Using Deterministic and Stochastic Population Models to Inform Bear Management

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OUTLINE

1. Population models overview
2. Variation and Uncertainty (stochasticity)
3. The RISKMAN model
4. Modeling harvest (boreal data)
5. Effects of stochasticity (Montana)
6. Other examples of how models can inform management.

Population models overview

Demographic population models use birth & death rates to estimate population size & growth rate over time.

- Age-structured models are needed to mimic population dynamics of discrete reproducers in age-structured populations
- Life-table and Leslie matrix models.
- True "individual-based" models.

Deterministic age-structured models

- Birth and death rates fixed (within age classes) and measured without error.
- Partial individuals (85% of 10 = 8.5)
- Useful for sensitivity analyses, and exploring how populations behave under different conditions.

Unrealistic & positively biased

- when applied to small populations,
- where birth and death rates vary
- where there is sampling error in estimates of birth and death rates.

Deterministic age-structured models

- Until we account for variation and uncertainty in model inputs, we're just guessing

- Qualitative differences in growth rate may be within the range of uncertainty in our field estimates

Stochastic models

- Simulate growth of the same population 100s or 1000s of times (trials).
- Sample from distributions of input parameters to allow for
  1) process variation in birth and death rates
  2) uncertainty in field estimates.
- Yield probabilistic results (across trials)

Because survival is temporary but death is permanent, the more variability in the system, the lower the mean rate of increase.

Stochastic models

Forms of stochasticity commonly included in population models:

1) Demographic stochasticity
2) Genetic stochasticity
3) Environmental stochasticity
4) Individual variation
5) Rare catastrophes
6) Sampling error

Stochastic models

Can be used to:

- Estimate probabilities of population growth or decline to specific sizes, risk of extinction, MVP size, λ, and sustainable harvest rate, *in the presence of variation and uncertainty in vital rates and population estimates*
- Estimate *relative rather than absolute risks* when data are of low quality or borrowed from other populations, and when modeling hypothetical ("what if") scenarios
- Given adequate data, to predict population size, growth rate, age & sex structure over time
- Identify data deficiencies

Questions?

RISKMAN

Nunavut Ontario

RISKMAN

Stochastic and Deterministic
Population Modeling

RISK MANagement Decision Tool
for
Harvested and Unharvested Populations

Version: 1.9.003

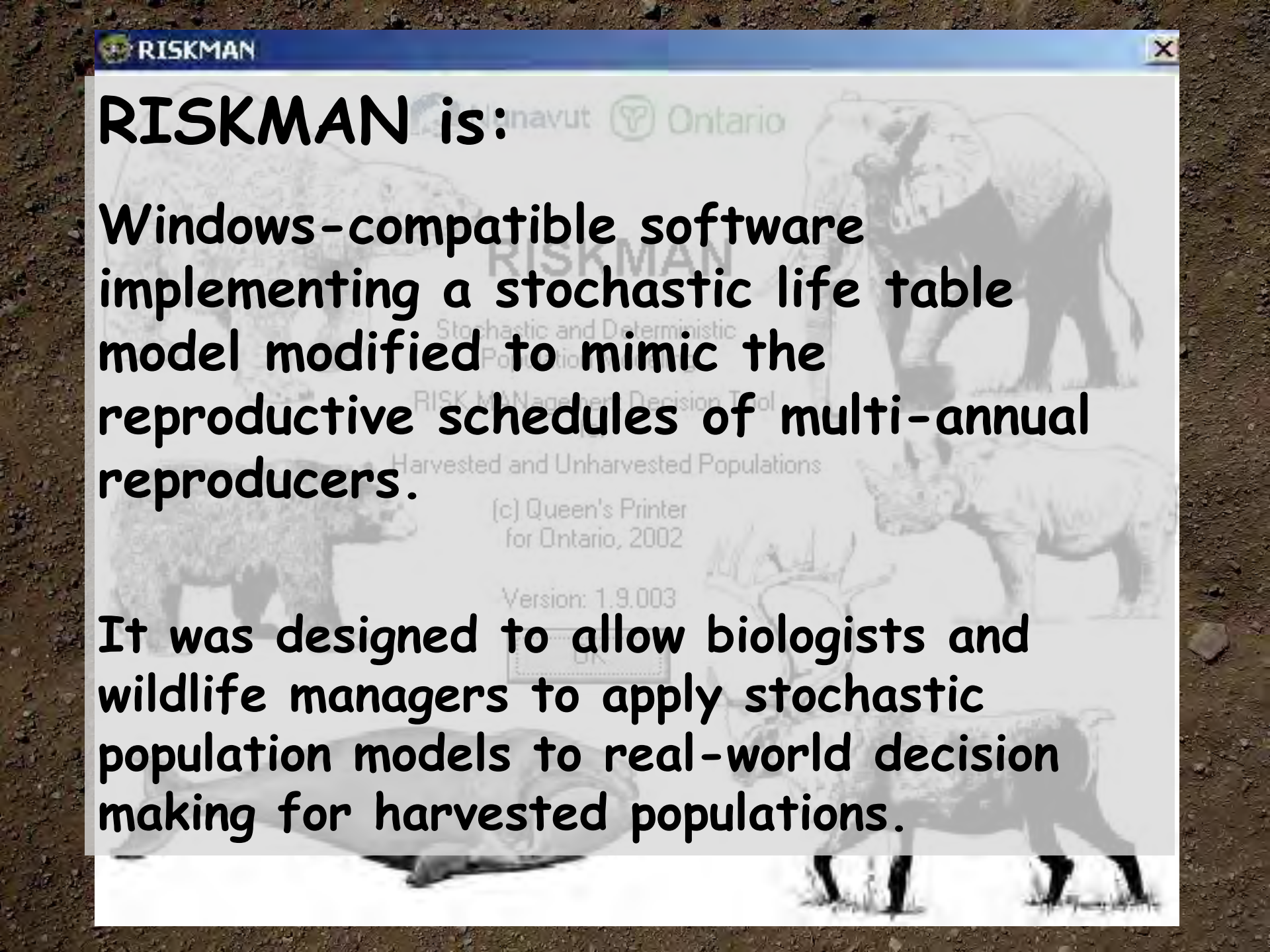
OK

RISKMAN

RISKMAN is:

Windows-compatible software implementing a stochastic life table model modified to mimic the reproductive schedules of multi-annual reproducers.

It was designed to allow biologists and wildlife managers to apply stochastic population models to real-world decision making for harvested populations.



What information do I need?

Inputs:

- Population size†
- Natural survival*†
- Recruitment*†
- Annual or seasonal harvests†
- Relative vulnerability of age/sex classes to harvest*

** In age & sex-specific arrays*

† and SE

Outputs

For each year of the simulation:

- Population size
- Growth rate
- Age & sex structure of the population and the harvest
- Total mortality due to harvest
- Reproductive value of adult females

As probability distributions across stochastic trials.

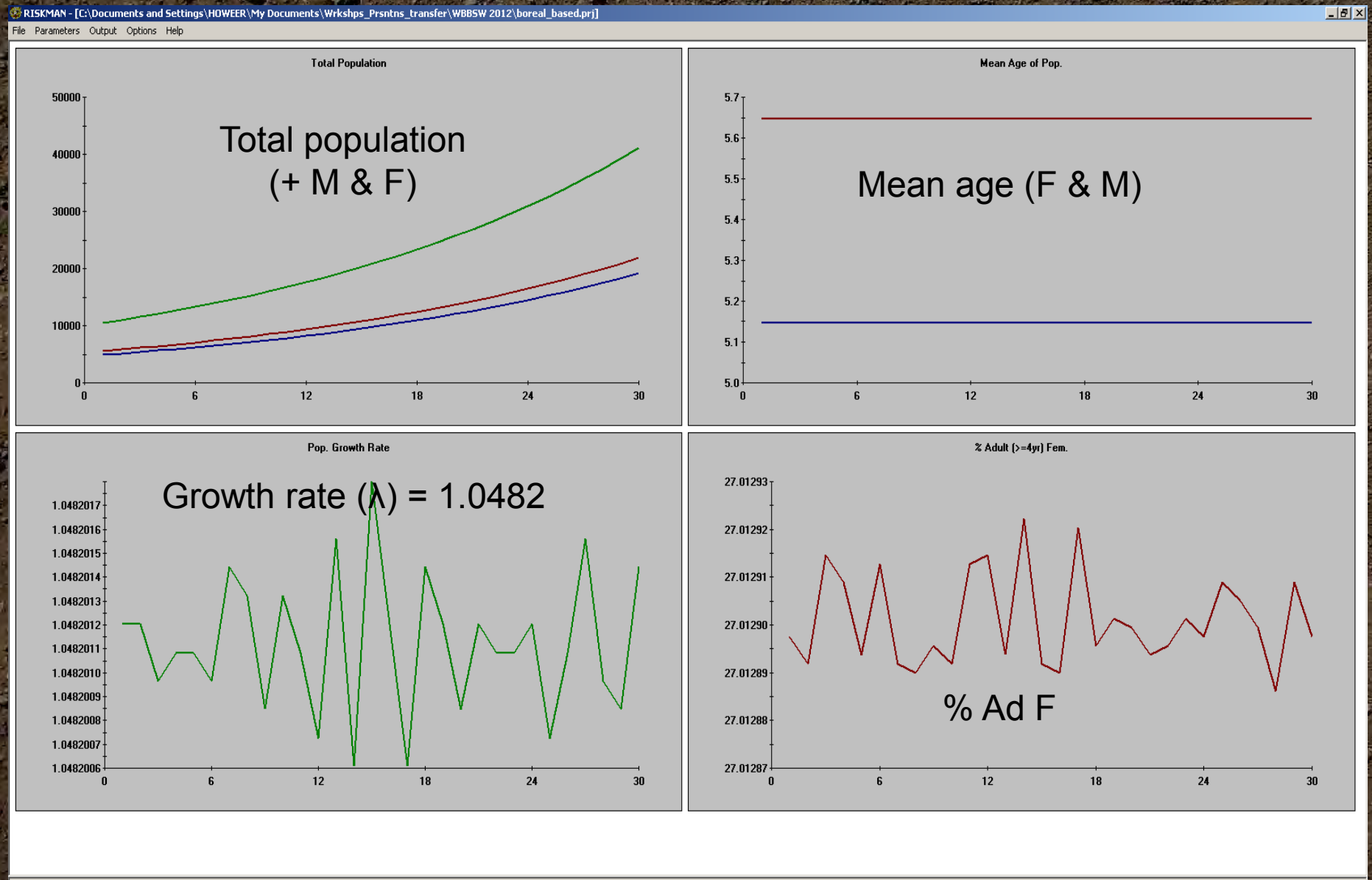
Features that make RISKMAN useful for modeling harvested bear populations:

- Allows for differential vulnerability of age & sex classes to harvest.
- Age & sex structure of the harvest varies dynamically with the availability of different age & sex classes in the standing population.
- Additional non-harvest anthropogenic mortality can be included in simulations.
- Flexible in regard to how animal density may affect birth and death rates.
- Windows interface & convenience features.
- Support (eric.howe@ontario.ca; other users)

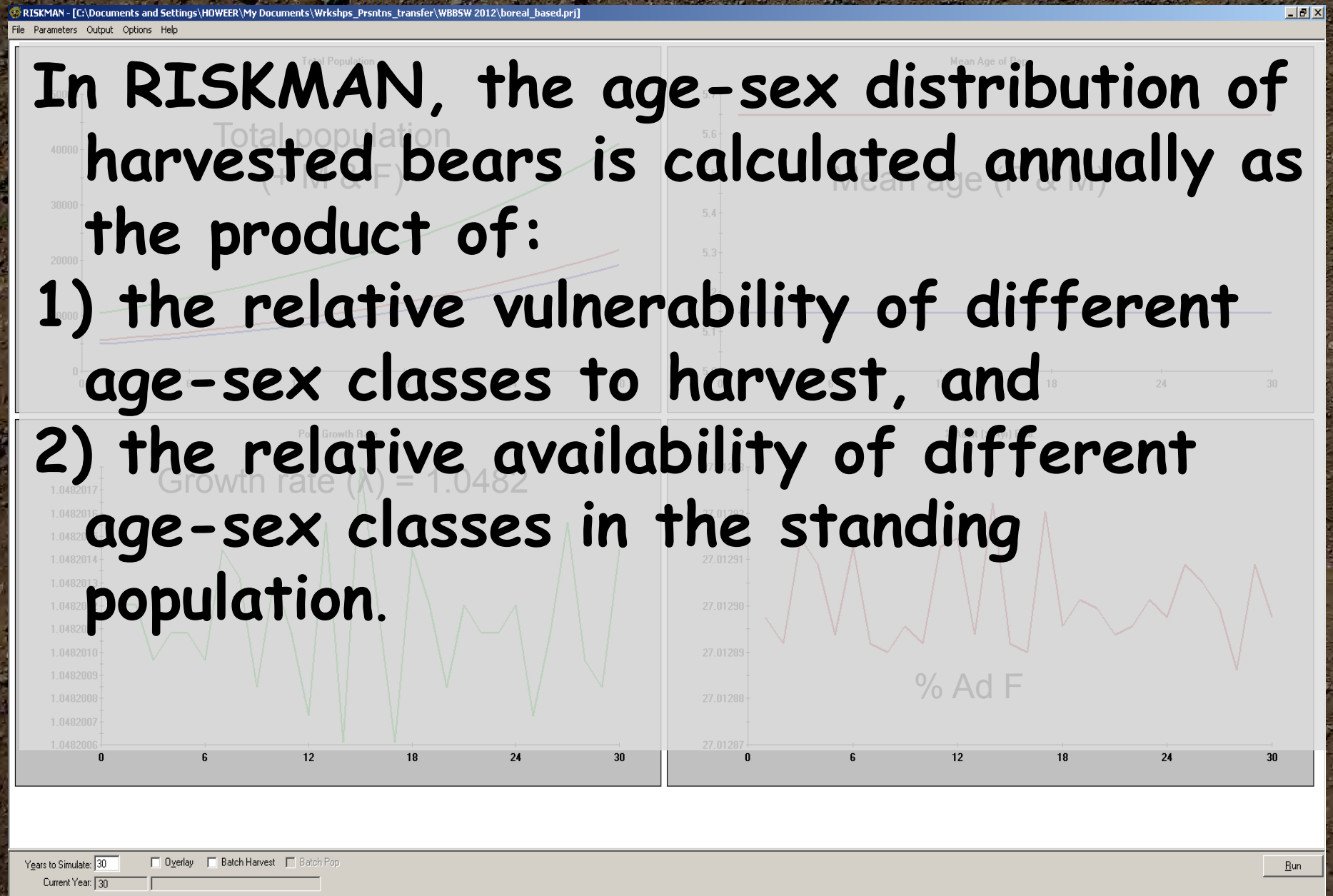
Features that make RISKMAN useful for modeling harvested bear populations:

- Stochastic mechanisms use the underlying variance in field estimates.
- Management objectives such as population viability, sustainable harvest, or population increases or decreases can be defined within the model.
- Results can therefore be expressed as the probability of achieving a specific management objective → "RISK MANagement"

Dynamic age-sex distribution of harvests



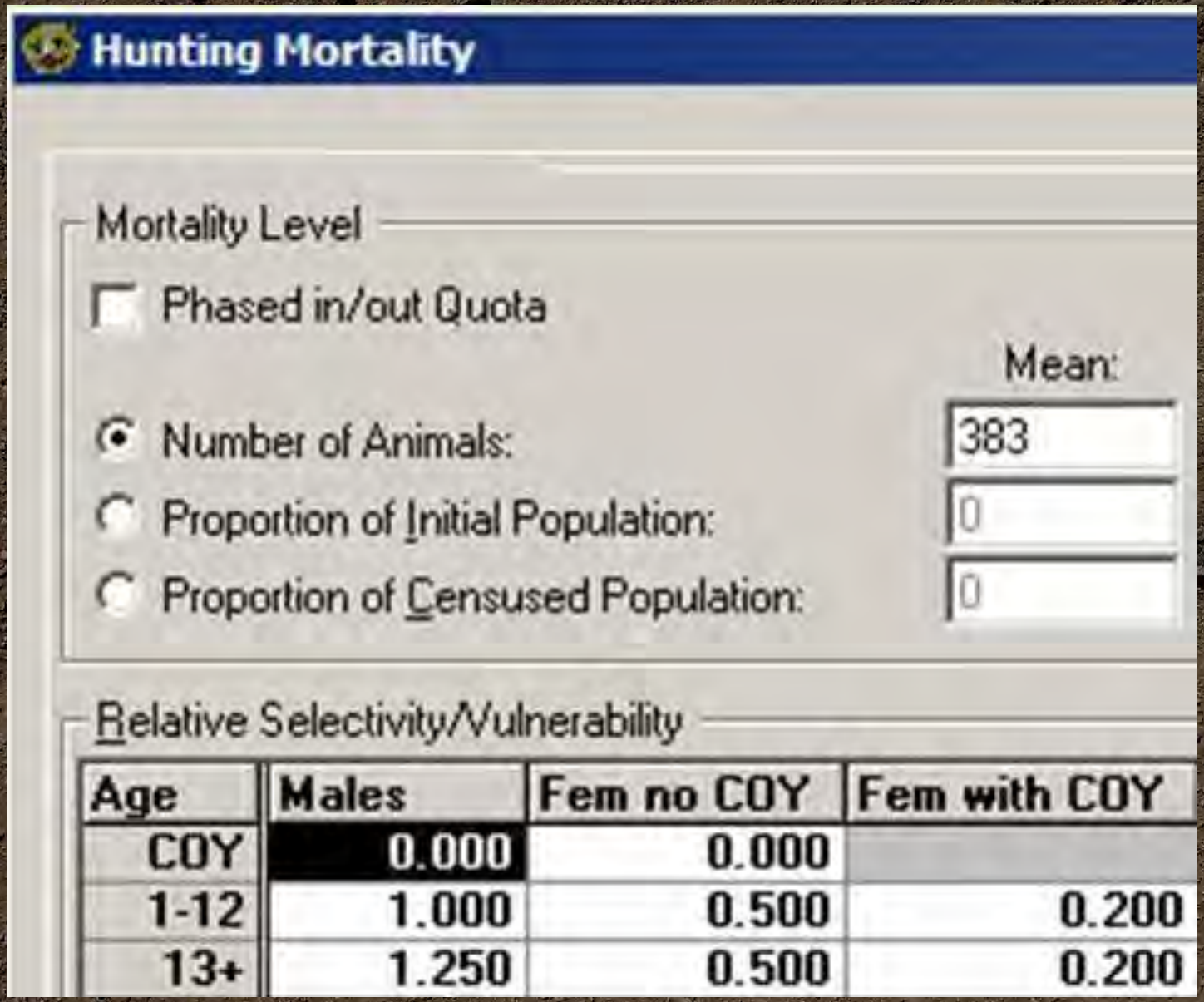
Dynamic age-sex distribution of harvests



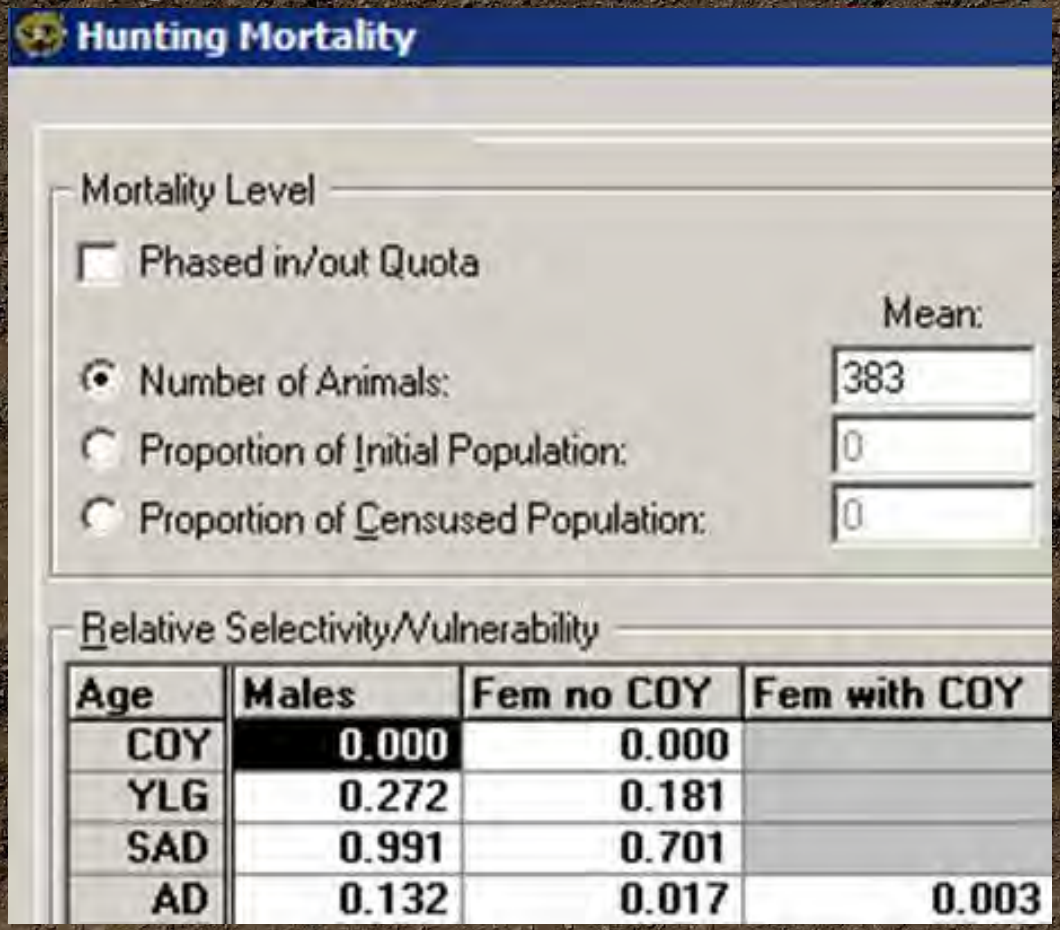
In RISKMAN, the age-sex distribution of harvested bears is calculated annually as the product of:

1) the relative vulnerability of different age-sex classes to harvest, and
2) the relative availability of different age-sex classes in the standing population.

Dynamic age-sex distribution of harvests



Dynamic age-sex distribution of harvests

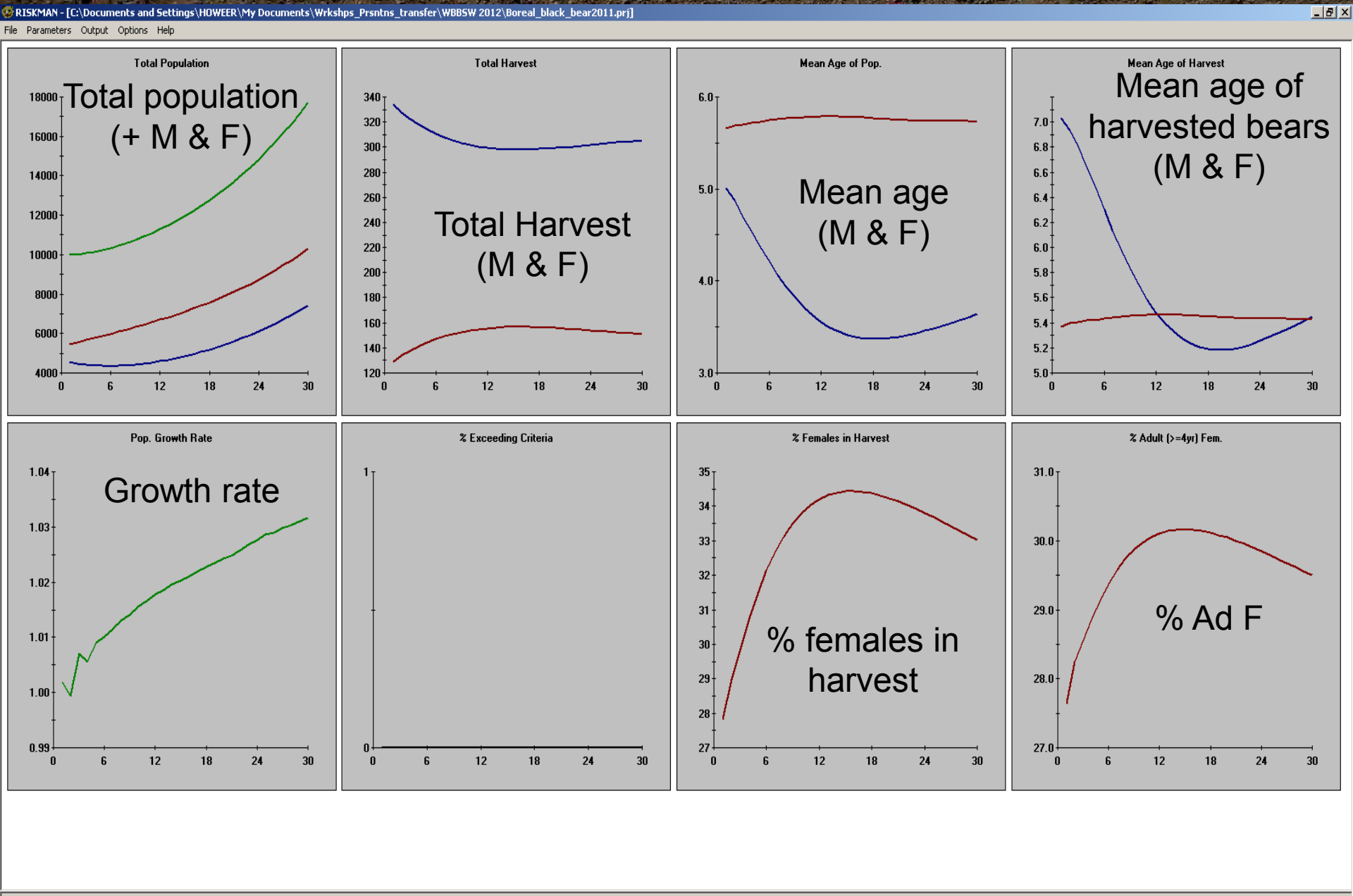


Age	Males	Fem no COY	Fem with COY
COY	0.000	0.000	
YLG	0.272	0.181	
SAD	0.991	0.701	
AD	0.132	0.017	0.003

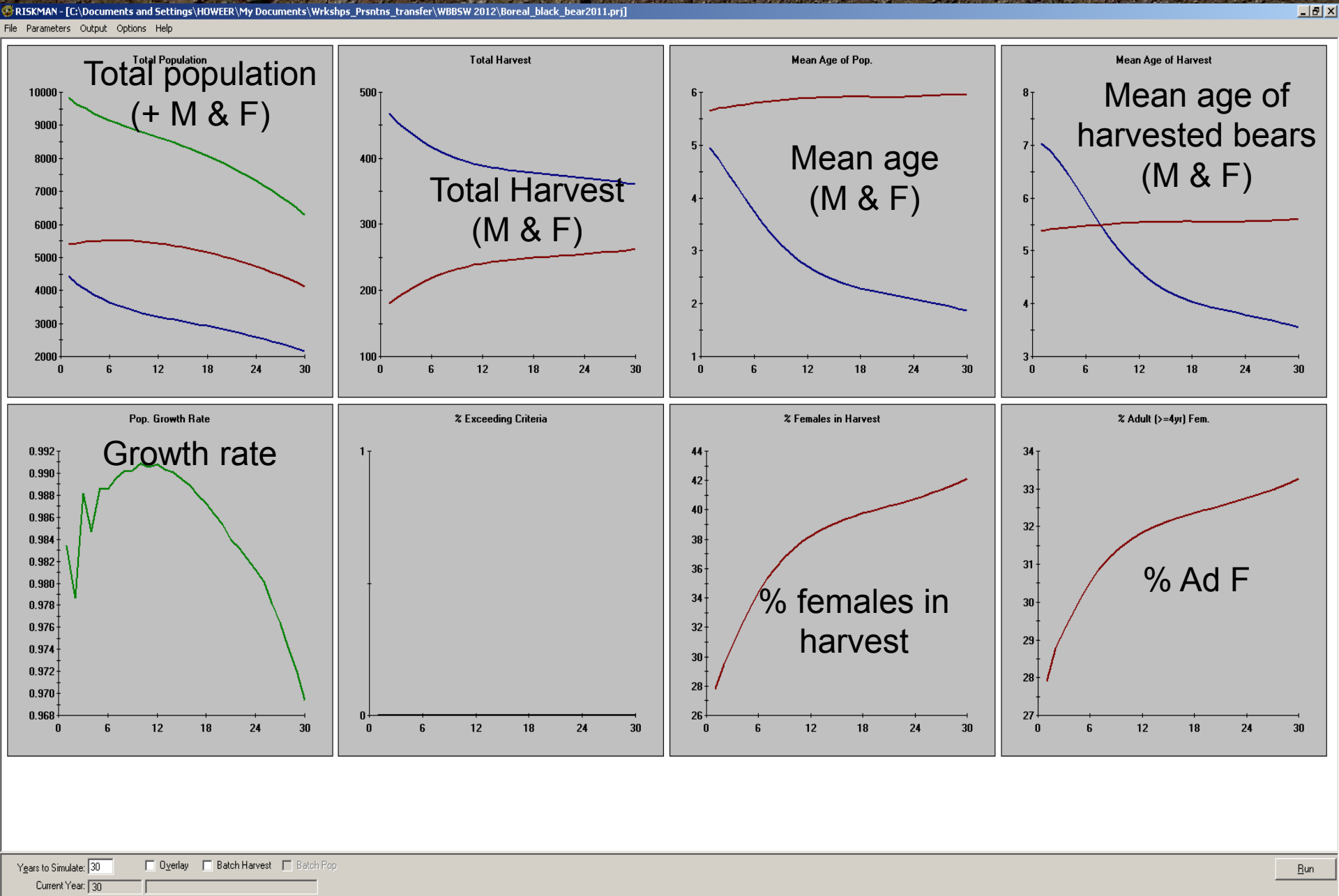
Note: When we use real harvest data to calculate an S/V array we must assume that the standing population age/sex distribution is representative of the harvested population.

The standing age distribution may be set to the stable distribution, or user-defined.

Dynamic age-sex distribution of harvests



Dynamic age-sex distribution of harvests



Dynamic age-sex distribution of harvests

- In the REAL WORLD
- Estimating population size precisely is difficult and expensive.
- Detecting trends is even more difficult
- We manage adaptively, and would like to avoid the need for drastic changes to harvest regimes.
- RISKMAN predicts harvest age & sex structure in the years leading up to and during declines...
- Facilitating "proactive" management to avoid declines and the need for drastic changes

More on harvests: phased in quota

Modeling harvest: Other options

Can include spring, fall, or both seasons.

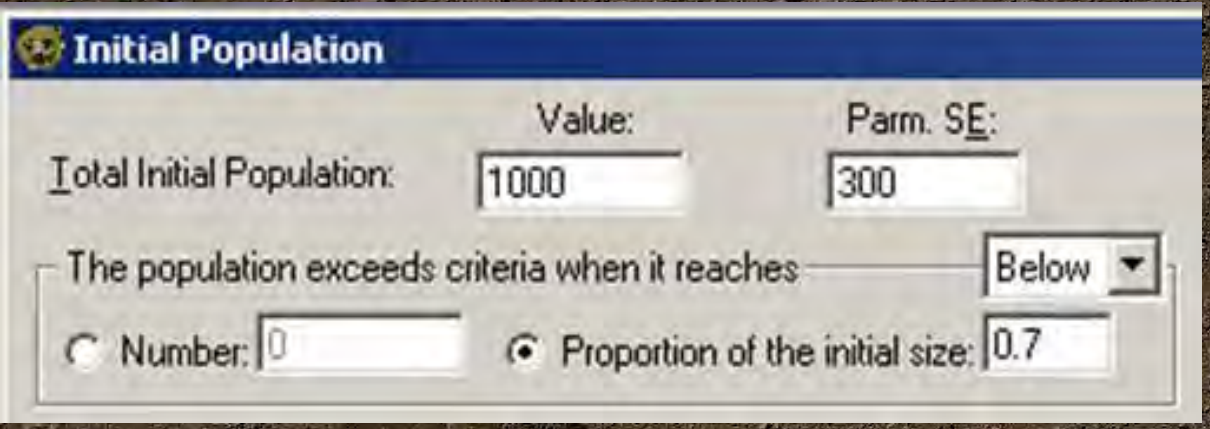
Can specify the sex ratio of harvested bears, rather than allowing it to vary dynamically.

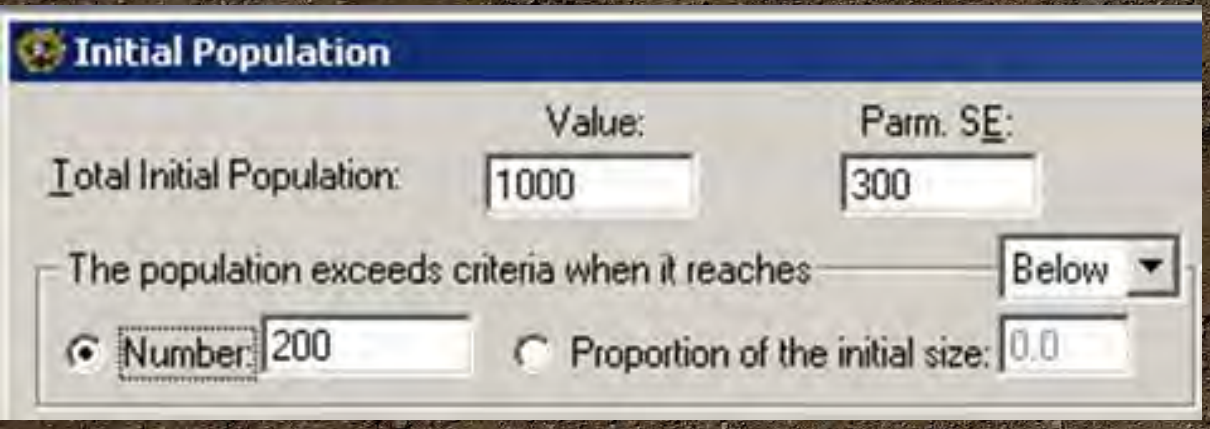
Can set harvest = to a fixed # of animals, or to a fixed % of the initial or annual population.

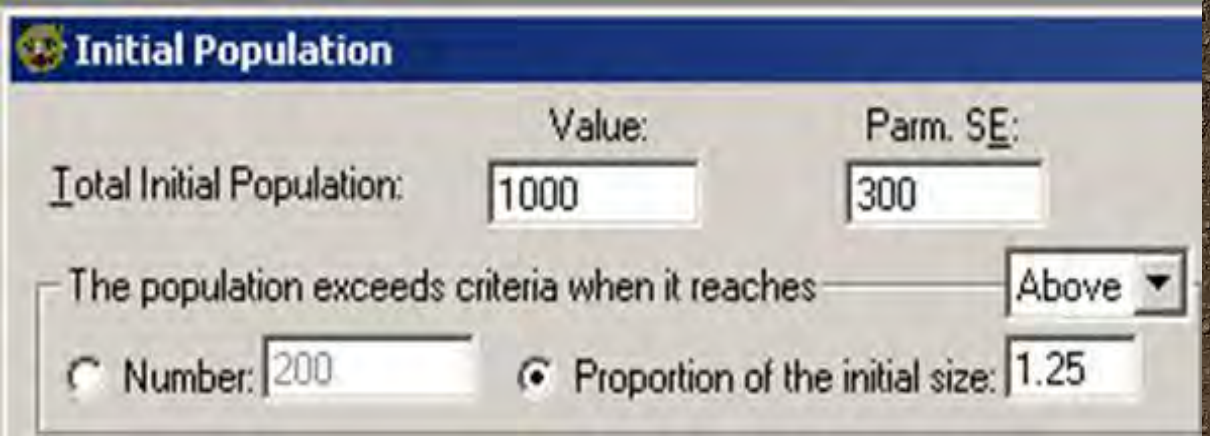
"Batch" mode to run multiple stochastic simulations with different harvest rates in 1 click.

The same functionality is available to additionally model "other" anthropogenic or cause-specific mortality.

Defining management objectives







Objective:

Sustainable harvest

Viability of an isolated or at-risk population

Limit bear depredation on agri/silvicultural, or other game species.

Questions?

Effects of stochasticity on model outputs

Examples using demographic data from Montana (roughly).

Black Bear Harvest Research & Management in Montana

2011 Final Report

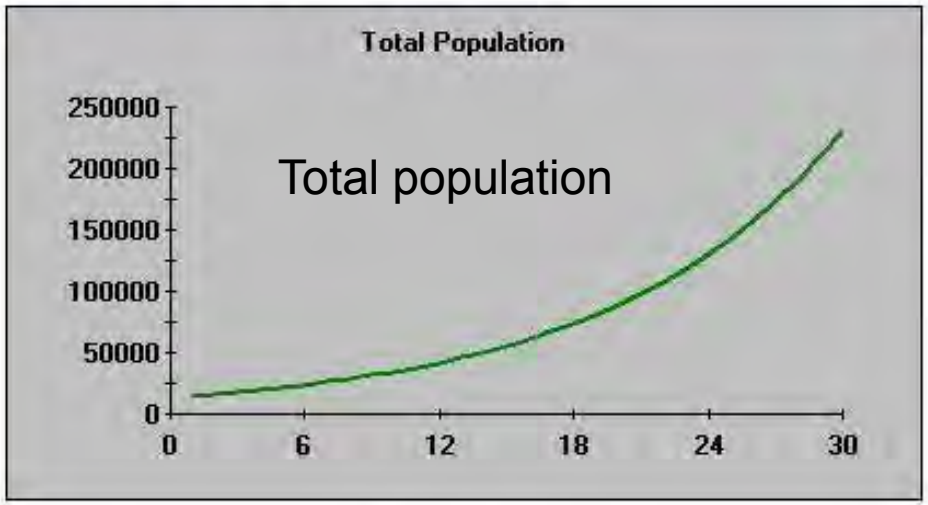
Richard D. Mace and Tonya Chilton-Radandt

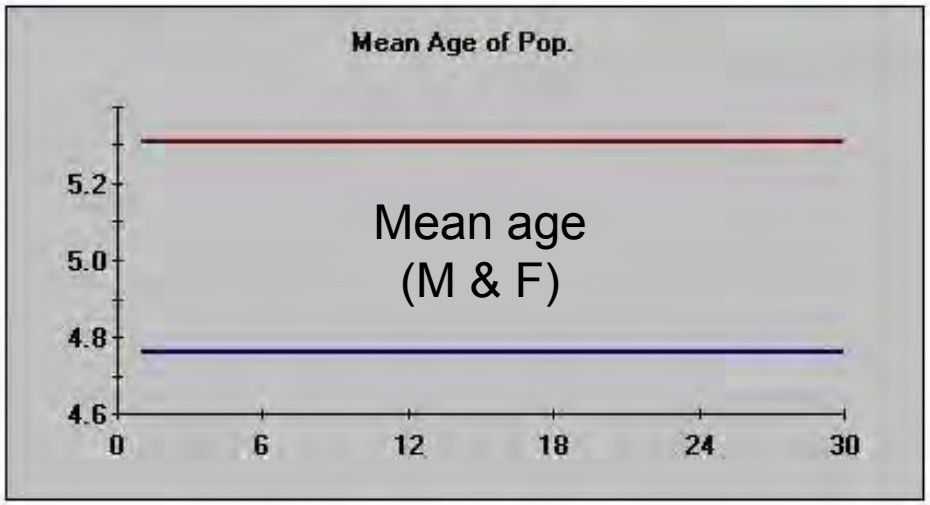
Montana Fish, Wildlife & Parks

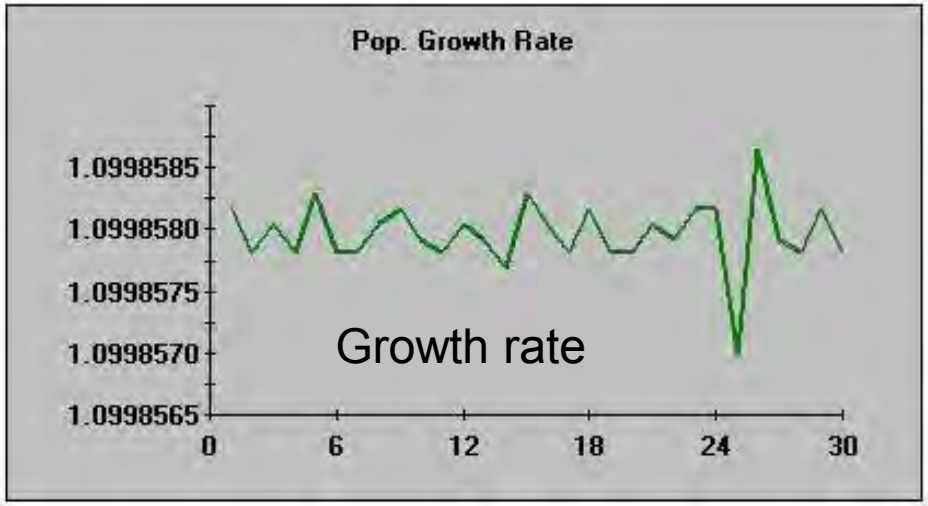
Wildlife Restoration

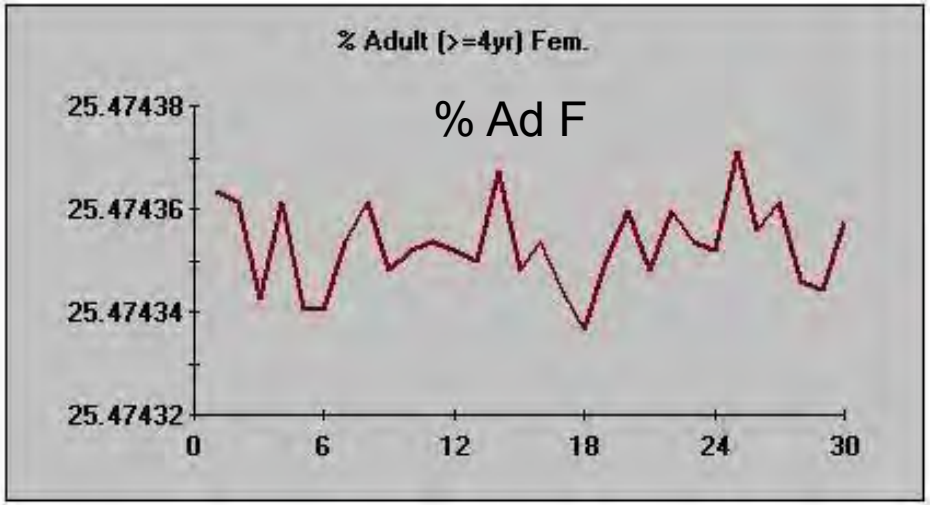
RISKMAN - [C:\Users\Eric\Documents\Bear Analyst\RISKMAN for WBBWS\Montana_black_bear.prj]

File Parameters Output Options Help









Years to Simulate: 30 Overlay Batch Harvest Batch Pop Run

Current Year: 30

RISKMAN - [C:\Users\Eric\Documents\Bear Analyst\RISKMAN for WBBWS\Montana_black_bear.prj]

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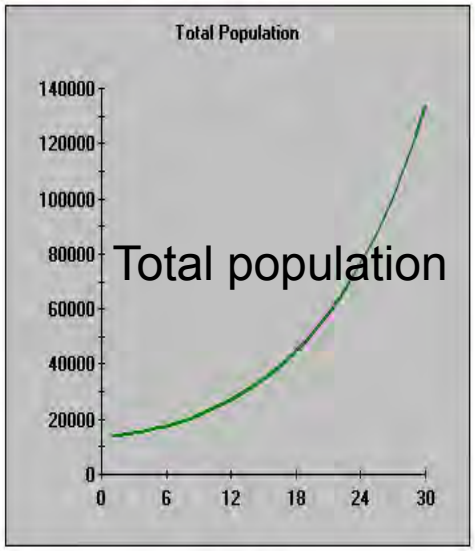

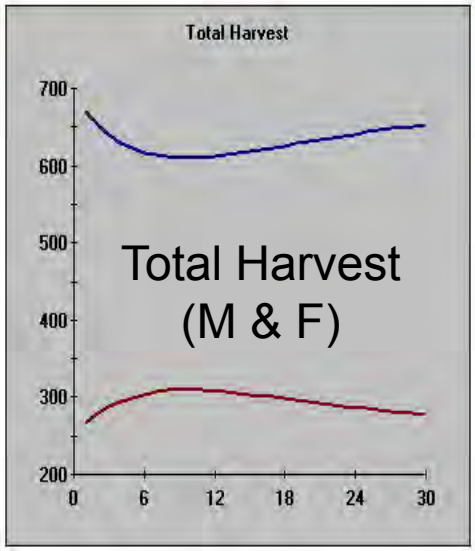

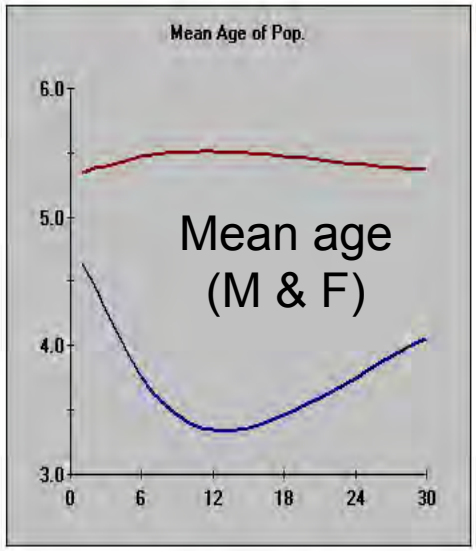

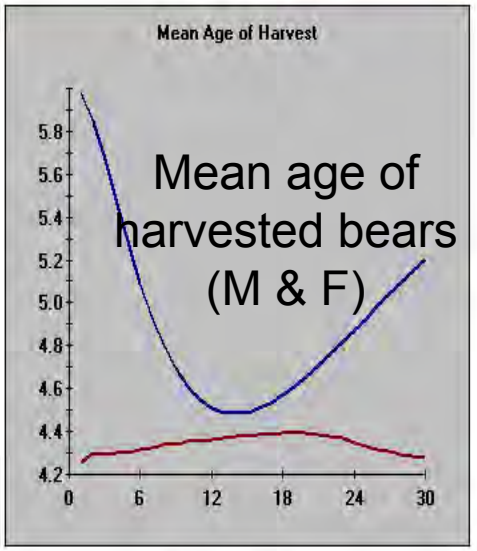

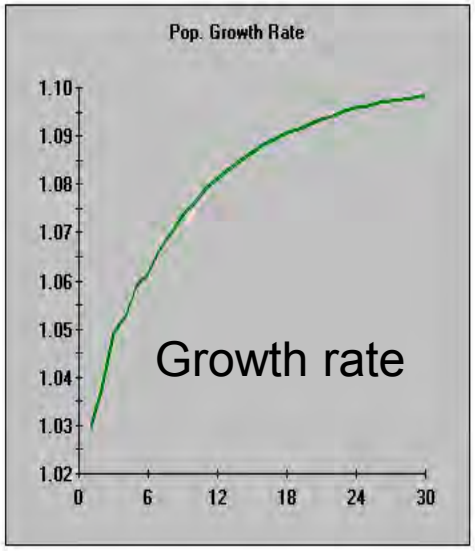

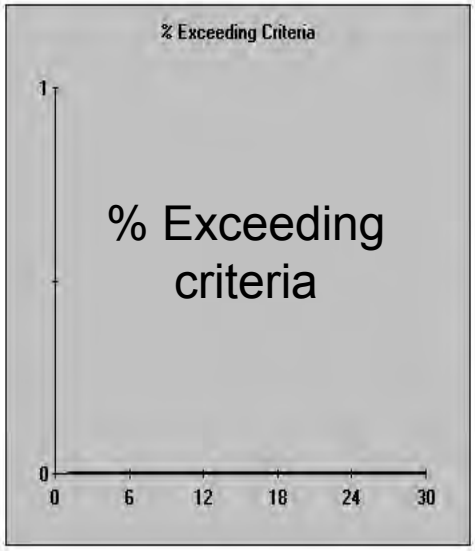

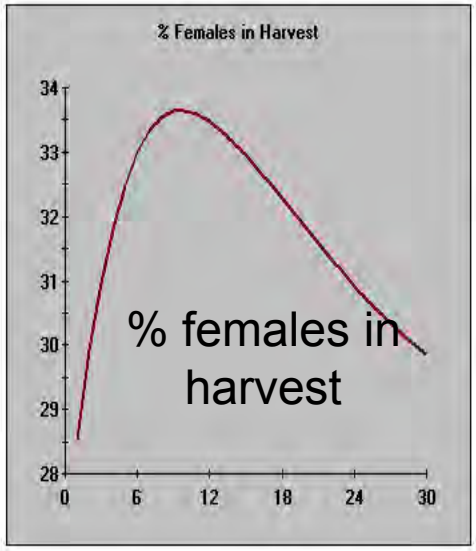

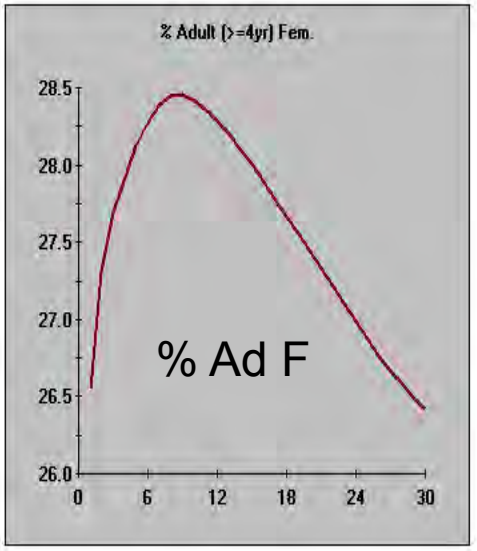

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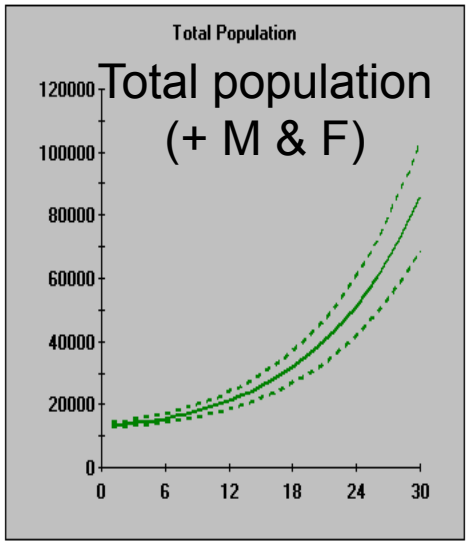
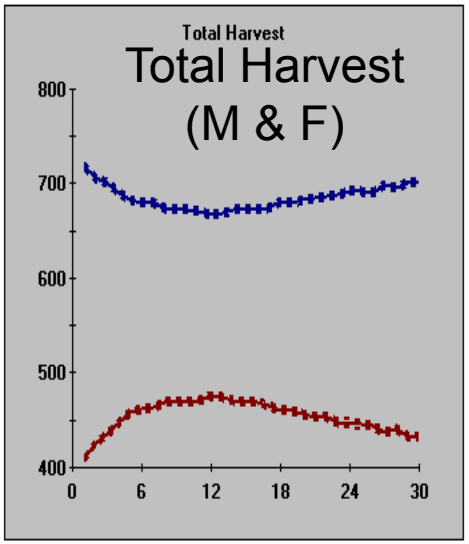
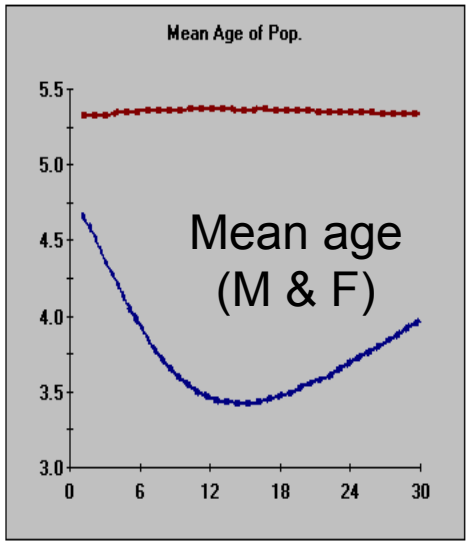
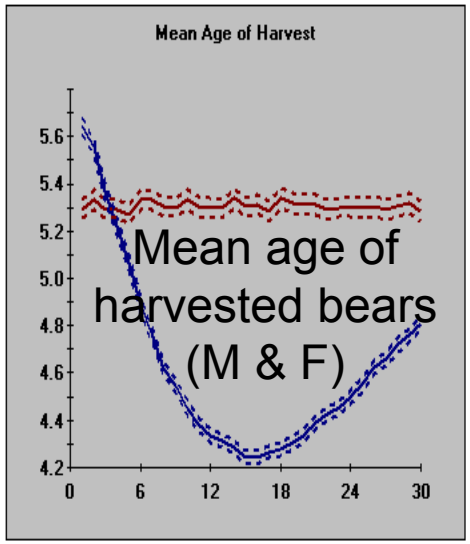
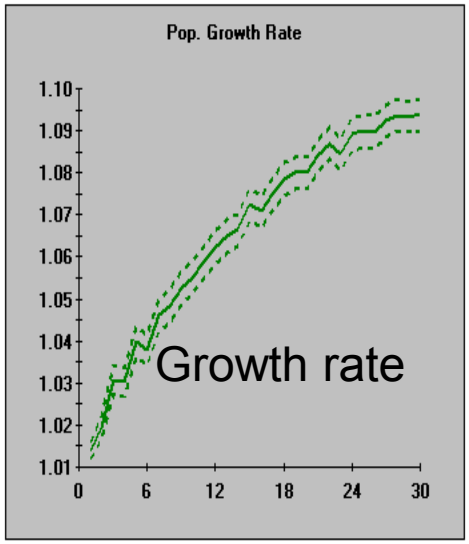
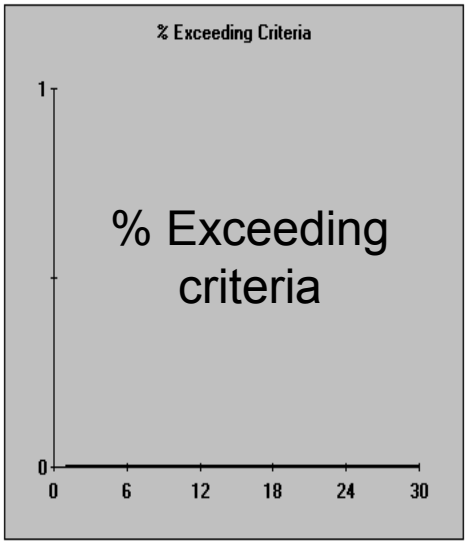


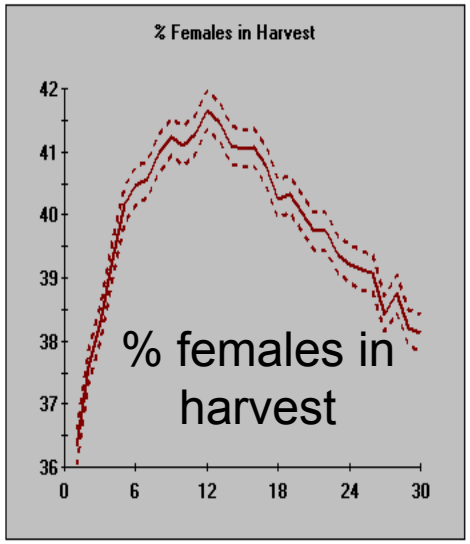


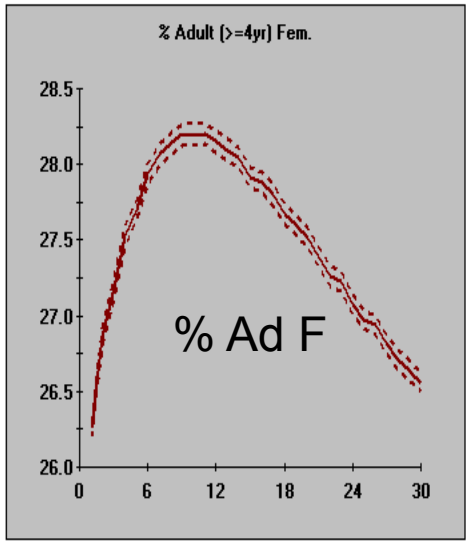












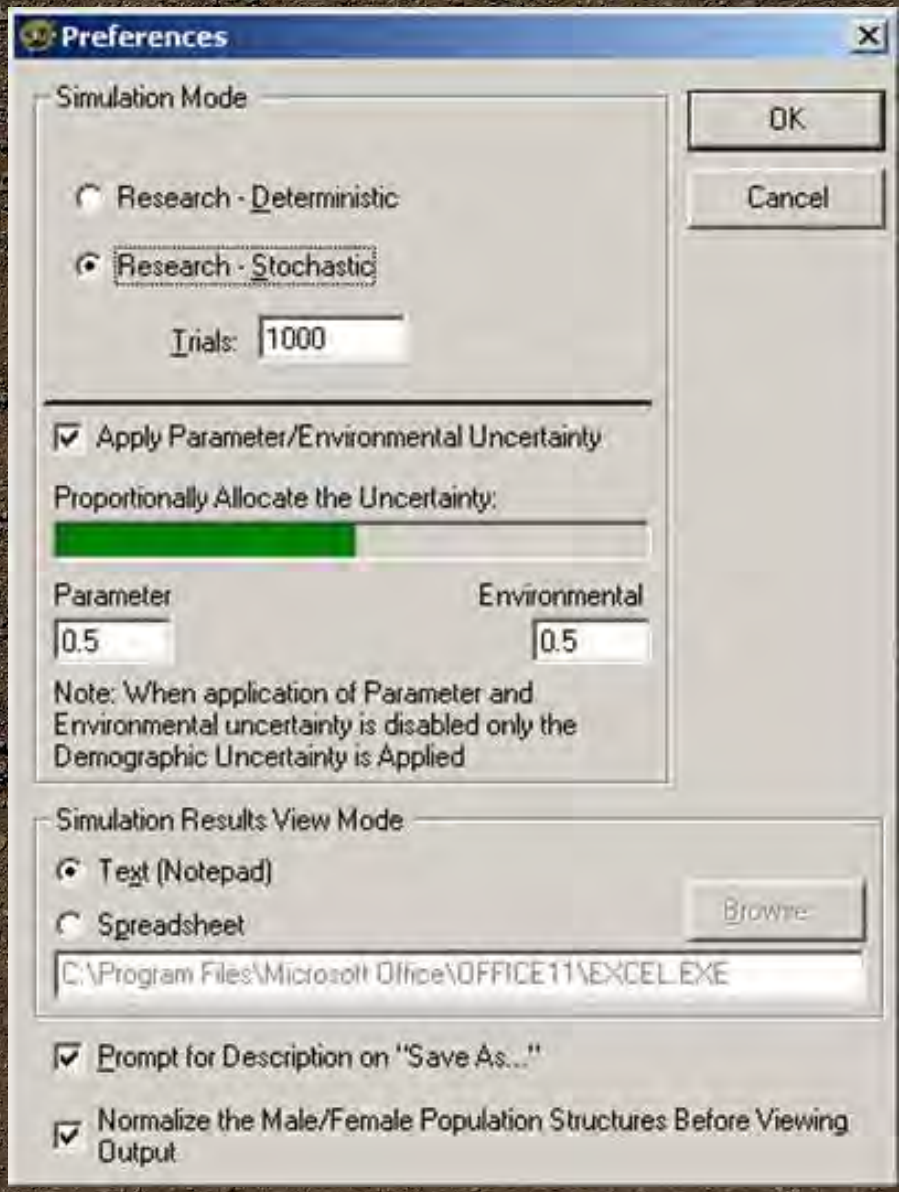
Years to Simulate: 30 Overlay Batch Harvest Batch Pop

Current Year: 1000: 30

Run

Environmental Stochasticity and Sampling Error

- Variances (SEs) around field estimates of vital rates reflect both process variation (actual differences among e.g. individuals, years), and sampling error.
- RISKMAN allows the user to define the proportion of the variance in a field estimate that is attributable to each
- These proportions can be estimated from raw data.



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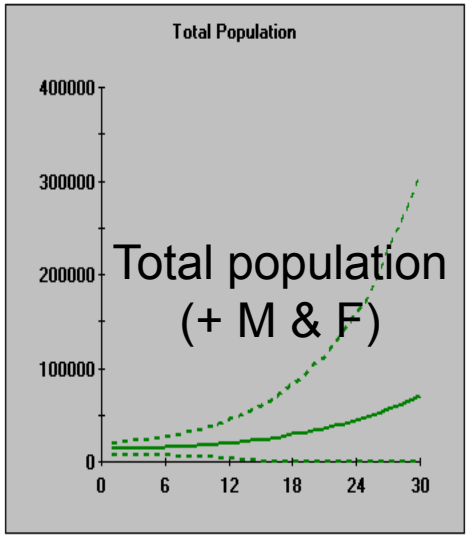

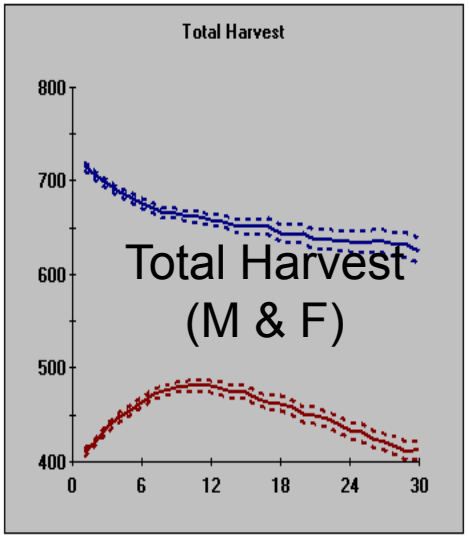

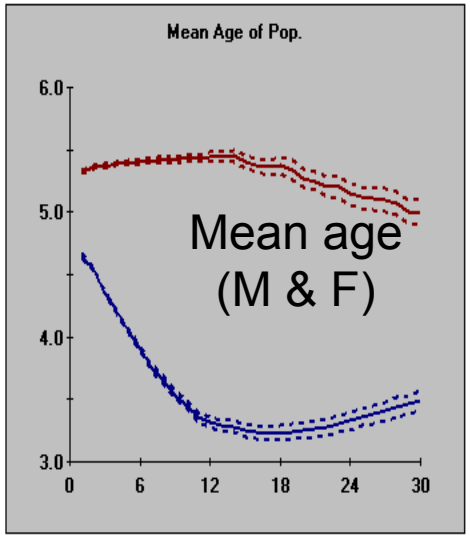

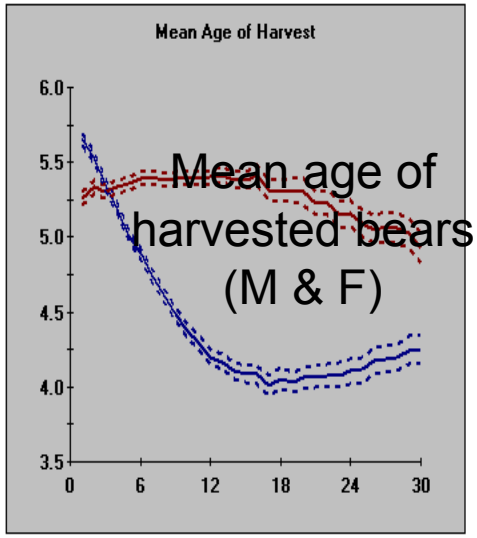

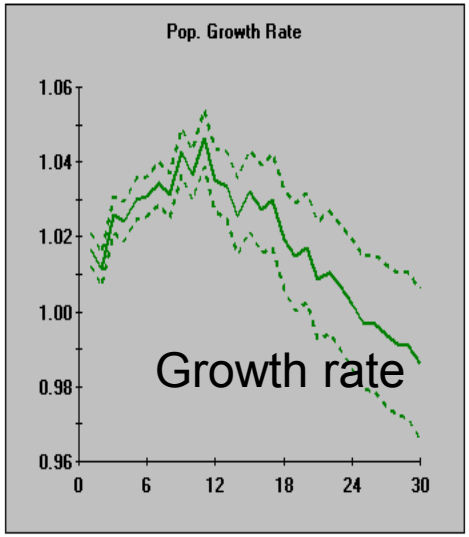

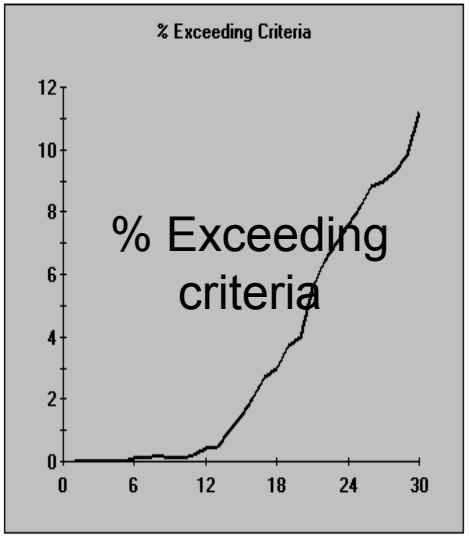

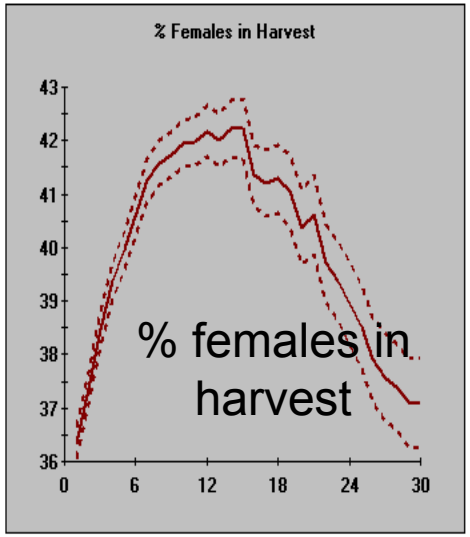

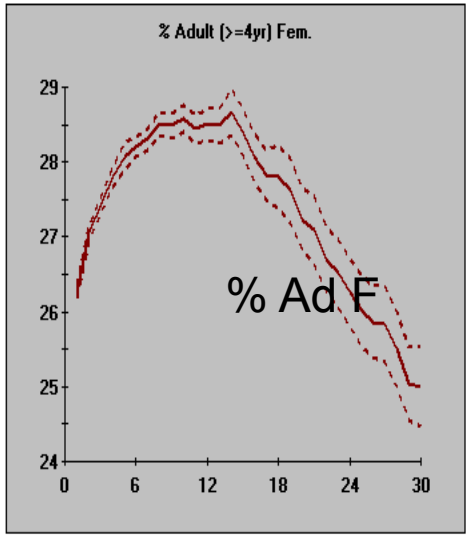

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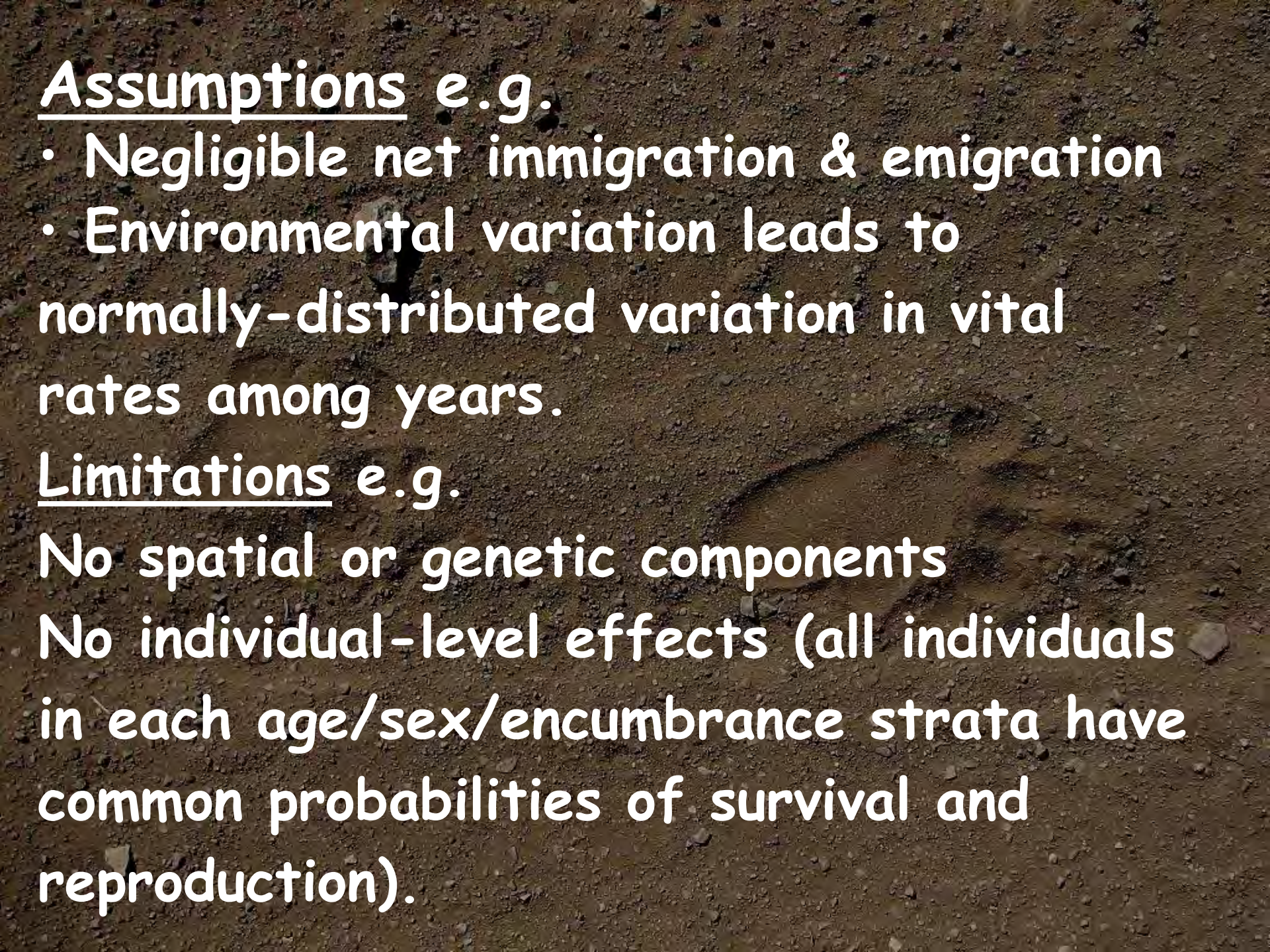
Questions?



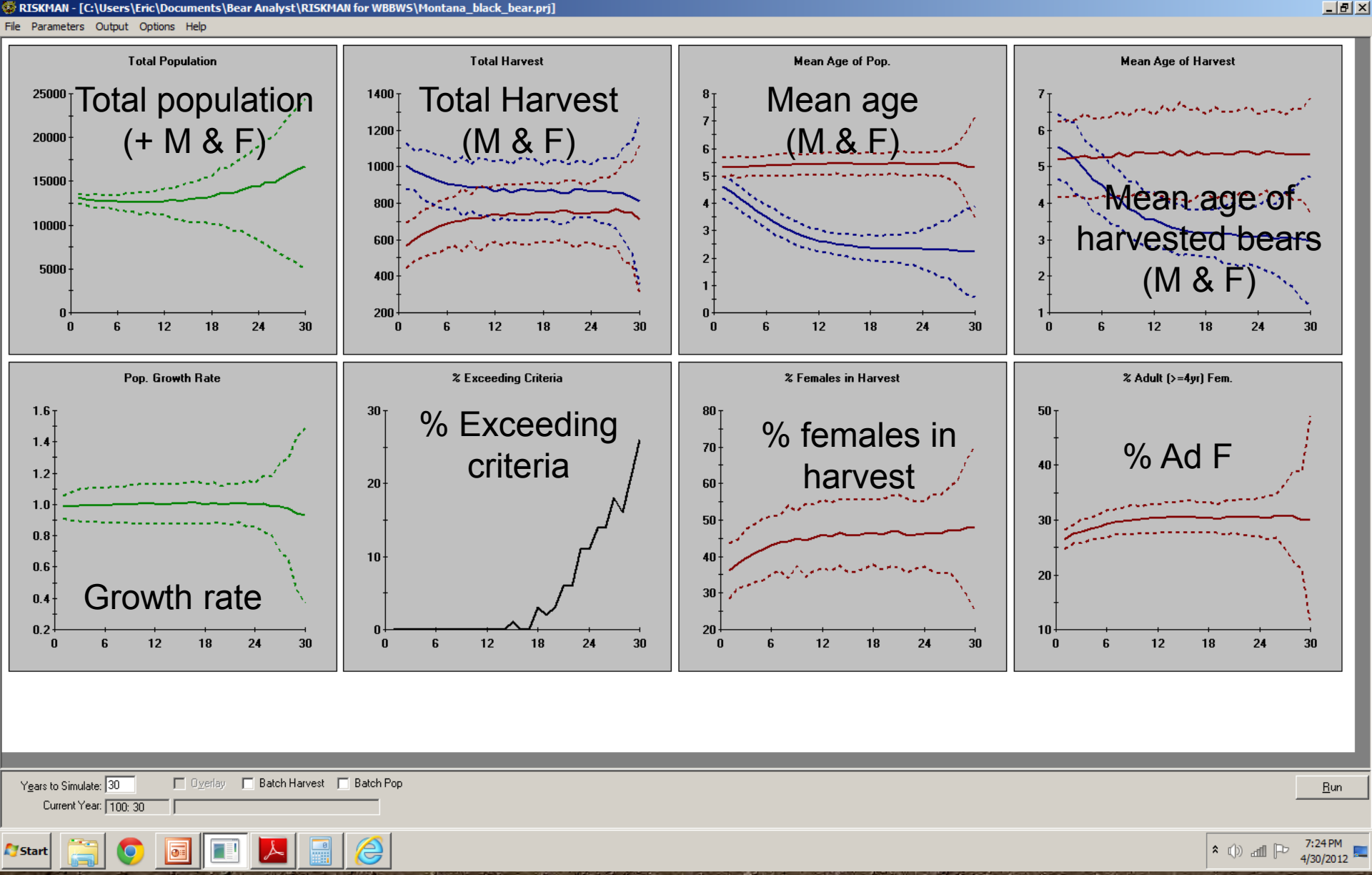
Assumptions e.g.

- Negligible net immigration & emigration
- Environmental variation leads to normally-distributed variation in vital rates among years.

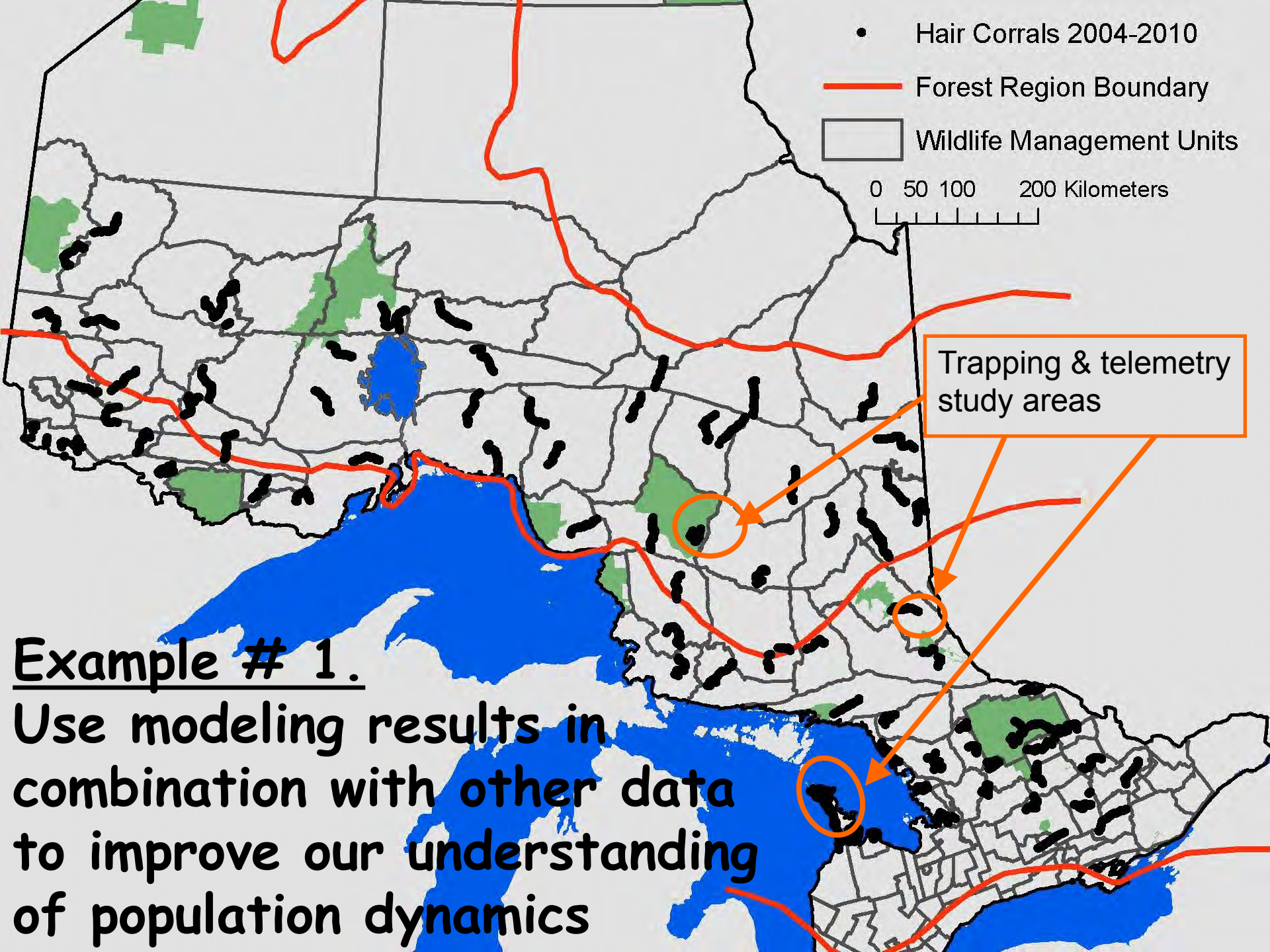
Limitations e.g.

No spatial or genetic components

No individual-level effects (all individuals in each age/sex/encumbrance strata have common probabilities of survival and reproduction).



Can models like RISKMAN be useful given their assumptions, limitations, and uncertainty??



Example # 1.

Use modeling results in combination with other data to improve our understanding of population dynamics

Local OMNR biologists model WMU-specific bear populations using RISKMAN.

Research section:

1. Packaged birth and death rates, age & sex structure, and selectivity/vulnerability arrays into 3 RISKMAN project files specific to different habitats.

2. Provides support and help with interpretation.

Local OMNR biologists:

1. Input Unit-specific population estimates (from DNA capture-recapture work), total harvests and other anthropogenic mortality (roadkill, Po'P).
2. Set the management objective (increase, decrease, or maintain the population).
3. Report probability of achieving the objective under current or proposed harvest regimes as part of quota recommendations.

HOWEVER…

WMUs are not geographically closed as the model assumes!

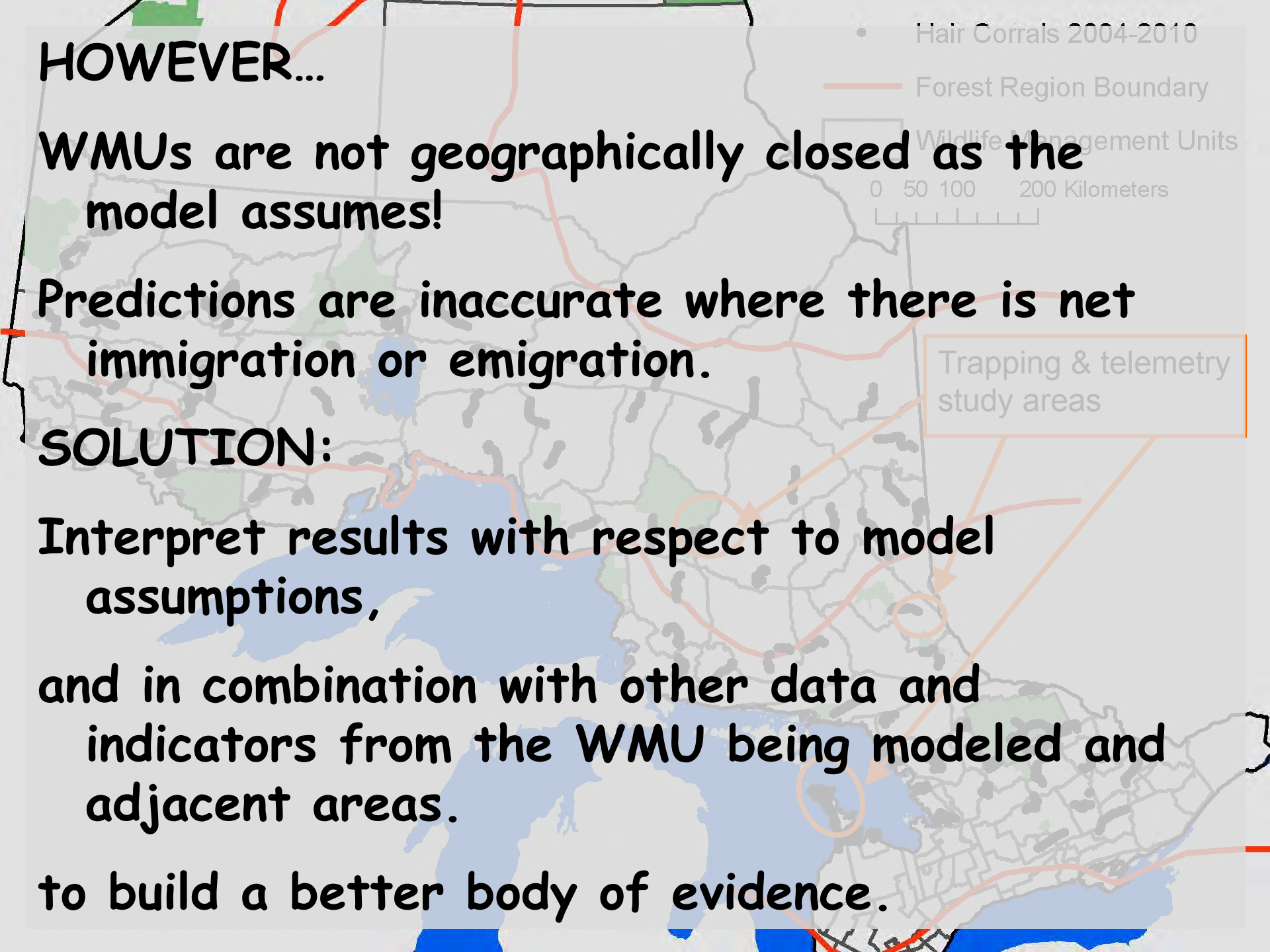
Predictions are inaccurate where there is net immigration or emigration.

SOLUTION:

Interpret results with respect to model assumptions,

and in combination with other data and indicators from the WMU being modeled and adjacent areas.

to build a better body of evidence.



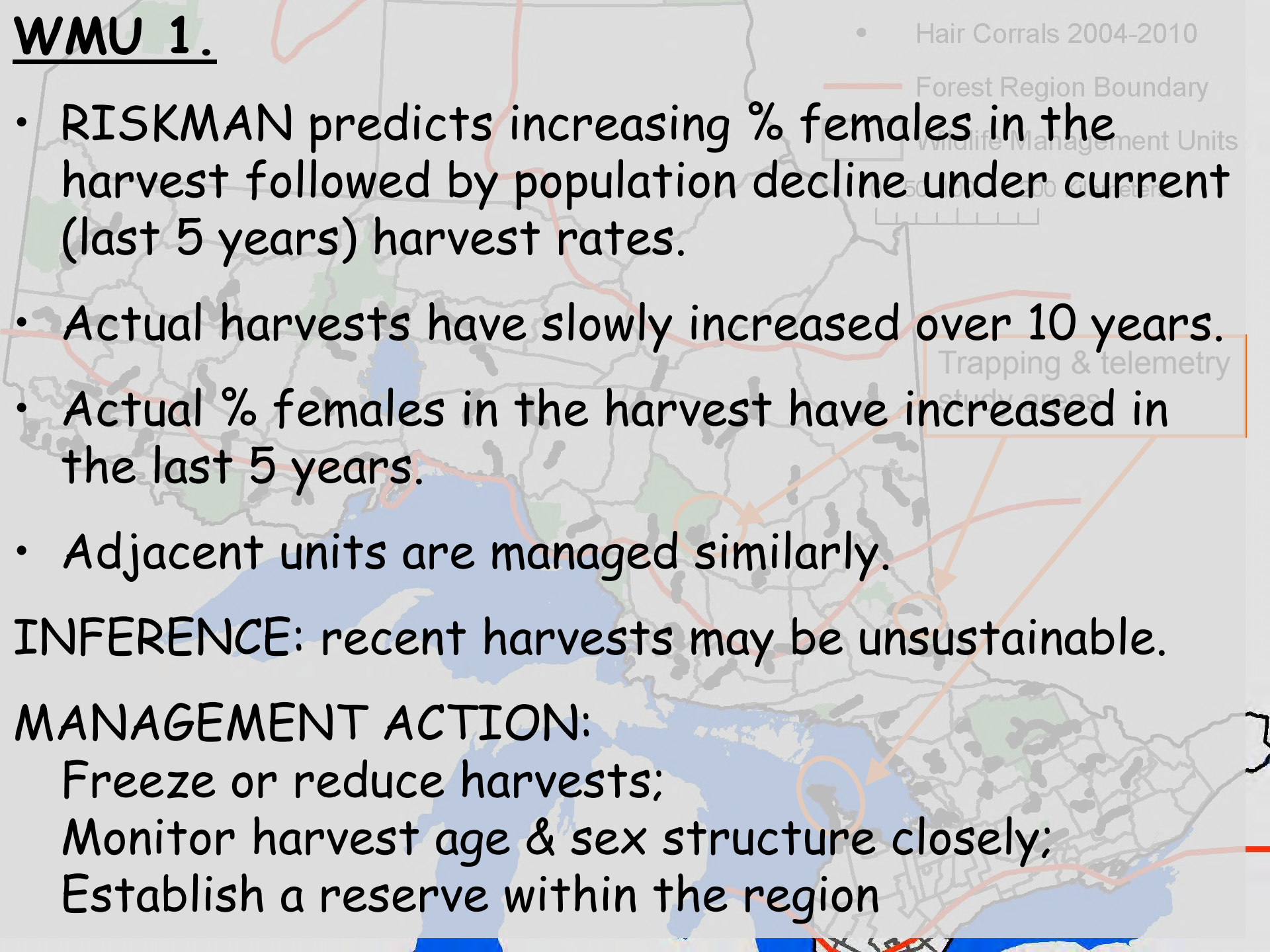
WMU 1.

- RISKMAN predicts increasing % females in the harvest followed by population decline under current (last 5 years) harvest rates.
- Actual harvests have slowly increased over 10 years.
- Actual % females in the harvest have increased in the last 5 years.
- Adjacent units are managed similarly.

INFERENCE: recent harvests may be unsustainable.

MANAGEMENT ACTION:

Freeze or reduce harvests;
Monitor harvest age & sex structure closely;
Establish a reserve within the region

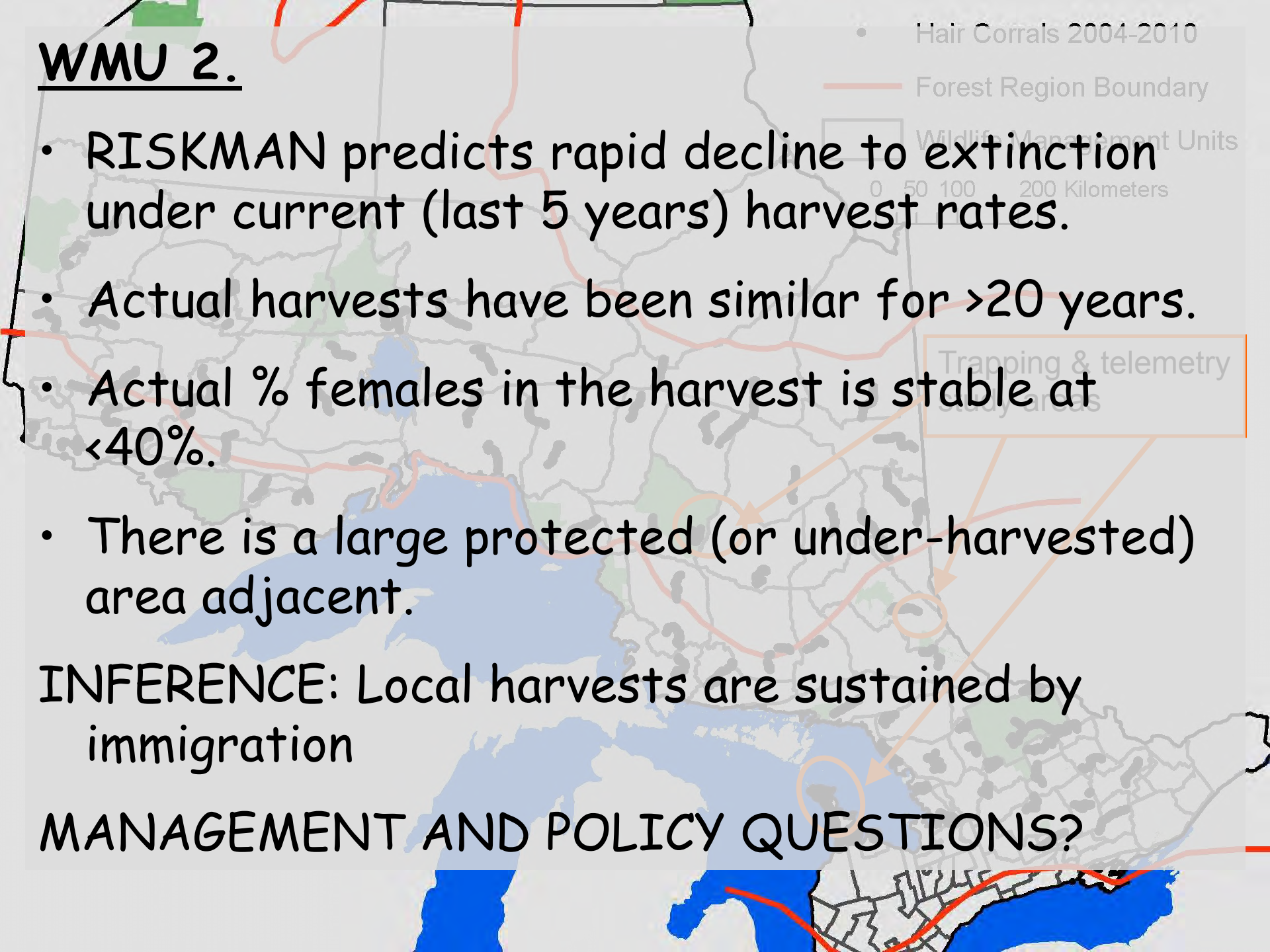


WMU 2.

- RISKMAN predicts rapid decline to extinction under current (last 5 years) harvest rates.
- Actual harvests have been similar for >20 years.
- Actual % females in the harvest is stable at <40%.
- There is a large protected (or under-harvested) area adjacent.

INFERENCE: Local harvests are sustained by immigration

MANAGEMENT AND POLICY QUESTIONS?



Can models like RISKMAN be useful given their assumptions, limitations, and uncertainty?

Example 2: Estimating relative risks associated with hypothetical scenarios.

Management and Conservation

Extirpation Risk of an Isolated Black Bear Population Under Different Management Scenarios

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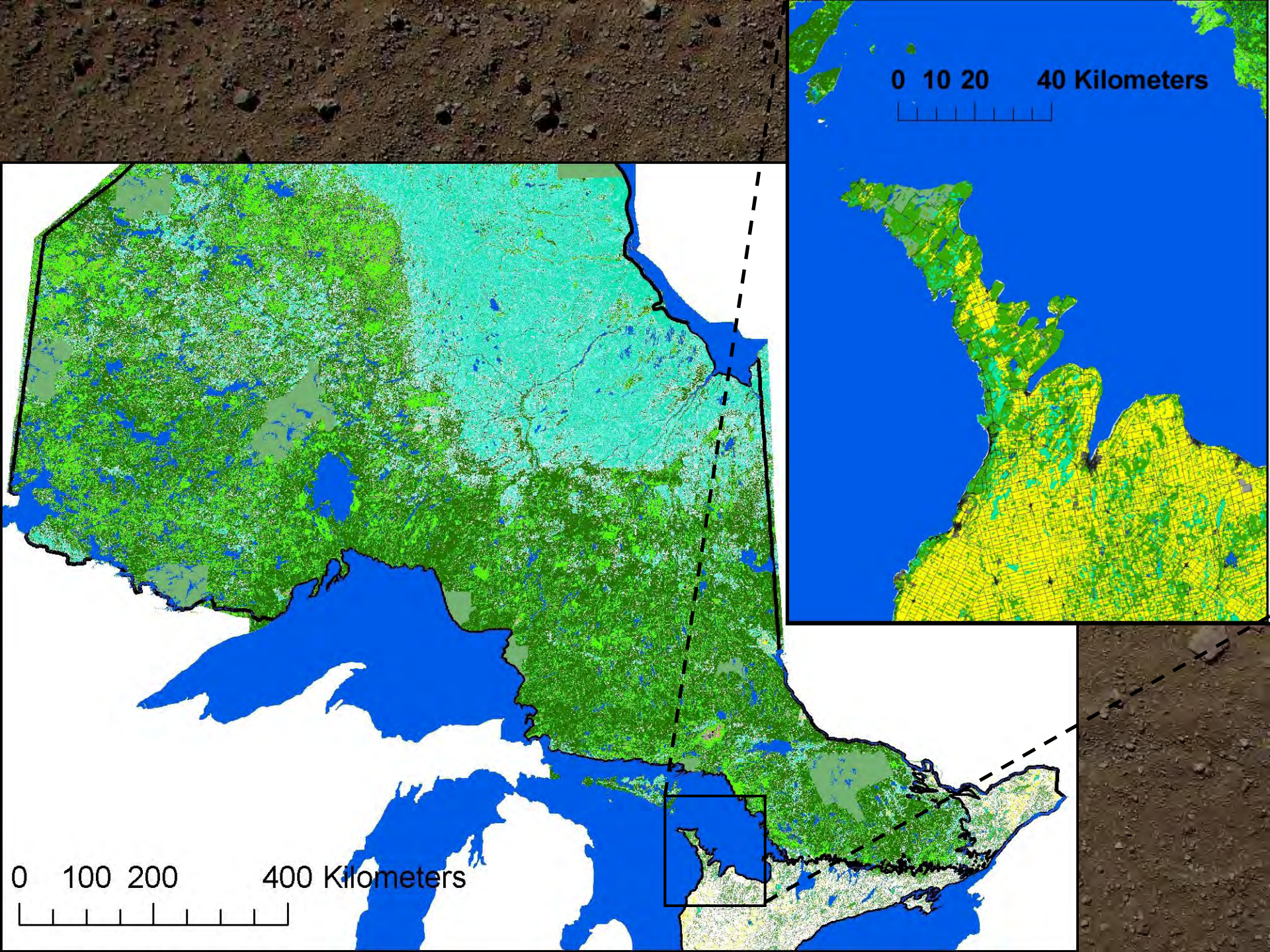
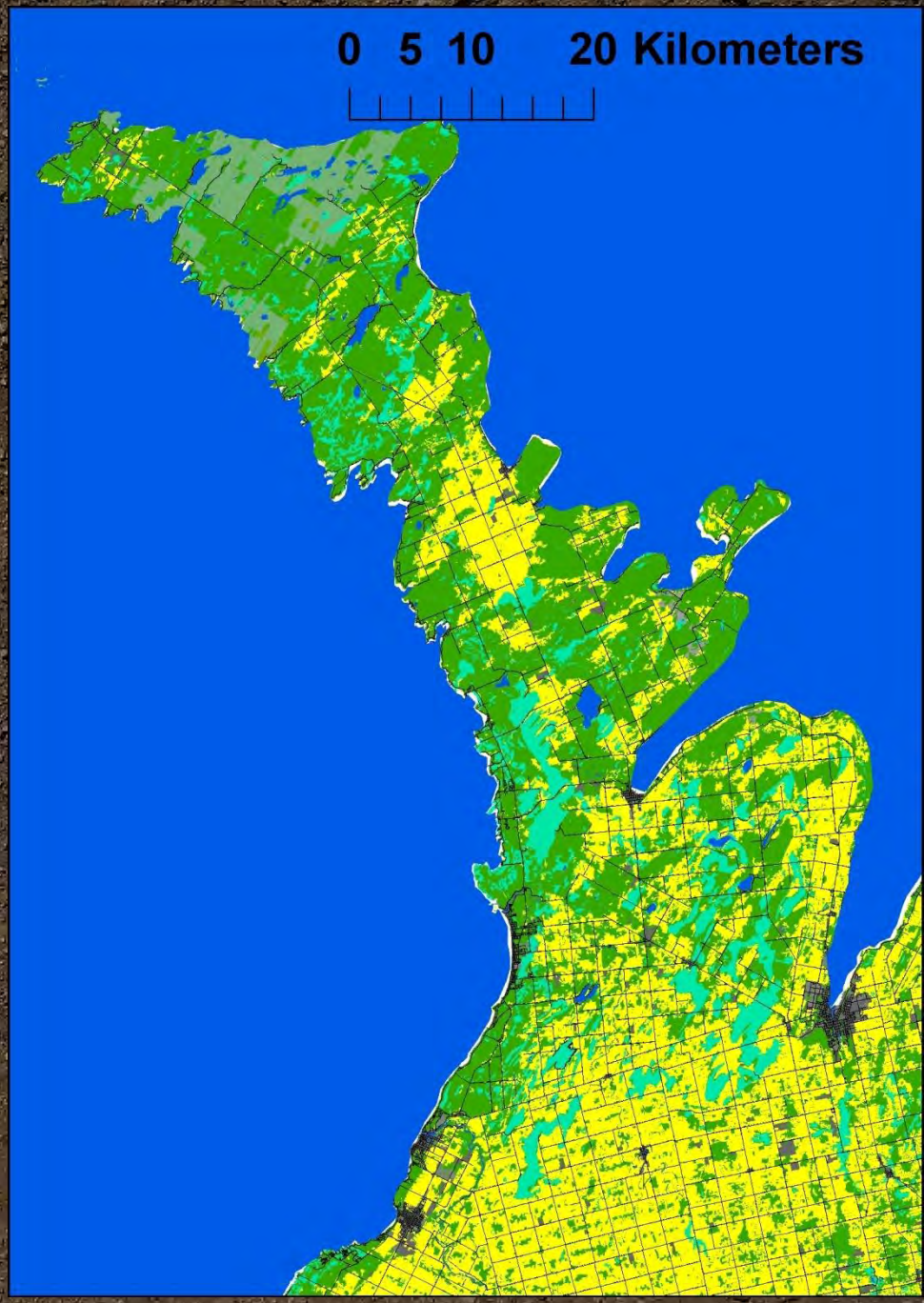

0 10 20 40 Kilometers
0 100 200 400 Kilometers

We identified three specific threats:

1) Habitat loss south of the protected area

2) Harvest

3) Non-harvest anthropogenic mortality (e.g. Po'P, roadkill, & dispatched "problem" bears)



Threats:

1) Habitat loss south of the protected area

2) Harvest

3) Non-harvest anthropogenic mortality

Management actions:

1) Prevent habitat loss

2.1) Reduce harvest

2.2) Reduce the portion of adult females harvested*

3) Reduce non-harvest anthropogenic mortality

LOTS OF UNCERTAINTY!

Local demographic data were sparse, so we borrowed data from a population occupying similar habitat.

We manipulated initial population size to reflect different assumptions about future range restriction due northward progression of human development.

Information on bear density south of the NP was not available.

We generated 9 different initial population estimates assuming 3 potential densities (20, 40, or 60/100 km^2) within each of the 3 nested areas.

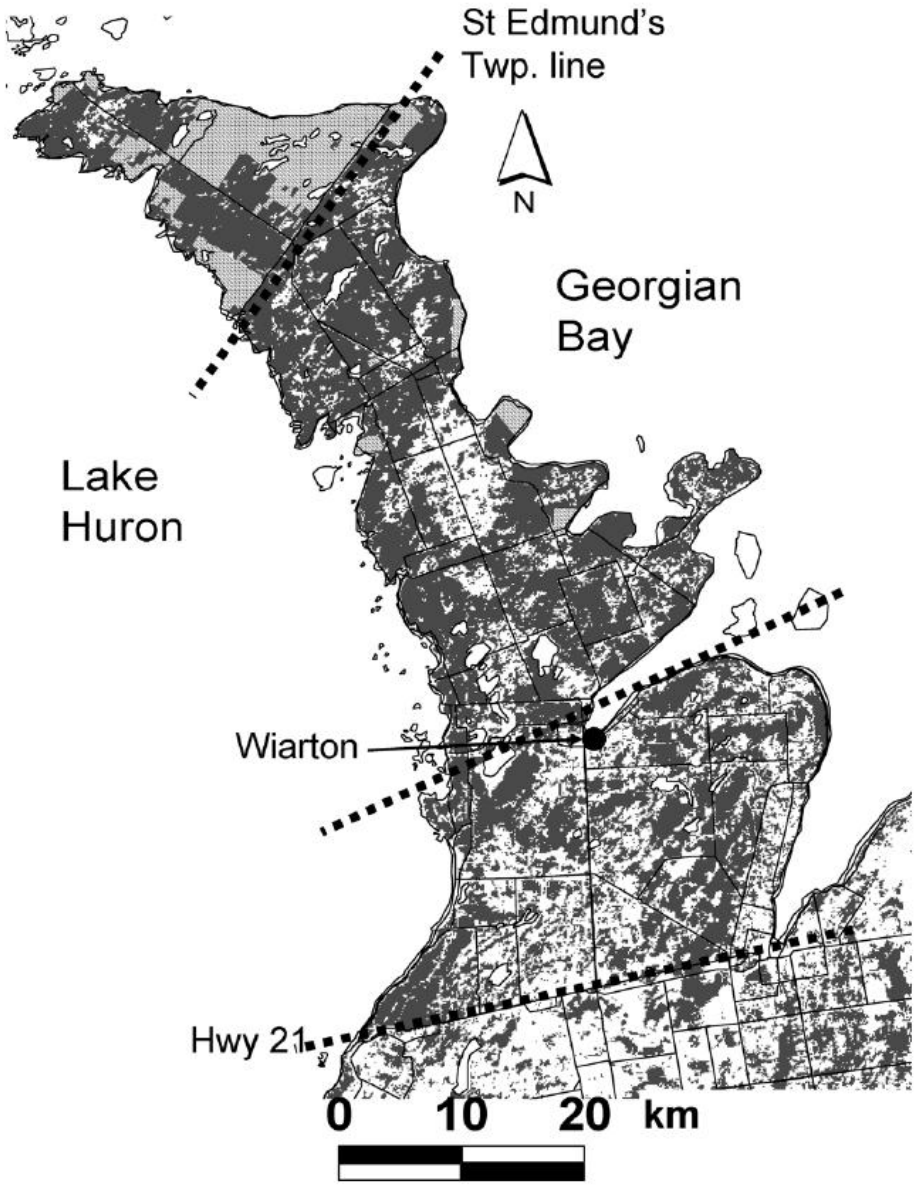


Figure 1. Bruce Peninsula in southwestern Ontario, Canada, 2000. Hatched areas are protected habitats, with Bruce Peninsula National Park in the north. Suitable bear habitat appears in gray; nonhabitat appears in white. Dotted lines indicate divisions between nested regions of habitat.

Table 3. Independent random factors, levels of each factor, and values entered into RISKMAN to populate a 4-way random effects analysis of variance for effects on extinction risk of black bears on the Bruce Peninsula (BP), Ontario, Canada, 1989–1998.

Predictors	Levels	Values
Region	Entire BP, 1,100 km^2	N_0[a] = 220, 440, 660
	North of Wiarton, 950 km^2	N_0 = 190, 380, 570
	St. Edmund's Twp., 220 km^2	N_0 = 53, 88, 132
INNM[b]	None	0
	Mean reported, 1998–2003	3 with SE = 0.65
	2 × mean reported, 1998–2003	6 with SE = 0.65
Annual harvest	None	0
	Mean projected, 1987–2003	8 with SE = 1.7
	Mean projected, 1996–2003	13 with SE = 2.0
S-V[c] to harvest	Provincial target	M:F = 3:2
	Low vulnerability of encumbered F	M:unencumbered F:encumbered F = 6:4:1
	Boreal observed	See Table 2

[a] Initial population size.

[b] Incidental non-natural mortality.

[c] Relative selectivity-vulnerability of age and sex classes to harvest.

Table 5. Significance of and percent of the total variance explained by each term in a 4-way random-effects analysis of variance testing for effects of region of available habitat, incidental non-natural mortality rate (INNM), harvest rate, and age and sex distributions of harvest (S-V) on extinction risk after 50 years for black bears on the Bruce Peninsula, Ontario, Canada.

Factor	df	Mean squares	*F*	*P*-value	% of total variance
Intercept	1	51.58523	8.065	0.056	
1) Region	2	4.70840	27.353	0.002	38.49
2) INNM	2	0.97036	51.802	<0.001	8.07
3) Harvest rate	1	0.77170	5.136	0.133	3.75
4) S-V of the harvest	2	0.42128	5.033	0.078	3.05

KEY RESULTS:

1) Habitat loss posed the greatest threat.

2) Non-harvest anthropogenic mortality (INNM) posed a greater threat than harvest.

CONCLUSIONS

Despite a lack of local data, we were able to identify key factors affecting the population's viability.

Where an immediate conservation concern exists, population models allow managers to prioritize research and management activities in a short time period.

We also concluded that improved estimates of population size would reduce uncertainty in risk estimates, and improved estimates have since been obtained (model results provided rationale for additional research).

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Population Viability of Barren-Ground Grizzly Bears in Nunavut and the Northwest Territories

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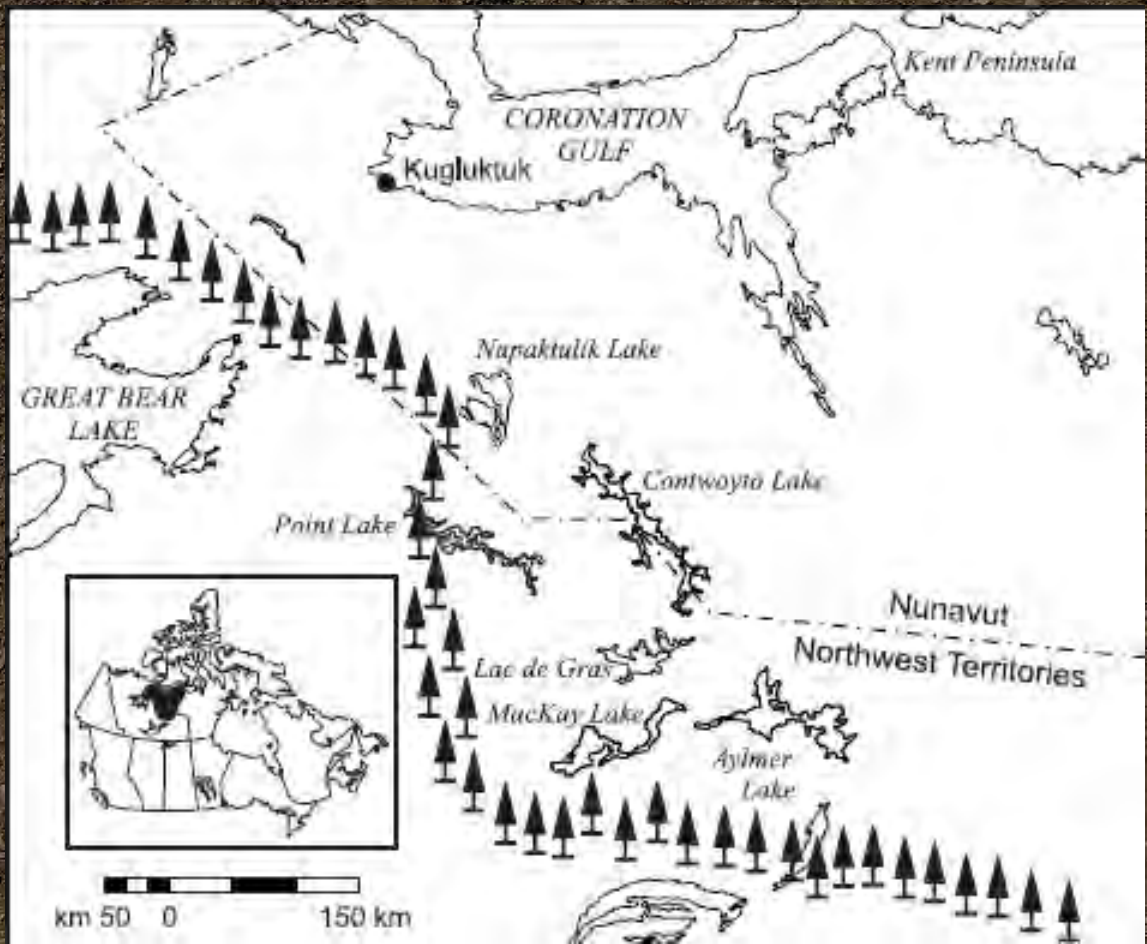
Example 3:
Where adequate local data are available, RISKMAN is appropriate for population viability analyses (PVA) of bear populations.

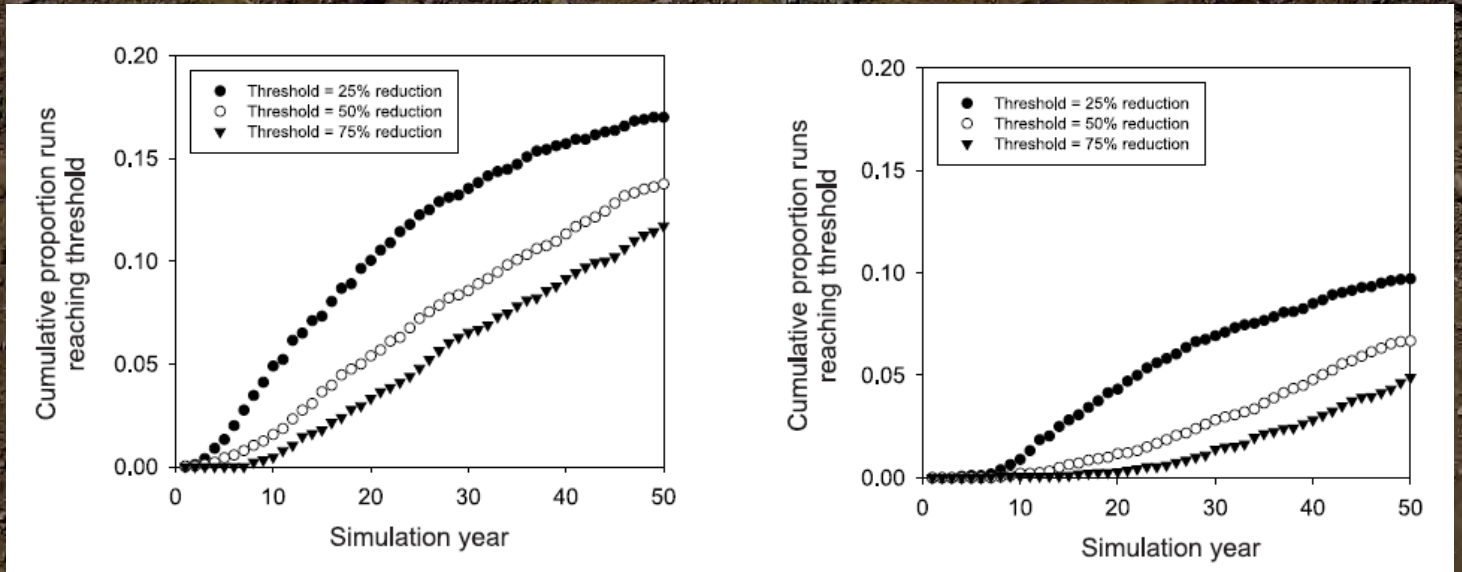


Methods

- Live-capture, telemetry, aerial ID & resight to estimate population size and vital rates.
- Used 3 SEs around the population estimate to assess and allow for uncertainty.
- Known anthropogenic mortality (mean 13.4 animals/yr) pooled and modeled as harvest ("best case" and "best guess" scenario).
- Also modeled higher rates of anthropogenic mortality*
- S/V array from field data and harvest records
- Used RISKMAN to estimate risk of decline by 25, 50, and 75% over 50 years.

Results

- Risk of decline was sensitive to SE on population size and adult survival rates.
- Low RISK (10% chance of decline by ≥25%) under best case scenario.
- Increasing annual anthropogenic mortality by 6 bears dramatically increased risk (10% chance becomes 42%) → Management Implications.



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Availability & Documentation

Distributed free online via:

http://riskman.nrdpfc.ca/riskman.htm

PDF documentation is also available there

Contact eric.howe@ontario.ca or other users for support.

Questions?