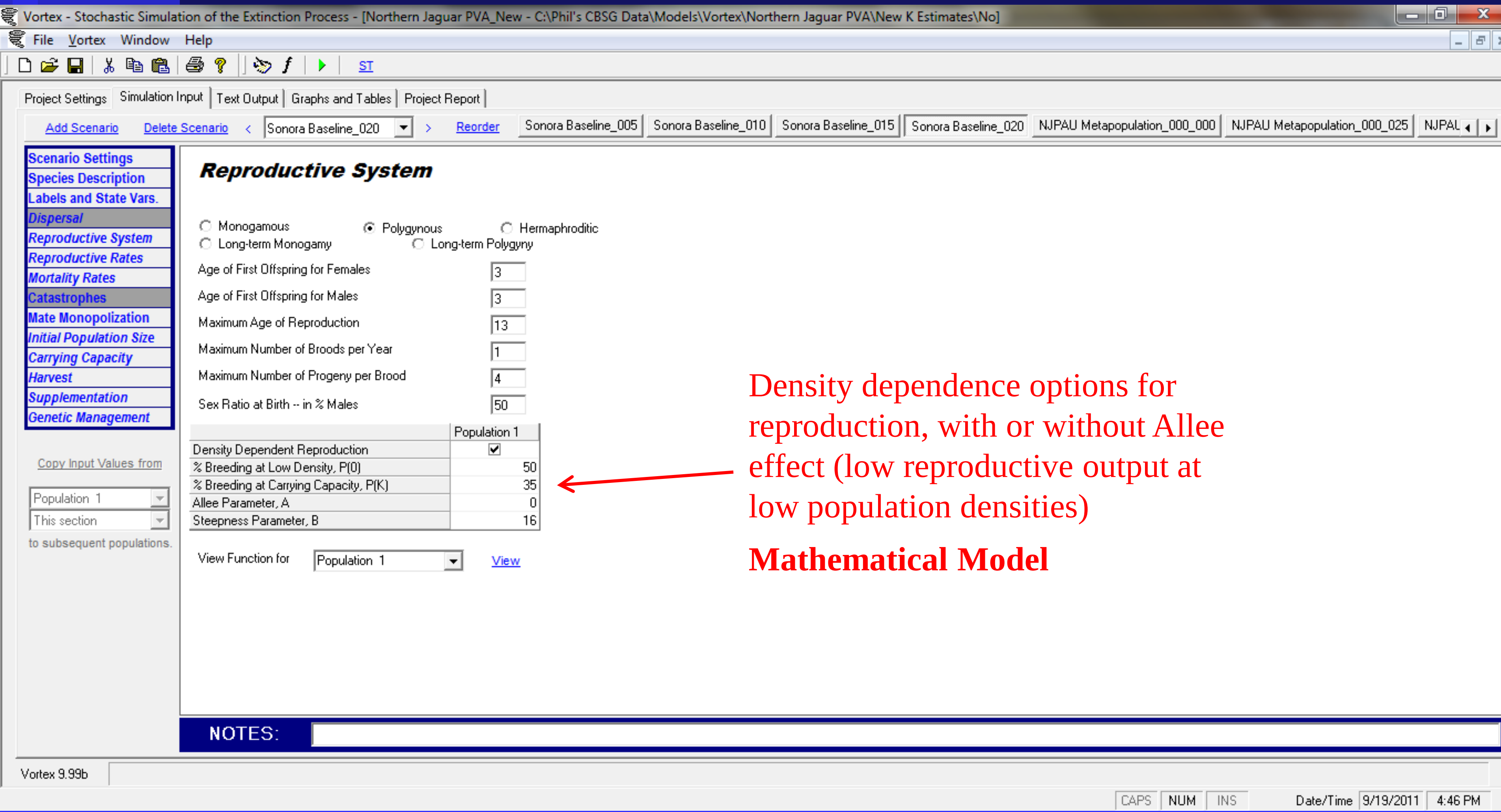


	Sinaloa	N Sinaloa	Sonora	N Sonora	US South I-10	US North I-10
Sinaloa	99.75	0.25	0.00	0.00	0.00	0.00
N Sinaloa	0.25	99.5	0.25	0.00	0.00	0.00
Sonora	0.00	0.25	99.475	0.25	0.025	0.00
N Sonora	0.00	0.00	0.25	99.55	0.20	0.00
US South I-10	0.00	0.00	0.025	0.20	99.65	0.125
US North I-10	0.00	0.00	0.00	0.00	0.125	99.875

<u>Metapopulation Structure</u>: Flexible specification of dispersal characteristics

Dispersal matrix among subpopulations within a metapopulation

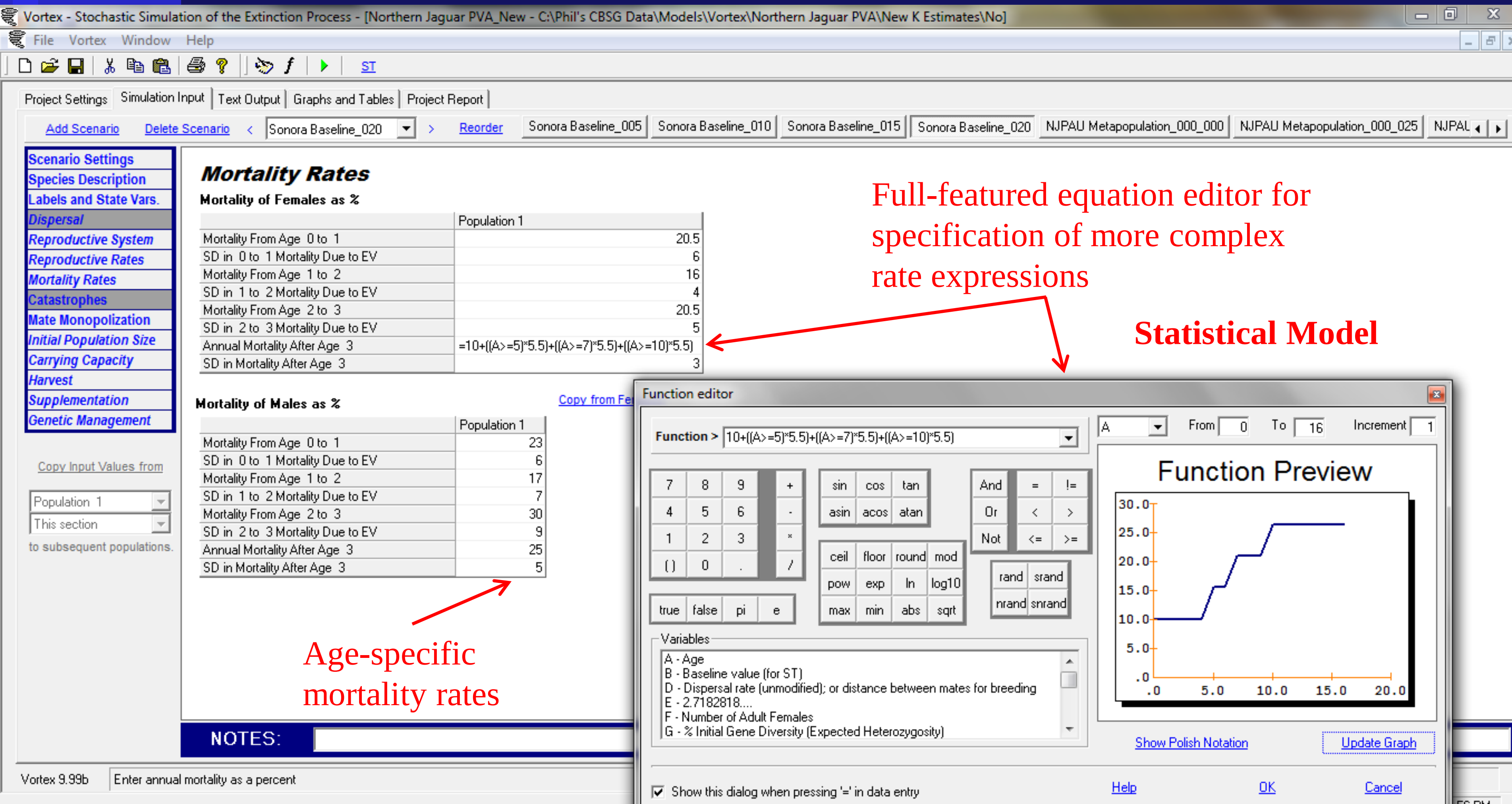
VORTEX Model Input Process



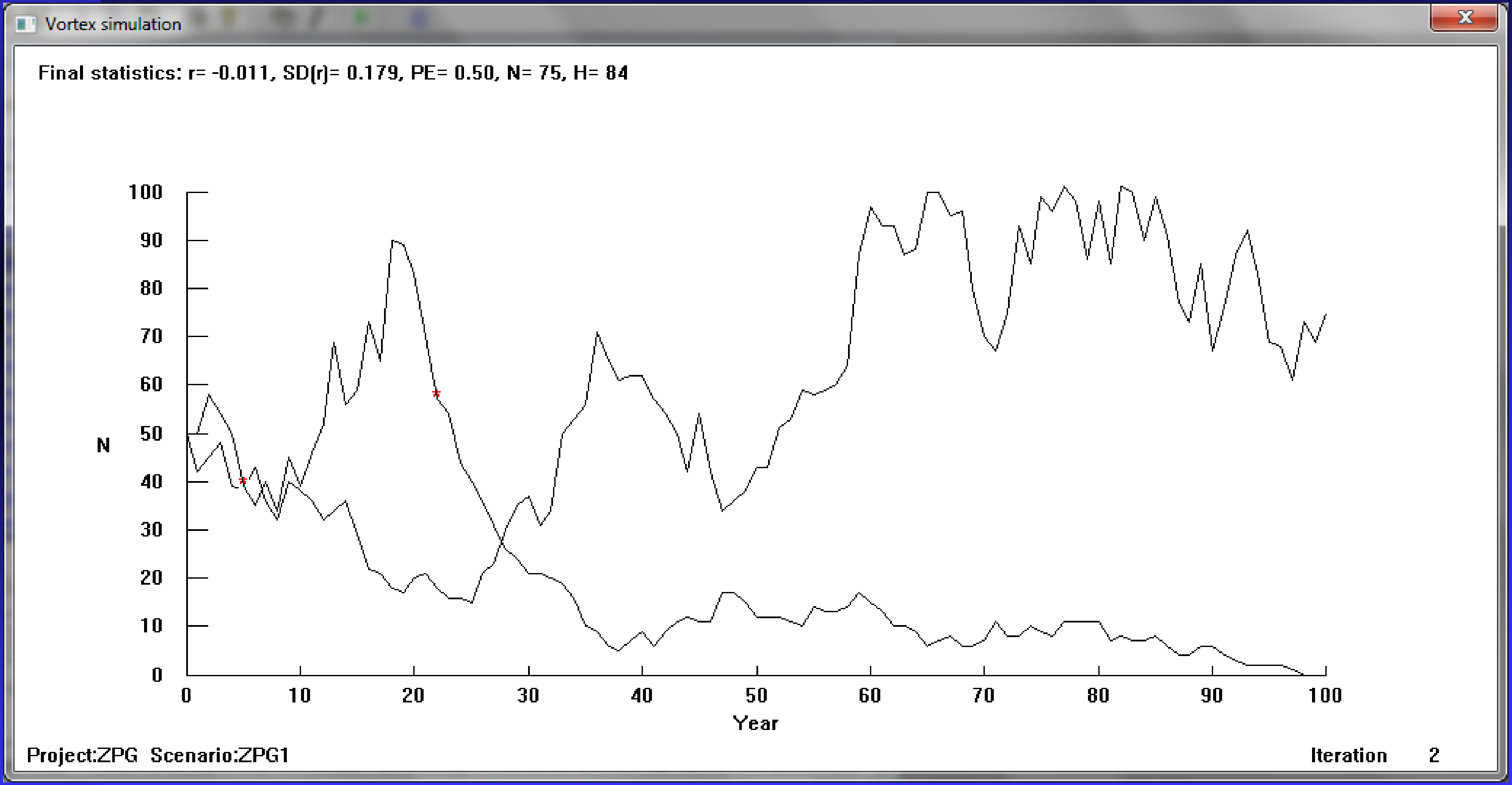
Density dependence options for reproduction, with or without Allee effect (low reproductive output at low population densities)

Mathematical Model

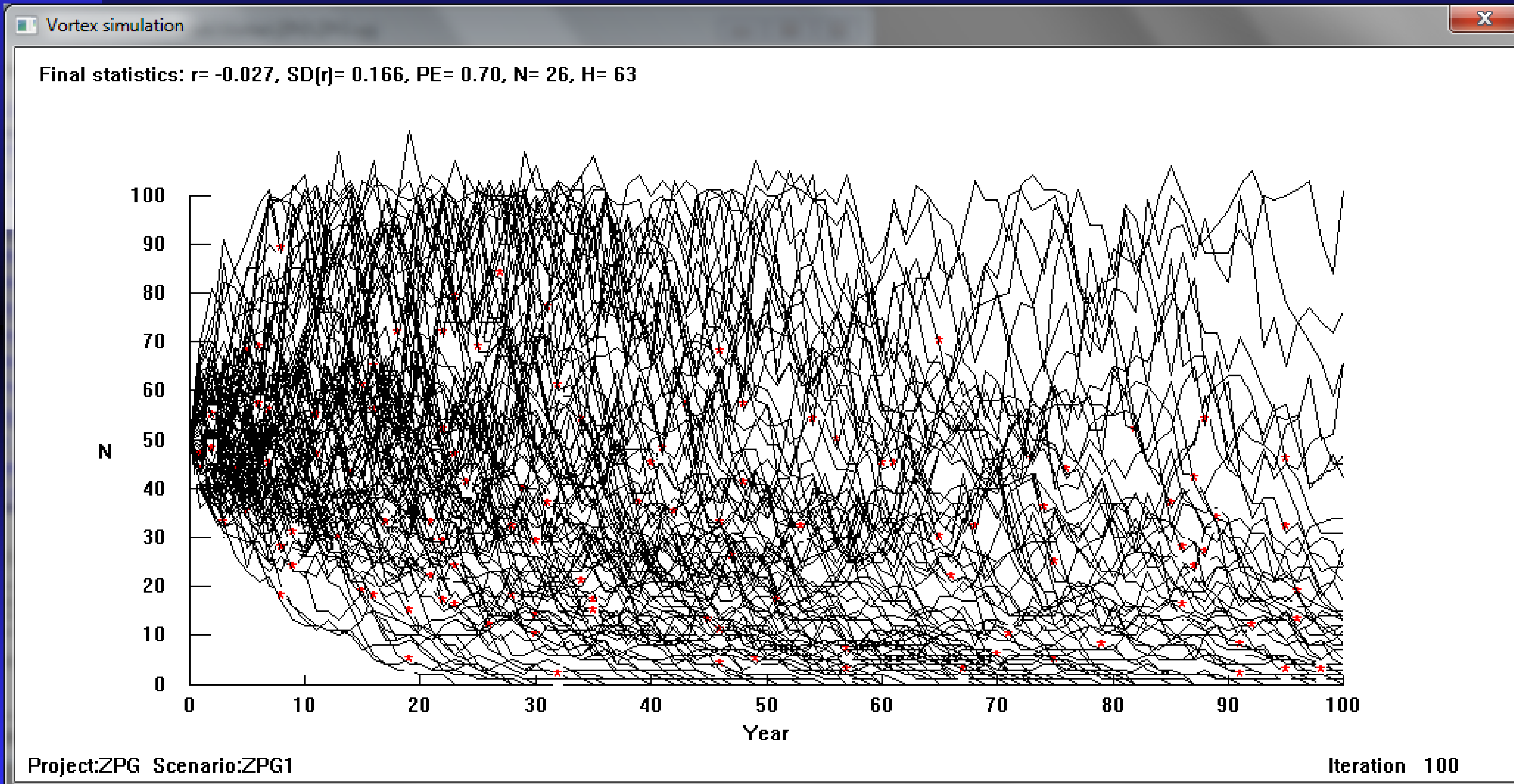
VORTEX Model Input Process



VORTEX Model Output



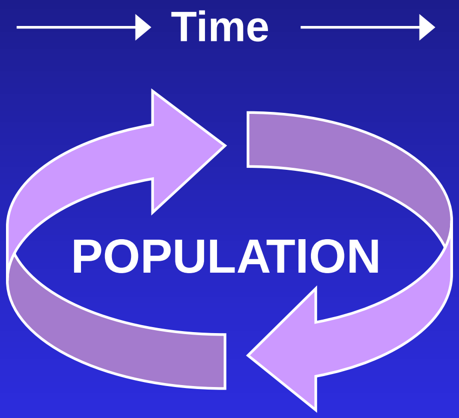
VORTEX Model Output



Sensitivity Analysis: “What if…?”

Uncertain demography:
±25% change in adult mortality

Fertility management:
20% drop in female breeding



Repeated Simulations

New estimates of:

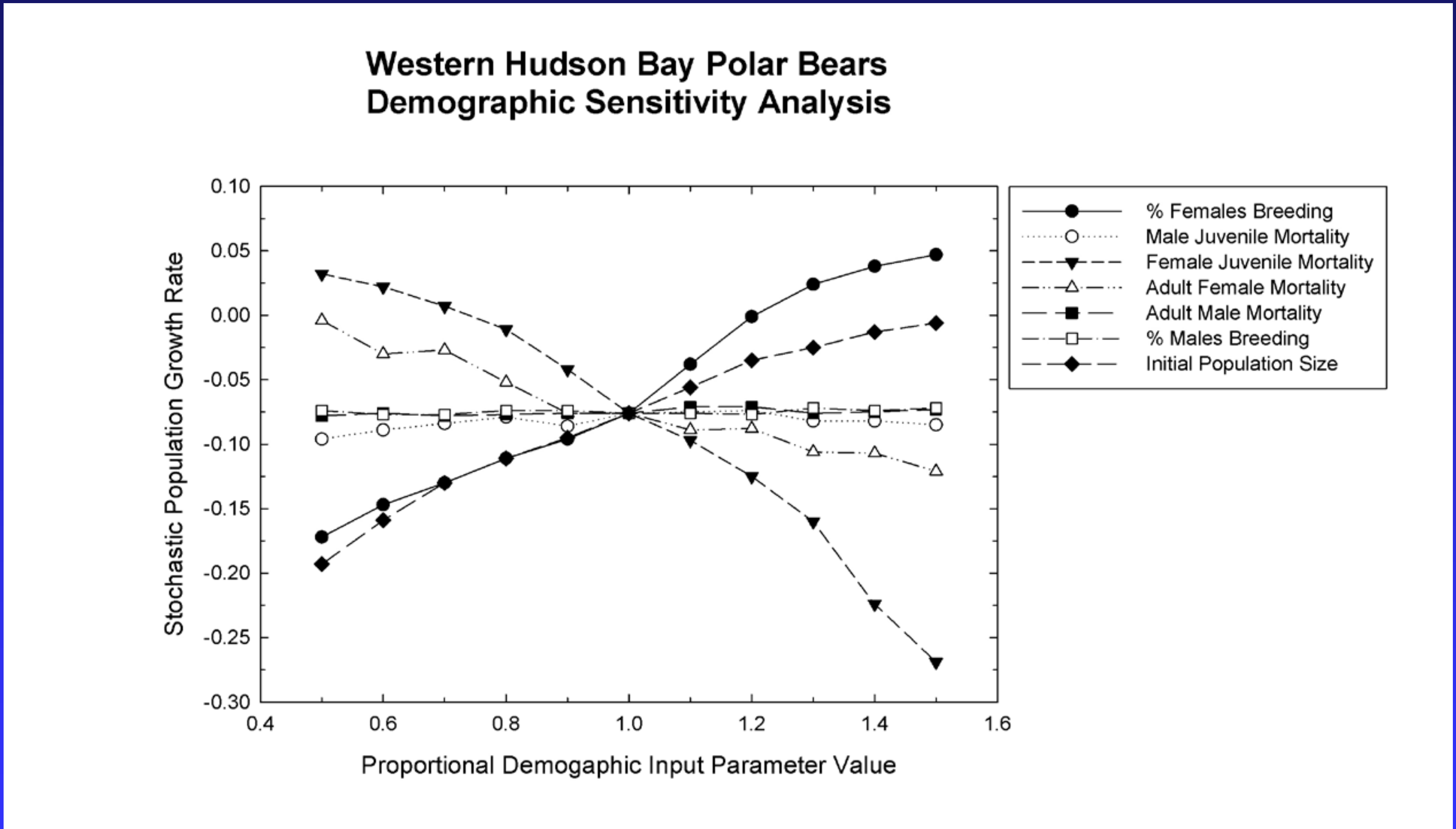
Population Size

Growth Rate

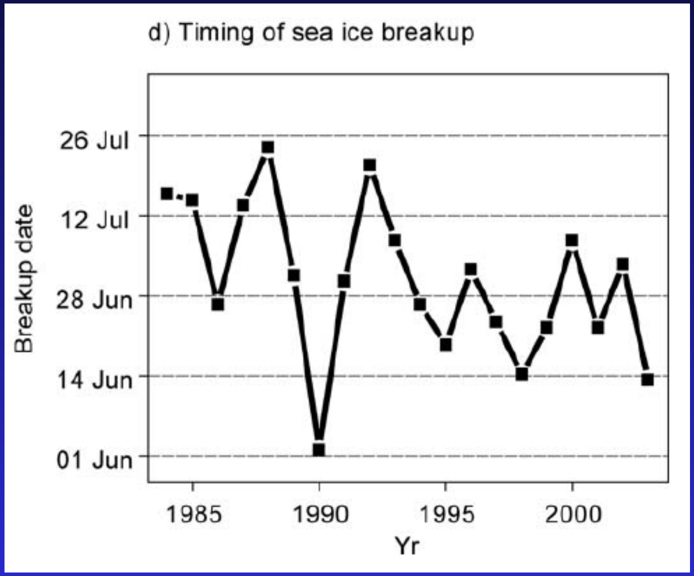
Extinction Probability

Genetic Diversity

Demographic Sensitivity Analysis

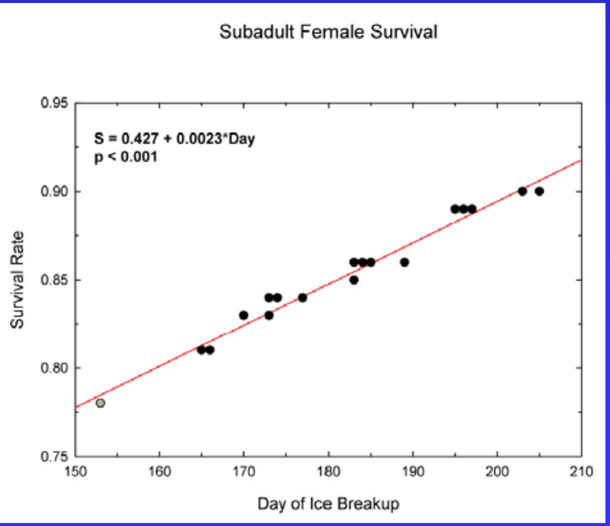


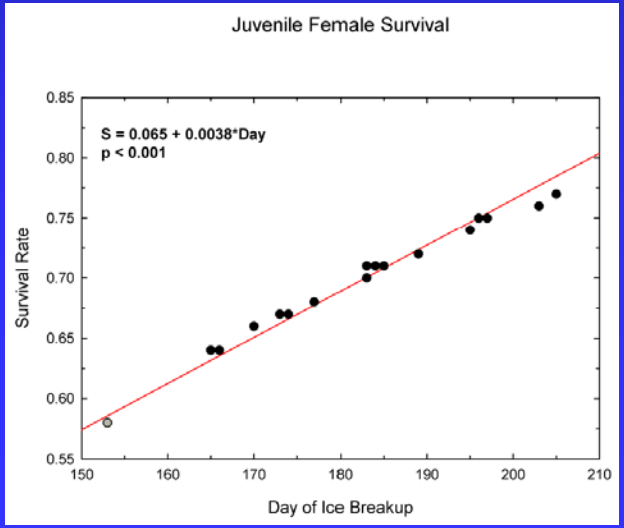
Modeling impacts of climate change: Polar Bears of Western Hudson Bay



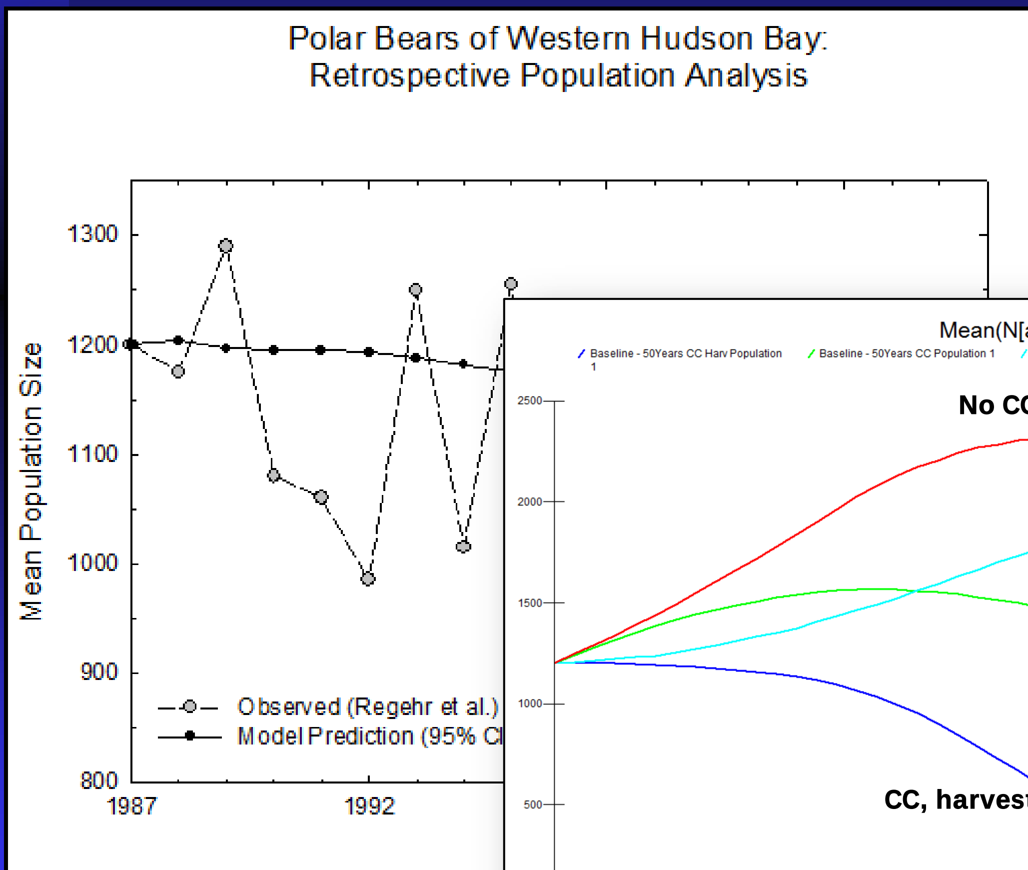
Regehr et al. 2007

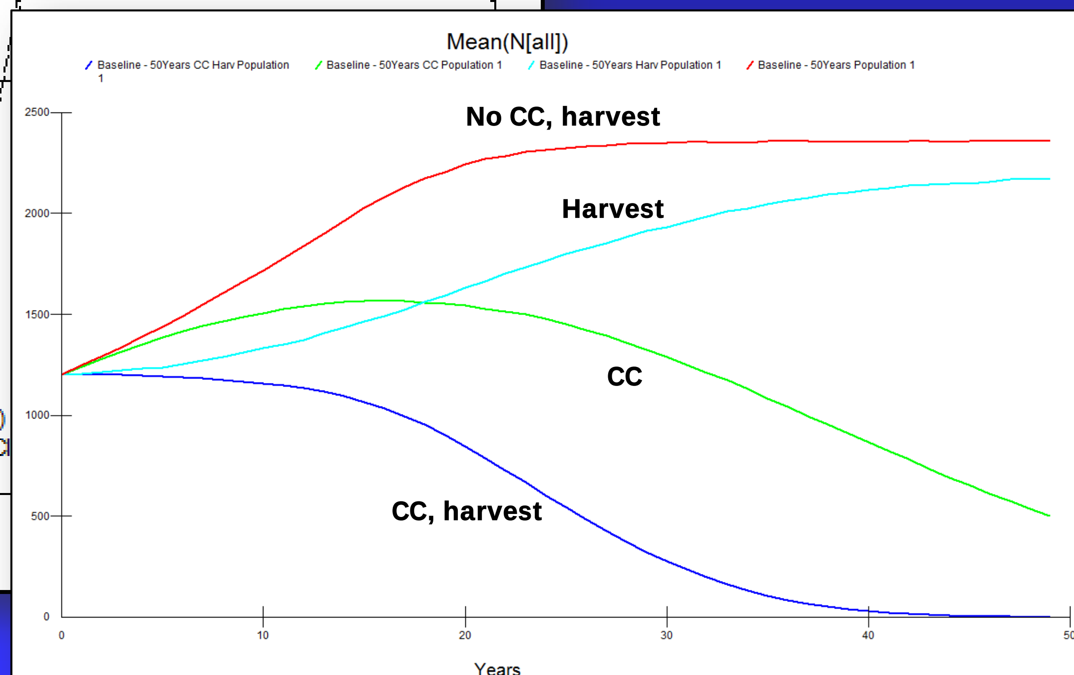
Statistical Model





Modeling impacts of climate change:
Polar Bears of Western Hudson Bay

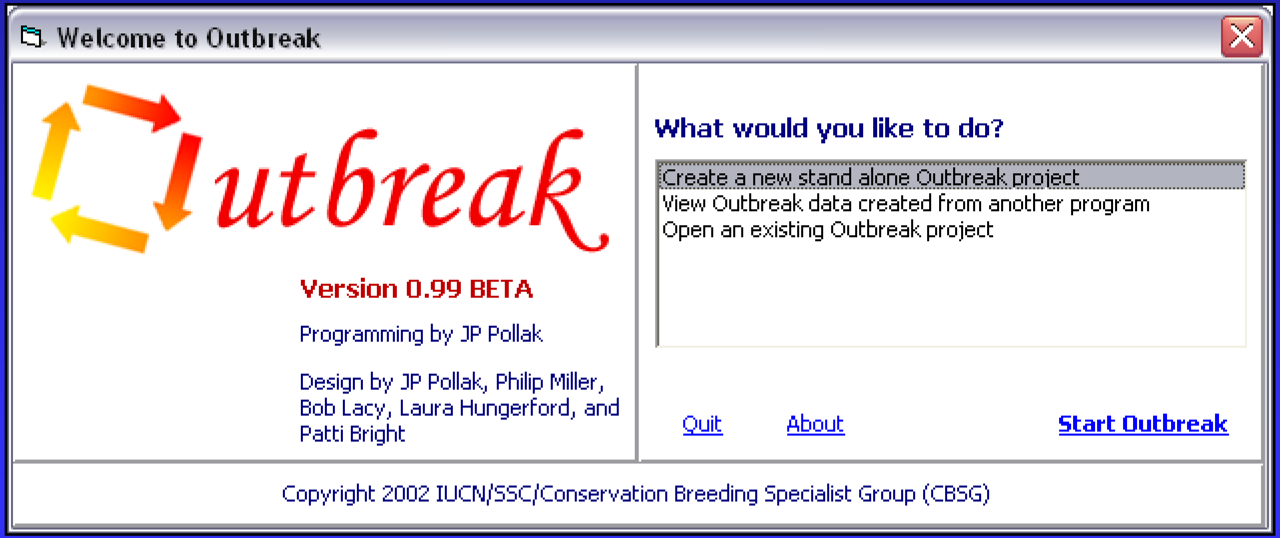




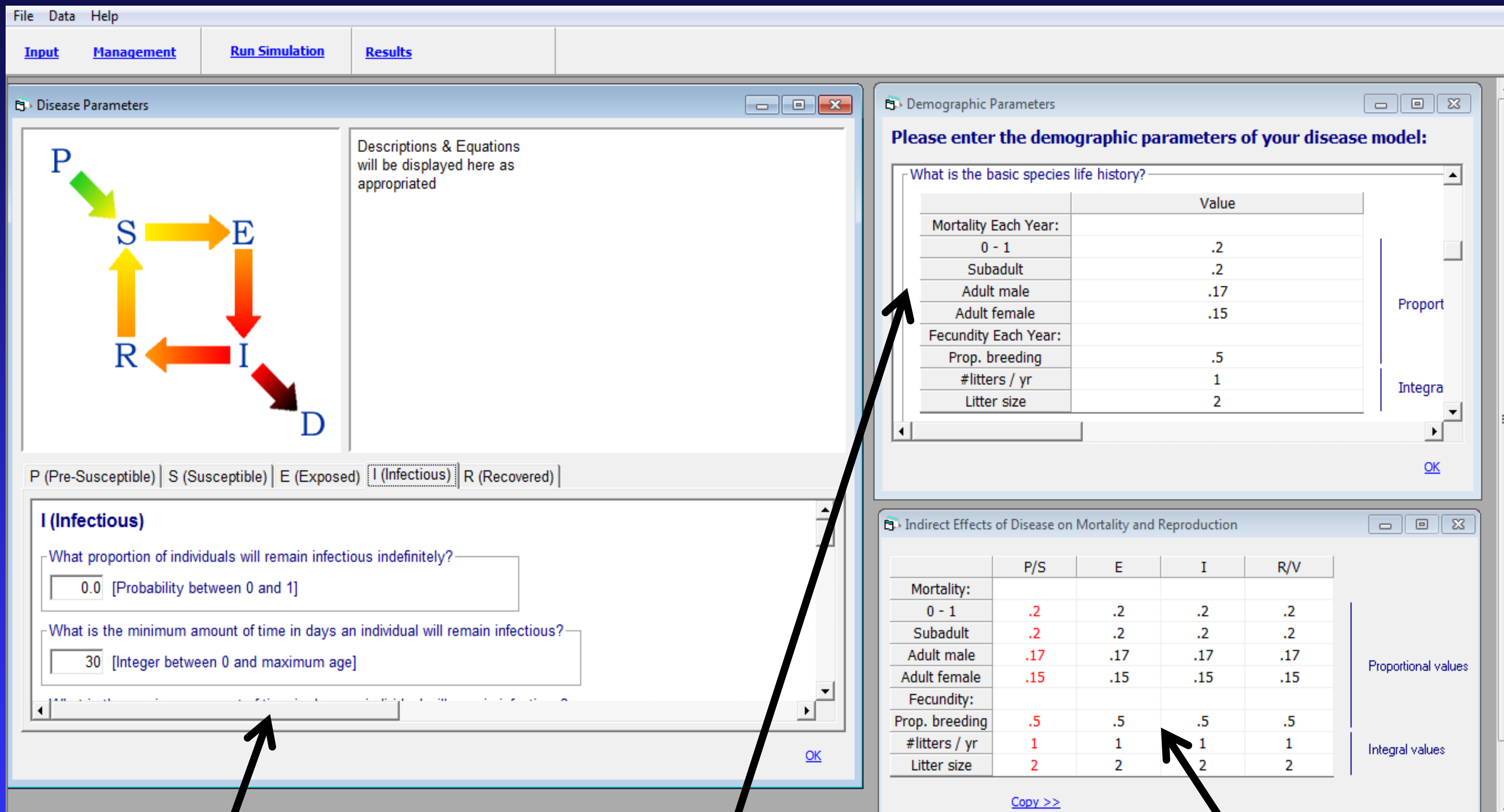
Tool Development for Disease Risk Assessment and Management

OUTBREAK

An individual-based simulation of wildlife disease epidemiology



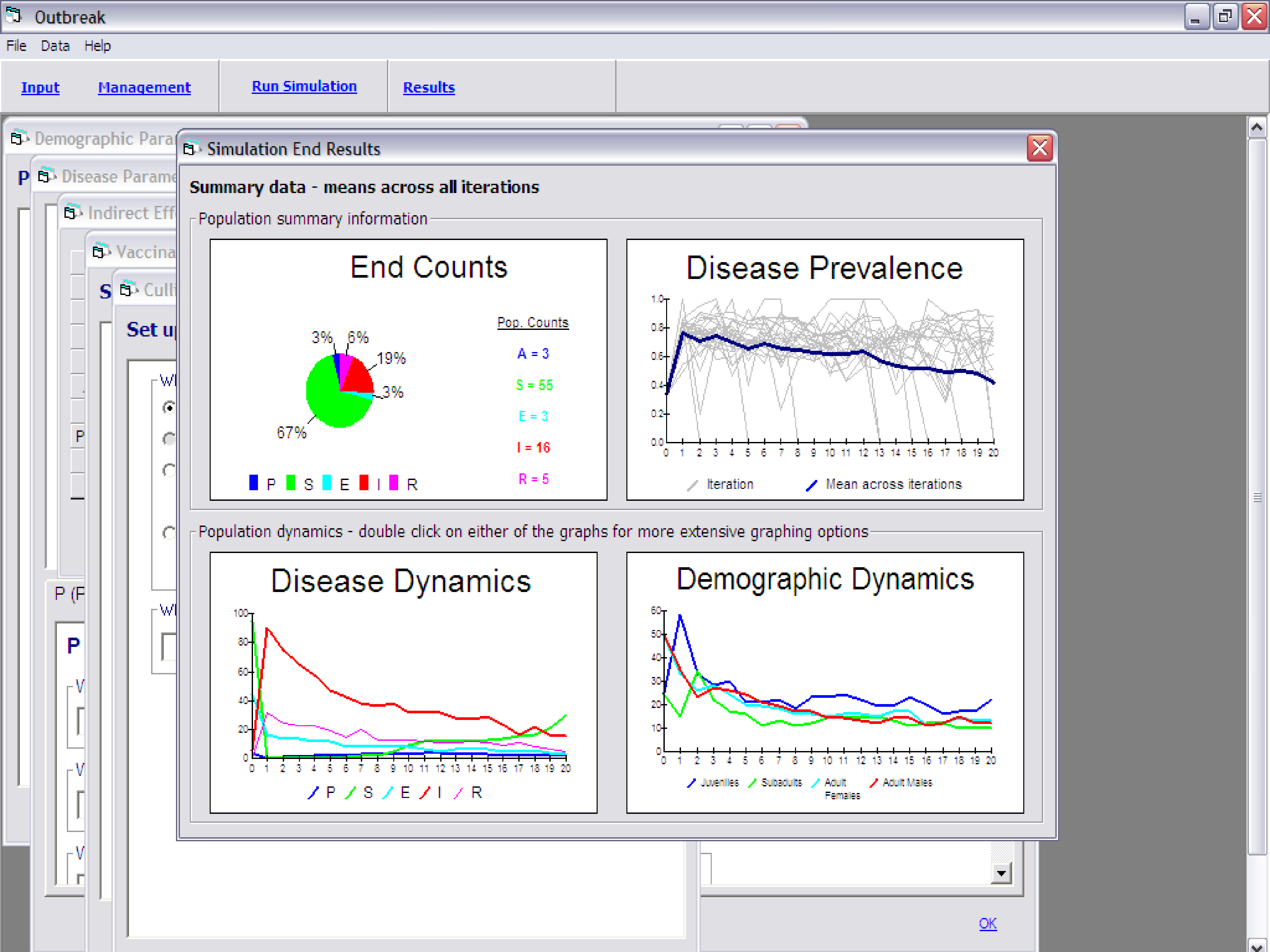
OUTBREAK



Standard SEIR model structure

Basic description of population demographics

Option for indirect disease effects

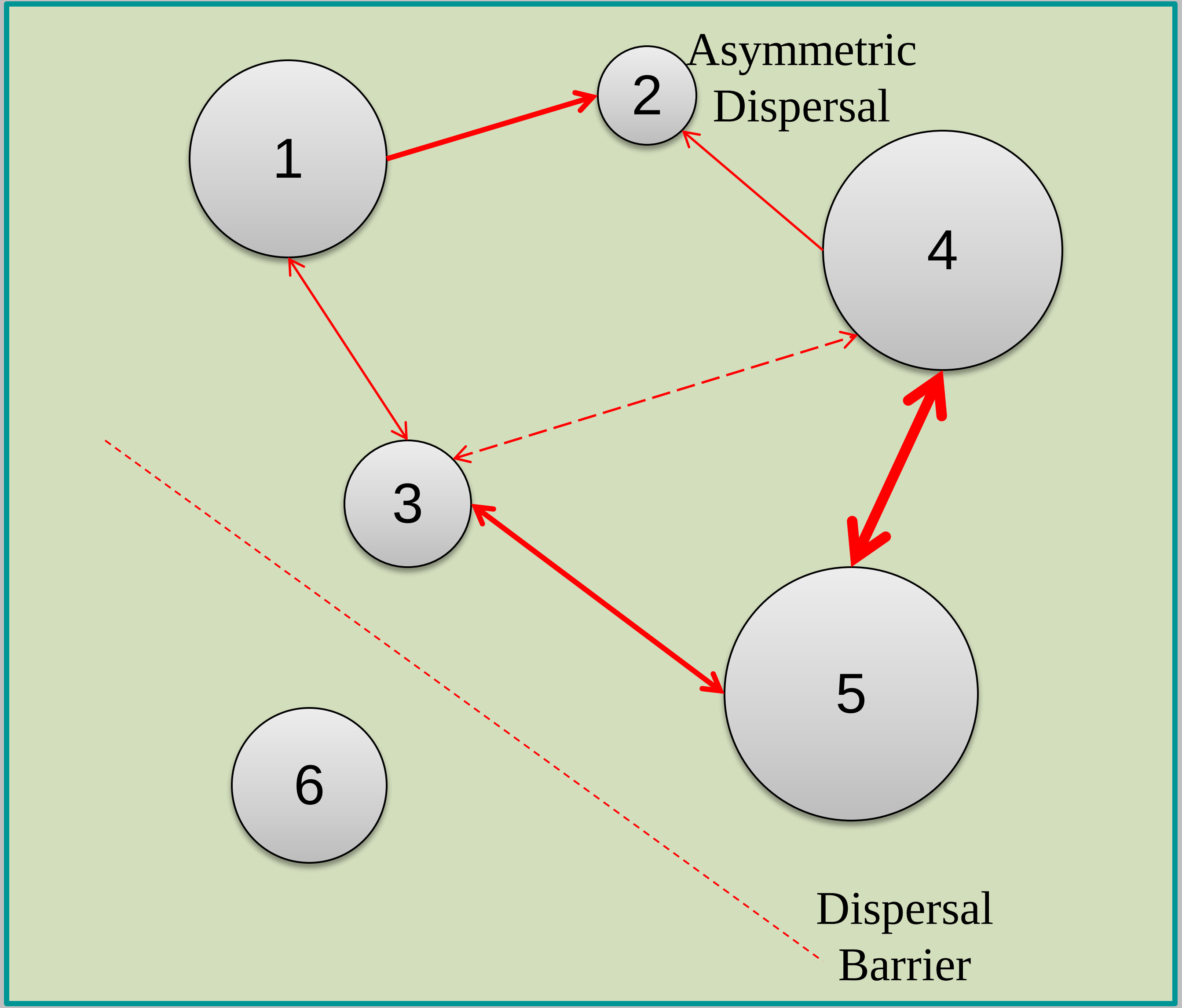

Outbreak
File Data Help
Input
Management
Run Simulation
Results
Demographic Para
Disease Parame
Indirect Eff
Vaccina
Culli
Set u
Simulation End Results
Summary data - means across all iterations
Population summary information
End Counts
Pop. Counts
A = 3
S = 55
E = 3
I = 16
R = 5
3%
6%
19%
3%
67%
P S E I R
Disease Prevalence
Iteration
Mean across iterations
Population dynamics - double click on either of the graphs for more extensive graphing options
Disease Dynamics
P S E I R
Demographic Dynamics
Juveniles
Subadults
Adult Females
Adult Males
OK

Issues to Consider in Free-Roaming Cat Population Management Analysis

- How important is an explicit consideration of the spatial dynamics of FRC population demography for management design?
  - Need for metapopulation analysis
- How do pathogens and disease play a role in the design of FRC population management protocols?
  - Susceptibility as a function of reproductive state
  - Reservoir for disease introduction / transmission to other species
- Can we expect more complex alterations to FRC population demography that could result from sterilization protocols?
  - Increased lifespan – Assateague Island horses
- What are the implications of population management protocols on associated species inhabiting the same landscape?
  - “Feral” – “Native” wildlife interface

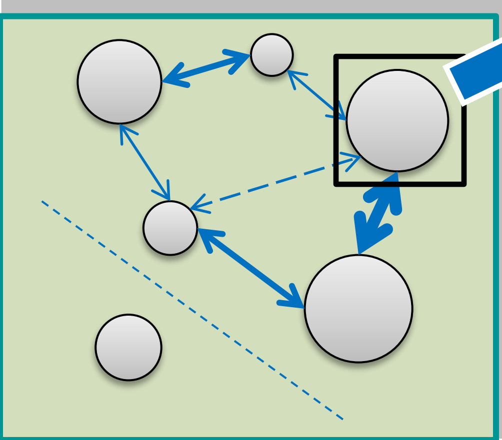
Potential Metapopulation Structure for Demographic Analysis

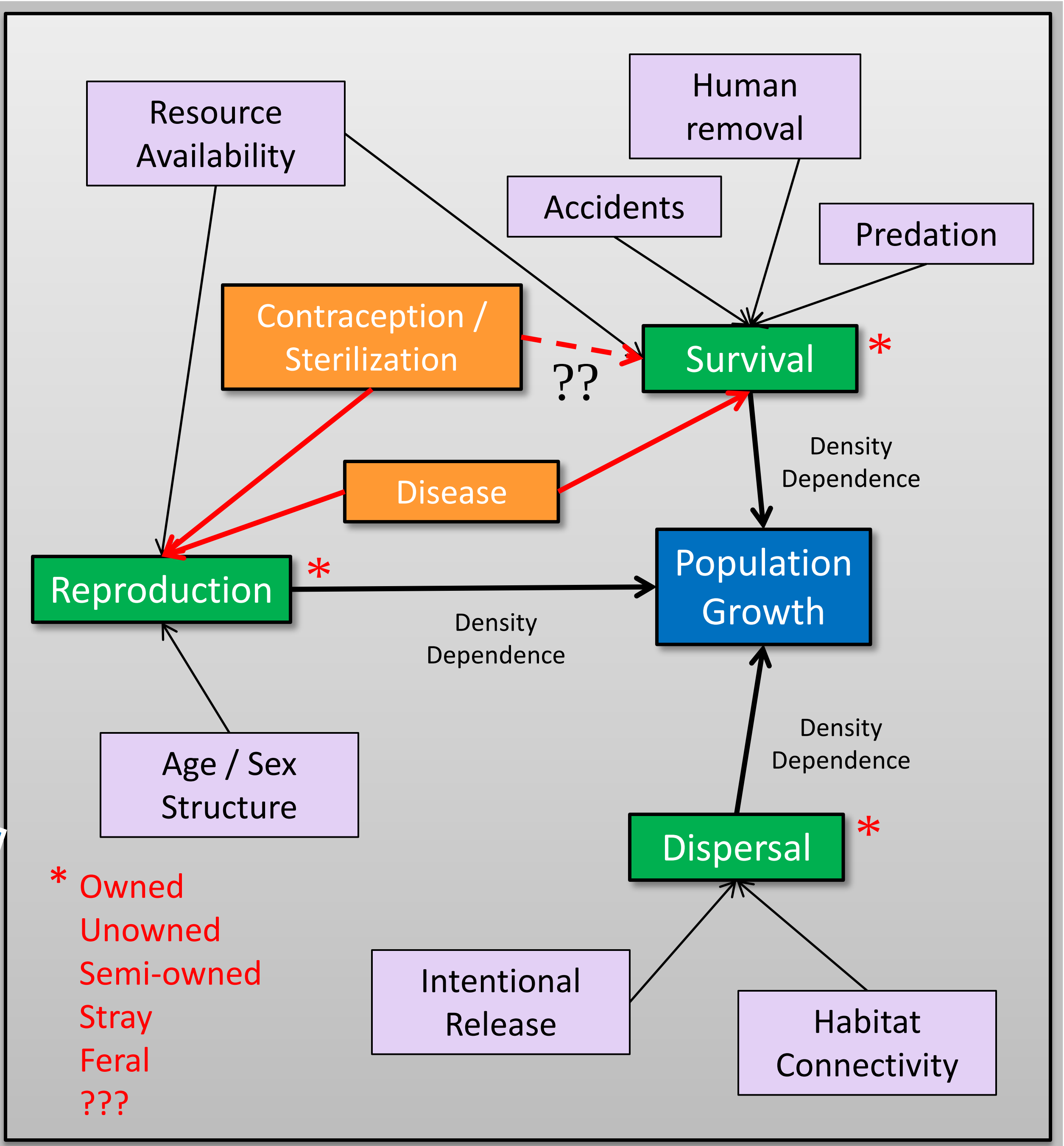
- Complex dispersal patterns – functions of density, distance, etc.
- Asymmetric dispersal may lead to "source-sink" dynamics across system
- If metapopulation structure exists, does reproductive management require attention to this structure?



Proposed Structure of Subpopulation System for Demographic Analysis

- Unique demographic characterization for each subpopulation where appropriate
- Does reproductive management influence survival rates (longevity)?
- How do other rate modifiers influence success of reproductive management strategies?





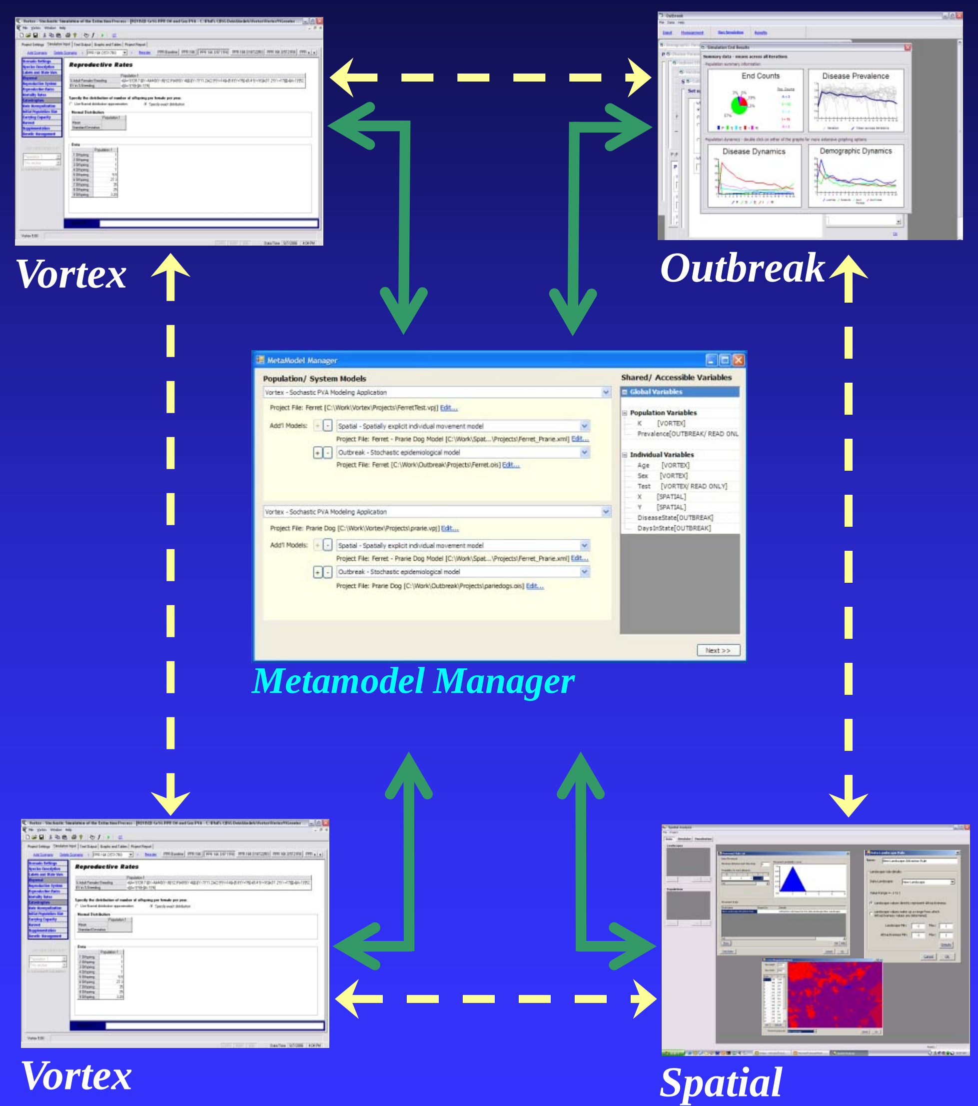
Biocomplexity Research Initiative for Species Conservation

Primary research focus:

- Developing **social mechanisms for engaging stakeholders** from a broad diversity of disciplines and perspectives
- Creating **new tools for using information from these stakeholders** more effectively in evaluating the risk of wildlife population extinction:

  Metamodeling

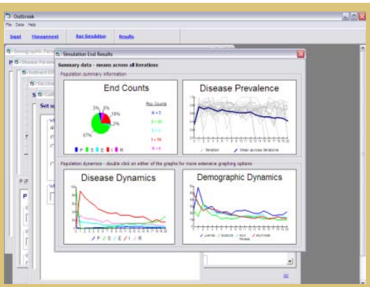
Metamodeling for Species Risk Assessments



Using a central communication hub as a mediator, called the “MetaModel Manager”, we can physically link traditional PVA programs like *Vortex* with other modeling tools such as GIS software, epidemiology simulation programs (*Outbreak*), animal movement models (*Spatial*) and other appropriate models.

Revolutionary approach to effective implementation of PVA methodologies

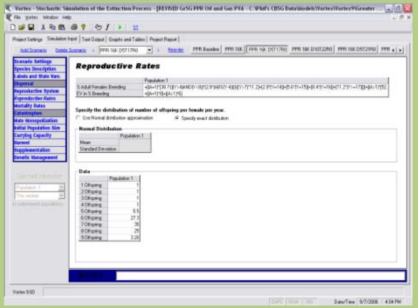
Two-Species PVA:
Black-Footed Ferrets and Black-Tailed Prairie Dogs



Outbreak

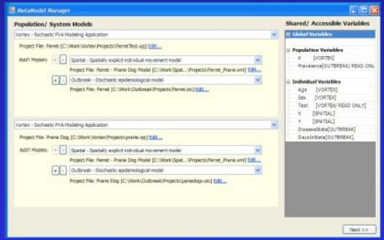
Sylvatic plague epidemiology

Number of infected animals



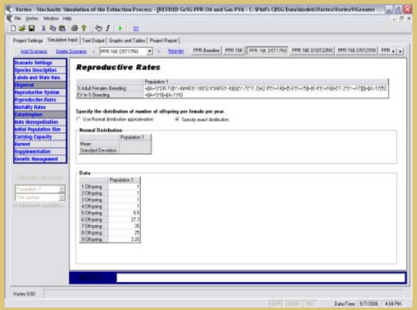
Vortex$_{(BFF)}$

Number of adult BFF



MMM

Number of BTPD

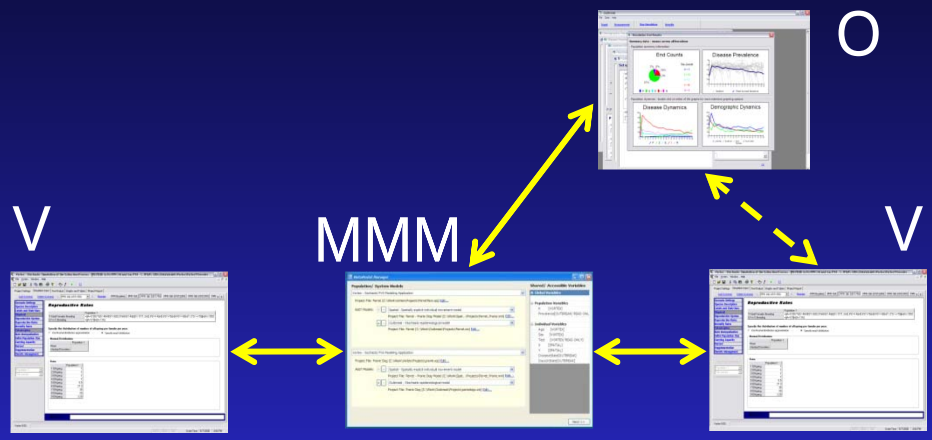


Vortex$_{(BTPD)}$

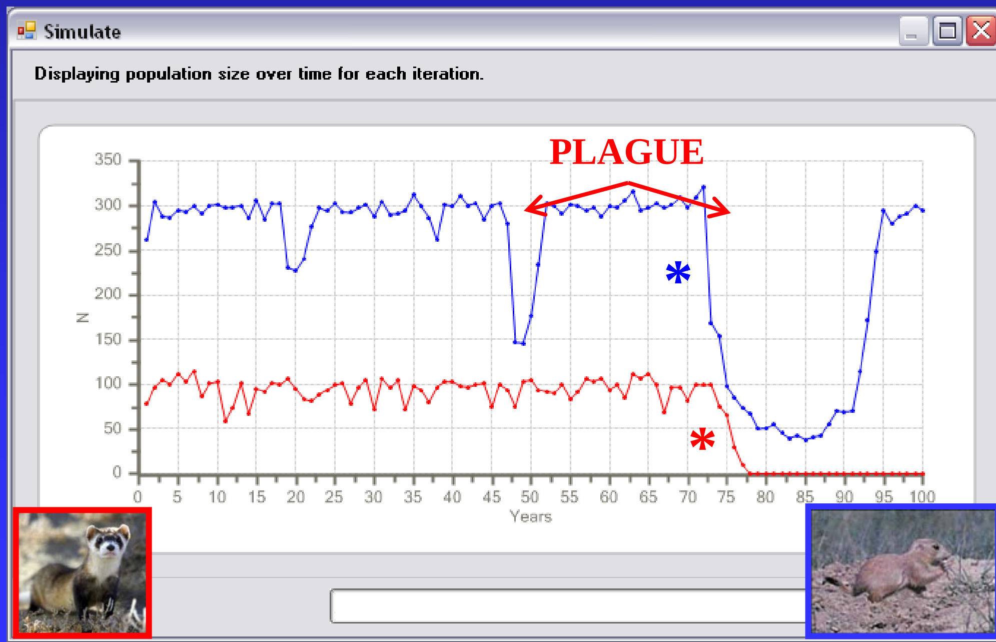
- **Mortality of all age-classes directly tied to prairie dog abundance (prey availability)**

- **No reproduction among infected individuals**
- **First-year mortality a function of adult ferret abundance**

Two-Species Metamodel with Disease:
Black-Footed Ferrets and Black-Tailed Prairie Dogs



Vortex – Vortex – Outbreak
linkage through MMM



Disease outbreak in prairie dogs → extinction of ferret population

Simulation Modeling of FRC Dynamics: Strengths

- Highly explicit – usually need to deconstruct larger system into components for effective analysis.
- System complexity makes derivation of analytical solutions very difficult, or can only be achieved by making simplifying assumptions that might be omitting important factors
- Can develop a projection for a specific case, incorporating all that we know about that situation, rather than identifying expected general trends for a generic case
- Valuable for processes that have a lot of uncertainty. Other models often can be used to calculate expected variation in results, but the generation of that variation in a simulation can make it easier to understand.

Simulation Modeling of FRC Dynamics: Weaknesses

- System complexity can often lead to difficulty in creating a realistic description of the many factors and their interactions
- Often computationally intensive, especially in the case of individual-based modeling environment – often precludes analysis of larger population sizes (N > 50,000?)
- Propagation of parameter uncertainty makes accurate predictive capacity very low

Using a variety of model types is often the most informative, especially in that results can then be compared to gain the strengths and recognize the weaknesses of each approach